DEVELOPMENT OF TEACHING AND LEARNING RESOURCES TO CHALLENGE STUDENTS' ALTERNATIVE CONCEPTIONS OF CORE IDEAS IN GENERAL CHEMISTRY

Thesis submitted for the degree of
Doctor of Philosophy (PhD)
at the University of Leicester

School of Chemistry
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April 2020

Development of Teaching and Learning Resources (TLRs) to Challenge Student's Alternative Conceptions of Core Ideas in General Chemistry Course

Abstract

Previous research has proved that chemistry is perceived to be a difficult subject for many students. Abstract concepts and the inability of students to make connections between the macroscopic, sub-microscopic and symbolic levels are believed to be the main reasons. To overcome this issue, this study focused on the development of teaching and learning resources (TLRs) that embedded these three levels of representation to challenge students' alternative conceptions in general chemistry. An action research methodology was employed to develop the TLRs. The four-stages, design, develop, evaluate and reflection were framed in a cyclic form. The design of the TLRs began by reviewing the literature to find common alternative conceptions to develop a plot which led to the development of the prototype. Pilot studies were used to refine the design of the final TLRs. Three TLRs have been produced; the Shape of Molecule Cards and Molecular Model Building, Leaflet of Electronegativity, and the Video of Intermolecular Forces. The results of these pilot studies suggested that all TLRs were suitable for use in the classroom following some minor changes based on student feedback. The findings of the pilot studies show that all students responded positively to the TLRs. Both quantitative and qualitative data analysis methods were used as the triangulation process to improve the validity and reliability of the research. The evaluation process started by implementing the TLRs at the University of Tanjungpura, Indonesia. The TLRs had a measurable impact on student understanding of the selected concepts and successfully challenged common alternate conceptions. These TLRs may be of further use to educators and educational researchers seeking to support student learning and gain a deeper insight into how students learn chemistry, and the methodology employed will be easily transferable to the development and evaluation of TLRs across a range of disciplines.

Dedication

This thesis is dedicated to the memory of Professor Annette Cashmore, my first supervisor, who always inspired me to be a better researcher and educator. I also want to dedicate this thesis to my husband, Luqman Hakim, my son Danish A. Al Faeyza and both of my parents who always provide the continual support, love and encourage me during all this time.

Acknowledgements

First and foremost, praises and thanks to Allah SWT, the Almighty for His guidance and blessing throughout the research.

I would like to express my deepest and sincere gratitude to both my supervisors, Dr Dylan P. Williams and Dr Chris Cane for their continuing support and guidance. They were instrumental in the commencement of this research and have shown confidence and faith in my abilities. Also, for all the time and efforts that they have afforded me.

I would like to thanks to both examiners, Professor Matthew Almond and Dr Sandeep Handa, for their time and thoughts for my research.

I would like to thank to Directorate General of Resources for Sciences Technology and Higher Education (DIKTI) Ministry of Research Technology and Higher Education of The Republic of Indonesia and the Tanjungpura University that have supported me to pursue my PhD.

I am extremely grateful for family, especially for my parents (Bpk Dedi AR and Ibu Zuhaida), husband (Luqman Hakim) and son (Danish Arsyil) for their prayers, love, caring, understanding, and continuing support to complete this research successfully. Also, I would like to express my thanks to my brothers (Deka Zufiandra, Dirhamsyah and Robiyanto) and sisters (Deti Apriani and Chica Fitriana (RIP)), who always support and encourage me with their best wishes.

Special thanks to Asriah Nurdini for her time, caring, support and for our precious discussion during this research. Also, I would like to thank to Judyanto Sirait, a friend and colleague who always provide his time to discuss and help me with my research.

Thanks to the lecturers and students who participated in the research. Sincere thanks to the lecturers (Eny Enawaty and Rahmat Rasmawan) for the two first year introductory chemistry units at Tanjungpura University, Pontianak, Indonesia for consenting to participate in the research despite the disruptions it may have caused. I would like to express particular gratitude to those students who volunteered to participate in the research, giving up their valuable free time and willingly expressing their understandings for the research.

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Abbreviations

AR	Action Research
BP	Bond Pair
EN	Electronegativity
LP	Lone Pair
LoEN	Leaflet of Electronegativity
MMB	Molecular Model Building
SoMCards	Shape of Molecule Cards
TLR	Teaching and Learning Resource
VoIF	Video of Intermolecular Forces
VSEPR	Valence Shell electron Pair Repulsion

List of Publications

Journal

Erlina, Cane, C & Williams, D. P. (2018). Predictions! The VSEPR Game: Using Cards and Molecular Model Building to Actively Enhance Students' Understanding of Molecular Geometry. *Journal of Chemical Education*. (Published)

Presentations

Erlina, Cane, C & Williams, D. P. (2016). A comparative and action research-based approach to developing new resources for teaching Chemistry in the UK and Indonesia. *Horizons STEM Conference, University of Leicester, UK.*

Erlina, Cane, C & Williams, D. P. (2017) The Development and Evaluation of a Card-game and Molecular Model to Enhance Students' Understanding of Valence Shell Electron Pair Repulsion Theory in the UK and Indonesia. *Horizons STEM Conference, Herriot-Watt University, Edinburgh, UK.*

Erlina, Cane, C & Williams, D. P. (2017). Card-game and molecular model to enhance students understanding of molecular geometry. *2nd International Seminar on Chemistry Education (ISCE), Universitas Islam Indonesia. (Presented)*

Erlina, Cane, C & Williams, D. P. (2018). Enhancing Students' Understanding of Shape of Molecule Based on VSEPR Theory Using Card-game and Simple Molecular Model. *ASERA 2018 Conference, Gold Coast, Queensland, Australia. (Presented)*

Erlina, Cane, C & Williams, D. P. (2018). Video of Intermolecular Forces to Improve Students' Understanding. *Horizons STEM Conference, University of Hull, UK. (Presented)*

Poster

Erlina, Cane, Chris, & Williams, Dylan. P. (2017). Developing new learning resources to address students' misconceptions of Shape of Molecule Based on Valence Shell Electron Pair Repulsion Theory (VSEPRT) in the UK and Indonesia. *Variety in Chemistry Education and Physics Higher Education Conference (ViCEPHEC), University of York, UK.*

Chapter 1
Introduction

Chapter Outline

The first chapter provides some background and the nature of scope of the research. The main themes of the research, which are models, chemical representations and learning; and the three objectives of the research that they correspond to are also outlined in this chapter. For each research objective there are a number of research questions that focus on a particular aspect of each objective. This chapter discusses the significance and justification for this research, providing some insight into why the research is important and worthwhile. A glossary of definition and terminology that is used in this research is provided in this chapter along with a description of the remaining seven chapters that constitute this thesis.

1.1 Introduction

As chemistry is considered to be a central discipline in scientific enquiry, students and researchers in other disciplines frequently need to employ chemistry concepts (e.g. biologists may describe the structure and properties of proteins in terms of the bonding and intermolecular forces that hold individual atoms together in polypeptide sequences). However, a large number of studies have proved that chemistry is considered to be a difficult subject for some students (Huddle & Pillay, 1996; Nakhleh, 1992; Gabel, 1998; Ozmen, 2004). Abstract concepts and the inability of students to make connections between macroscopic, sub-microscopic and symbolic representations of these concepts are believed as the main reasons for this difficulty. Hence, to gain further insight into this problem and to investigate means of overcoming it, this project has developed a series of new teaching and learning resources (TLRs) which employ three levels of representation of concepts to engage students in learning chemistry and to promote conceptual understanding of basic chemistry.

In order to achieve the aim, action research was applied in this project. Action research was used to design, develop and evaluate the TLR. The initial TLR was the shape of molecule cards (SoMCards) and molecular model building (MMB) to enhance students' understanding of molecular geometry based on VSEPR theory. The second TLR was a leaflet on electronegativity (LoEN) to promote students' understanding on electronegativity, bond type and polarity. The last TLR was a video of intermolecular forces (VoIF), to help students grasp the concepts of intermolecular forces. All TLRs have been piloted to a small group of students prior to the first and second cycle of the evaluation.

Questionnaires, tests (pre and post), interviews and observation were used as research instruments. Data collected were analysed using qualitative approaches. However, quantitative data were also presented to validate the findings as part of a triangulation process to maintain the quality of the study.

1.2 Background

Chemistry is the branch of natural science which is concerned with the study of the properties and changes of matter, the laws and principles related to changes in substances as well as the theories that interpret these changes (Slabaugh, Parsons 1976). In addition to that, chemistry plays an important role in our society. Sjöström (2007), described the many areas that chemistry is applied to such as chemical engineering, biotechnology, pharmaceutics and food technology. Therefore, understanding chemical concepts not only helps us to understand the behaviour and transformation of matter but it is also of prime importance to understanding concepts relevant to other disciplines such as biology, physics, medicine and agronomy.

Previous studies have shown that a significant number of students consider chemistry to be a difficult subject to learn (Huddle, Pillay 1996; Nakhleh, 1992; Gabel, 1998; Özmen, 2004). A number of studies have revealed that students at all levels may struggle to learn chemistry (Nakhleh 1992; Carter, Brickhouse 1989; Gabel 1998; Kind 2004; Taber 2002). It has been shown that the subject's perceived difficulty may put some students off studying chemistry (Gabel 1998). This attitude towards the subject may reduce students' interest and enthusiasm in the subject (Stocklmayer, Gilbert 2003) resulting in a decreased likelihood that these students will choose to study the subject at higher levels (Chittleborough 2004).

The perceived difficulty of the subject is believed to be caused by the often abstract and complex nature of many chemical concepts (Gabel 1999; Nakhleh 1992; Taber 2009; Rogers, Huddle & White 2000). Obstacles in understanding the basic concepts correctly will prevent students from developing an understanding of more complex chemical principles due to the tiered nature of the subject (Kean, Middlecamp 1994).

Another potential reason for misconceptions was proposed by Johnstone (1993) is that students are unable to make relationships between the three levels of representation in chemistry, i.e the macroscopic, the symbolic and the sub-microscopic. This may be particularly relevant where instruction emphasises the macroscopic and symbolic levels without making connections to the sub-microscopic level. Dori et al. (1996) stressed that many teachers do not understand the importance of integrating the three levels of representation, so their students may be particularly likely to encounter difficulties when learning basic chemistry.

To prevent this, several researchers suggested the integration of the three levels of representation in chemistry teaching and learning practice (Nicoll 2001). Additionally, a number of studies have highlighted the importance of teaching chemistry at the sub-microscopic level and making the relationship between this level and the macroscopic and symbolic clear in order to improve students' conceptual understanding (Sanger, 2000, Kozma *et al*. 1997, Nakhleh 1992, Nurrenbern & Pickering 1987, Andersson, 1990, Novick &Nussbaum 1981, Wu, Krajcik & Soloway 2001, Griffiths & Preston 1992, Osborne & Cosgrove, 1983, Bodner & Domin 2000, Ardac, Akaygun, 2004, Chandrasegaran, Treagust & Mocerino 2007, Chandrasegaran, Treagust & Mocerino 2008, Ebenezer, 2001, Tasker & Dalton 2006). As stressed by Kozma *et al*., (1997), simultaneous presentation of macroscopic, sub-microscopic and symbolic representations could reduce the likelihood of students forming incorrect (or alternative) conceptions. Treagust, Chittleborough & Mamiala (2003) found that symbolic and sub-microscopic representations are used to explain the macroscopic nature of chemical phenomena. The same study also said that to understand the abstract concept of chemistry, students need to develop an individual understanding of sub-microscopic level, as a consequence an extensive range of symbolic levels like the models, problems and analogies is necessitated to give a concrete description (Griffiths & Preston, 1992, Gabel, 1999).

Integrating multiple representations in teaching chemistry can be achieved through the use of models. Wu & Foos (2010) suggested the use of analogies to explain abstract concepts, such as diagrams and molecular models. Rogers, Huddle & White (2000) found that models could significantly improve students' conceptual understanding at the microscopic level. In their research they used a concrete model for teaching electrochemistry by using two boxes joined together, polystyrene balls at the same size to describe atoms and ions and marbles to delineate valence electron. A diagram representing this model is shown below.

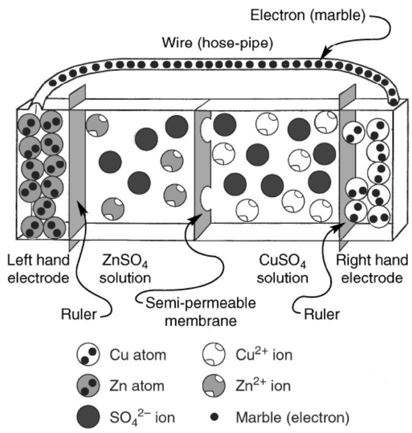


Figure 1. 1 Concrete model for teaching electrochemistry

Proofs of the merit of using analogies have been increasingly highlight (Wong, 1993) in term of concrete models when teaching theoretical chemical concepts, and also to assist the notions of development and clarification of remediating misconceptions (Brown & Clement 1989). Hence, models and analogies could act as learning resources. Embedding the three levels of representations in TLR is a challenge. This has been the focus of the project.

TLR can take a variety of forms, such as PowerPoint presentations, videos, simulations, animation, graphic, games and etc. Among these, games are believed to bethe most interesting resource for students, because they could make learning chemistry more fascinating and enjoyable (Russell, 1999; Myers, 2003). As stressed by Orlik (2002) in his review on the use of active methodologies in teaching of science, especially chemistry, one and the most valuable instruments to engage students in learning science is educational games. In addition, in teaching and learning process it is very importance that the game also results in student learning, at either cognitive or affective level, to facilitate the development of favourable attitudes toward chemistry (Franco-Mariscal, *et al*., 2014). Plenty of research has used games in terms of engaging students in learning chemistry; examples include, “elemental periodica” developed by

Bayir (2014) to learn about elements, compounds, and the periodic table, the "old prof card game" by (Granath & Russell 1999) to teach element symbols, "CHeMoVEr" (Russell, 1999) to teach nomenclature, equation balancing, and product-predicting skills, "puzzle" (Boyd, 2007) to teach matter and measurement, atoms, molecules and ions, stoichiometry, aqueous reactions, thermochemistry, electronic structure of atom, periodic properties of elements, chemical bonding, molecular geometry, bonding theories and gases. Related to this, a number of researchers have found that games supply captivating opportunities to empower students' mental structures and may also improve abstract thinking and promote relevant abilities of students, such as attention, memory, creativity and imagination (Vygotsky, 1967; Piaget & Inhelder 1979; Bruner, 1983; Franco-Mariscal, *et al*., 2012; Moreno, *et al*., 2014; Carney, 2014; Silva & Ribeiro, 2017). Interestingly, educational games also become a powerful tool to elevate students' motivation in learning science.

In general, therefore, it seems that developing resources in teaching and learning chemistry in connection with representing abstract concepts is significant and worthwhile. TLR in this project presented in three different forms. The first TLR is activity-based using cards and molecular model building to enhance student understanding of how to predict the shape of molecules based on VSEPR theory. The cards combine the activity to answer all the questions given in the cards and building molecular models based on their answer. This activity will allow students to integrate the three levels of representations, especially at sub-microscopic and symbolic levels. By emphasising these representations, promoting conceptual understanding might be achieved. As described by Treagust, Chittleborough & Mamiala (2003) sub-microscopic and symbolic level can be used to explain macroscopic phenomena and the integration among them which are essential to build a conceptual understanding of chemistry. The second TLR is utilising a leaflet to explain the topics of electronegativity, bond type and polarity, which is called the LoEN. The LoEN presented in full colour and provides the explanation along with the figures, chart, diagram and tables to support students' understanding. The LoEN explains the relationship between electronegativity, bond type, bond character and polarity of the molecules. The LoEN also adapts the three levels of representations approach in the symbolic level. The last TLR is presented as a video to explain the topic of intermolecular forces. The video which called the VoIF addressed all the alternative conceptions that students held based on reported findings of a number of researchers in some of chemistry education and science education journal. The VoIF presented the whole concepts covered in the Intermolecular Forces (IMFs). Diagram, images and figures were used to explain the concepts as well as to visualise the abstract concepts of IMFs.

1.3 Research Questions

The project focuses on developing TLRs which will help students to challenge their alternative conceptions of general chemistry concepts. The aim of the project is to develop targeted TLRs to challenge students' alternative conceptions of core ideas in general chemical concepts. These TLRs are be targeted to overcome the problems with common misconceptions that students faced in learning basic chemistry concepts by providing scaffolding to allow better concept visualisation.

Regard to the aim of the study, the main objective in which it also implements in the focus of study: developing targeted TLR by embedding chemical representations in order to challenge students' alternative conceptions of core ideas of general chemistry.

Several research questions were developed to direct the study. These questions were arrived at based on the focus of this study. The focus of this study has one ultimate question, "how to develop TLRs that contribute to promoting students' conceptual understanding in learning basic concepts of chemistry". To develop this question, several sub-questions need to be addressed:

1. How should educators develop targeted TLRs in order to challenge students' alternative conceptions of core ideas in General Chemistry?
2. What is the impact of the targeted TLRs on student learning?
3. How effective are these targeted TLRs at providing engaging learning experience?

1.4 Significance of the research

This research is important since it will produce new resources in teaching and learning chemistry in order to elevate students' conceptual understanding of basic principles of chemistry. Therefore, this will provide an insight into the value of alternatives for instructors and students to teach and learn chemistry in an effective way. It will also contribute a methodology for developing and assessing the resources which may be useful to others creating resources both in chemistry and other disciplines.

As a chemical educator there is an obligation to society to provide students with some degree of chemical literacy in order to be able to communicate about chemistry in general, including some issues that related to chemistry in society and being able to deal with chemicals and analyse results and evidence, and have an appreciation of hazards and risks connected to chemistry (Lagowski 2000, Shwartz, Ben-Zvi & Hofstein 2005). Hence, this project presented some approaches to address the problems in teaching and learning chemistry.

1.6 Justification of the Research

This study is focused on improving students' conceptual understanding of basic chemistry concepts by developing new teaching and learning resources using chemical representations. Chemical representations are used based on research findings that confirmed one of the main impediments of learning chemistry is the inability of students to make connection between macroscopic, sub-microscopic and symbolic. In this thesis, I describe three TLRs that were developed on different topics. All the topics chosen were based following a review of the literature that addressed students' misconceptions. The targeted TLRs developed in this study utilised three different forms to accommodate all learning styles.

1.7 Definition and Terminology

There are numerous terms that are used in this thesis to convey particular-meanings. To prevent any misunderstandings and clarify any ambiguities, definitions are provided.

Core Ideas of Chemistry – simple concepts that build students' comprehensive understanding of chemistry complex concept.

Chemical representations - according to Wu, Krajcik & Soloway refers to various types of formulas, structures and symbols used in chemistry (2000, p.2)

Conceptual change – a model of learning initially proposed by Posner et al. (1982).

Conceptual understanding – students' perception about concept.

Teaching and Learning Resource **-** texts, videos, software, and other materials that teachers use to assist students to meet the expectations for **learning defined** by provincial or local curricula.

Macroscopic – observable, able to be seen or experienced.

Model – defined by Gilbert and Boulter as "the presentation of an object, an even or an idea" (1995, p.1)

Representation – a likeness used to describe or depict (Hughes *et al*., 1995).

Sub-microscopic – the atomic or molecular level of chemical representation of matter

Symbolic – a representation of the sub-microscopic or macroscopic level.

1.8 Organisation of thesis

The organisation of the thesis is based on the research objectives. In addition to this first chapter, the thesis consists of a further seven chapters as illustrated in Figure 1.2. It is divided into 3 sections in order. The first boxes (Chapter 1, 2 and 3) indicate the research design programme that was done first. The second boxes (Chapter 4, 5 and 6) describe the results and findings using methods presented in Chapter 3. Chapter 4, 5 and 6 also discuss the objectives of the study. Meanwhile, the last boxes (Chapter 7) explains the evaluation and conclusions based on the findings.

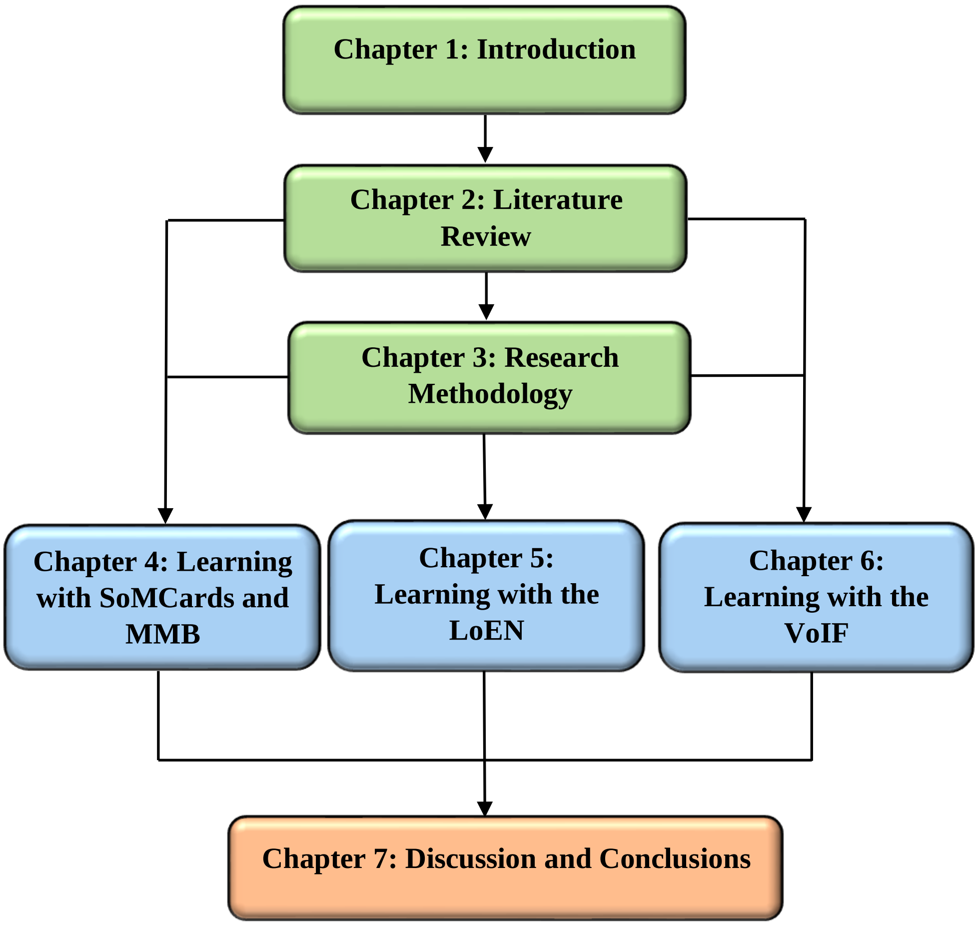
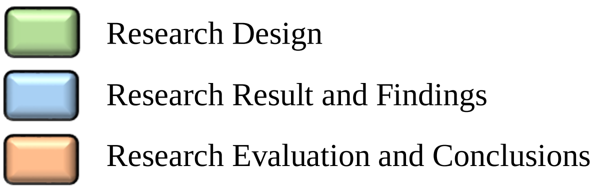


Figure 1. 2 Organisation of Thesis



Chapter 2 describes the extensive literature focusing on this research's main concepts and other related concepts. In order to achieve the research's aim and objectives, Chapter 3 constructs the research outline. This produces the research design that leads to the technical and non-technical research activities. Chapter 4 is the description of the initial TLR that was developed to challenge student's alternate conceptions on the shape of molecule based on VSEPR theory. The TLR was developed as a card-based activity. A simple molecular model was also developed along with the cards. Chapter 5 consists of the rationale for the second TLR which was developed in leaflet format to help students understand the topic of electronegativity, bond type and polarity. Chapter 6 discusses the development and implementation process for the last TLR which is the Video of Intermolecular Forces (VoIF). Chapter 7 discusses the 3 different formats of TLRs based on the findings. The conclusions and implications of the research also included in this chapter. Titles of each chapter are:

Chapter 2 Literature Review: Teaching and Learning Resources, Chemical Representations, Problems in Learning Chemistry and The Core Ideas in General Chemistry Course.

Chapter 3 Research Methodology

Chapter 4 Findings and Discussions: Understanding the Shape of Molecule based on VSEPR Theory by using Cards (SoMCards) and Molecular Model Building (MMB)

Chapter 5 Findings and Discussions: Enhancing Students' Understanding of Electronegativity, Bond Type and Polarity by using Leaflet (LoEN)

Chapter 6 Findings and Discussions: Using a Video Resource to Enhance Students' Understanding of Intermolecular Forces (VoIF)

Chapter 7 Discussion and Conclusions

1.9 Summary

This chapter has provided an overview and some background information of the research. The statements of significance and justification of the research support the objectives and research questions of the study. The chapter concluded with a glossary of terminology that is used in the thesis and an outline of the contents of the following seventh chapters.

Chapter 2

Teaching and Learning Resources, Chemical Representations, Problems in Learning Chemistry and The Core Ideas in General Chemistry Course

Chapter outline

This chapter reviews literature on teaching and learning resources (TLRs) and chemical representations. The first part of this chapter discussed about the TLRs. The second part explain the chemical representations used in this project. The role of visualisation in learning chemistry is presented in the next section. Alternative conceptions that students experienced as the main problems of understanding chemistry explained in the fourth section. In addition to that, description of general chemistry course based on syllabus of general chemistry of Department of Chemistry Education University of Tanjungpura where the study took place are described in detail. In the next section, topics presented in all TLRs considered as the core ideas in general chemistry course are also explained.

2.1 Teaching and Learning Resources (TLRs)

The common goal of teaching and learning is the development of learner understanding (Newton, 2000). Understanding is the ability to think and act flexibly with what one knows (Perkins, 1994). Teaching and Learning Resources (TLRs) are tools used to facilitate the process of teaching and learning. All things that teachers or instructors used in their classroom to teach are considered as teaching and learning resources. These include textbook, images, maps, photograph, sketches, diagrams, video, educational games, poster, flashcards, apps, website, etc. TLRs are often referred to as teaching materials, learning materials, instructional materials or learning media. In this study the term TLRs is used to describe the activities that the researcher's created and the experiences that students have when engaging with them.

The main purpose of using TLRs in the class is aiding the teachers with the presentation and transmission of educational content and the achievement of instructional objectives. The purpose also implies that TLRs can be used to support students' engagement in the learning experience while assisting the students in gaining knowledge and acquiring different abilities and values (Bušljeta, 2013). To achieve the goal, teachers should choose an effective TLRs. Several factors must be considered when choosing TLRs as suggested by Bušljeta (2013); the compatibility of TLRs with instructional objectives (e.g. what are students expected to learn and to what level?) and tasks, students' characteristics, teachers' knowledge and abilities, the characteristics of TLRs which should be informative, easily accessible, and contribute to the clarity and quality of teaching and learning process. These factors are also considered when developing the targeted TLRs.

The TLRs in this study were developed to help support the teaching and learning process. The effectiveness of the TLRs developed were measured by implemented the TLRs in the General Chemistry Course. Prior to the implementation, the pilot studies were conducted to obtain the initial insight into the effectiveness of the TLRs and to identify any issues that would need to be addressed. Three TLRs have been developed in this study, Shape of Molecule Cards (SoMCards) and Molecular Model Building (MMB), Leaflet of Electronegativity (LoEN), and Video of Intermolecular Forces (VoIF).

The topics presented in the TLRs were chosen based on two reasons which were identified as a result of the review of the literature. The first of the topics was predicting the shapes of molecules, since electronegativity and intermolecular forces are central to many other concepts in the chemistry curriculum (Nicoll, 2001; Kind, 2004; Tarhan, *et al*., 2007; Cooper, Williams and Underwood, 2015). The second of these reasons was considered difficult to understand for many students (Nicoll, 2001; Sumarni, 2010; Ardiansah, 2013 and 2018, Peterson, *et al*., 1989; Birk and Kurtz, 1999; Tan and Chan, 2003, Winarni, 2006 and 2016). A limited amount of research has been reported to relating to overcoming this problem (Nicoll, 2001; Chan, 2003; Muchson, 2013).

The choice of the formats for the TLRs was made based on the fact that the targeted TLRs developed in this study would be implemented in Indonesia where the internet connection is poor to access existing resources and there is less advanced technology. Thus, all targeted TLRs were developed with a minimum use of advanced technology. A detailed explanation about the choices of the topics and the format of the TLRs are presented in the section 4.1 Chapter 4, section 5.1 5 and section 6.1 in chapter 6.

2.2 Chemical Representations

A representation is defined as a way to communicate the phenomena, objects, events, abstract concepts, notion, mechanism, system, or a process (Chiu & Wu, 2009). Therefore, representation is a way of encoding very complex ideas in an easy to communicate format.

Chemistry has been described as a subject that can be represented at three different levels. The three levels representations in chemistry consist of; macroscopic, microscopic and symbolic. These representations have been a spotlight for decades to all researchers and chemistry educators (Gabel, Samuel & Hunn 1987, Gabel 1998). Johnstone (1982; 1993) defined the three levels of chemical representations as follows:

- The macroscopic level – comprising real and tactile chemicals, which may or may not be part of students' daily experiences, for instance an observation of a change of phase or color.
- The sub-microscopic level – comprising the particulate level, which can be used to depict the motion of electrons, molecules, particles or atoms, such as water which comprises a collection of molecules, each consisting of an oxygen atom and two hydrogens atoms.
- The symbolic level – comprising a large variety of graphical representations, algebraic and computational forms, such as chemical symbols, formulas, and structures by using letters, signs, and subscript, for example water is H_2O and table salt is NaCl. H_2O and NaCl both served as the symbolic level for water and salt.

Furthermore, Johnstone (1982) describes the macroscopic as descriptive and functional, and the sub-microscopic level as representational and explanatory. Examples of each of the three levels of chemical representation are shown in Figure 2.1. Harrison and Treagust (2002) reported that many students at Grade 8 (age 13-14) and even for some science teachers of Grade 8-10 were having a poor sub-microscopic level of understanding of the particulate of matter. The term sub-microscopic refers to levels from the particulate level through to the nanoscopic level and even smaller. Boo (1998) and Gabel (1998) highlighted in their studies that many secondary school and college students, and even some teachers, have difficulty transferring from one level to another. These findings suggest there is a need to emphasise the difficulty of transferring between the three levels representations (Treagust & Chittleborough, 2001).

Erduran and Scerri (2002) stated that chemistry education needed to stress a philosophical approach. In addition to that, they propose that the "teaching and learning of chemistry can be improved through an understanding of the structure of chemical knowledge". The current emphasis on the philosophy underpinning the knowledge of chemistry would underline the significance of the role of models and representations in the science process.

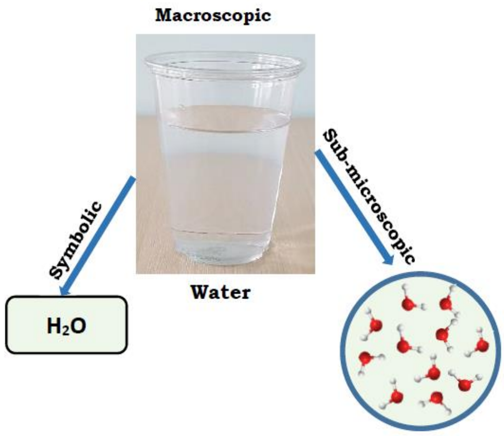


Figure 2. 1 Three levels of Chemical Representation using water as an example (Erlina, Cane & Williams 2018).

2.3 The Role of Visualisation in Learning Chemistry

The term of visualisation is used to name a representation, to point out to the process of generating a graphical representation or as a synonym for visual imagery (Vavra *et al.*, 2011). The representation is generally visual, either still image or dynamic animations, two or three dimensional, but can also refer to tactile representations, for example physical models, or audio representations, such as increasing volume to simulate increasing energy (Jones & Kelly, 2015). According to Bishop (1989) visualisation can refer to the product, object or visual image or the process, activity or skills.

In chemistry, visualisation has numerous applications. Visuospatial skills are highly needed to comprehend chemistry concepts. The importance of learners' differences and the role of visualisation in reducing how much students have to remember in chemistry was highlighted by Wu and Shah (2004). Moreover, they claim that visualisation provides multiple representations of the same information, which enables "students to visualise the connections between representations and relevant concepts". Visual representations have several important functions in chemistry: to make connections visible, to present the dynamic and interactive nature of chemistry, to promote the transformation between two-dimensional and three-dimensional thinking, and to reduce how much students need to remember by making the information explicit.

The models are forms of representations, especially for the microscopic level. According to Justi & Gilbert (2000) a model is a representation of a phenomenon, an object, or the notion. For instance, the use of a Molymod set to depict the structure of water molecules. The use of a model in the classroom could improve students' understanding of chemistry concepts, like the study conducted by Rogers, Huddle and White (2000) who use a concrete model for teaching electrochemistry by using two boxes joined together, polystyrene balls at the same size to describe atoms and ions and marbles to delineate valence electron (see figure 1.1 in Chapter 1). The outcome was significantly promoted student understanding on electrochemistry concepts.

Another type of model used in chemistry are those that make use of computer animation. This approach was first developed by Merril & Ridgway in 1969 by using space-filling models and animation followed by Smith (1970), Davies and Moore (1976), Smith *et al.*, (1985), Greenbowe (1994), Tasker (1994), Kozma & Russell (1997), Tasker & Dalton (2006), and Akaygun & Jones (2013).

Johnstone (1993) proposed the reason chemistry was challenging for novice students to learn was largely due to it being a complex tangle of three levels of representations: macroscopic level of the visible and laboratory aspects, symbolic level of chemical symbols, formulas and mathematics and the sub-microscopic level of the interaction of atoms, molecules and ions. The reason of the theory is that experts could move easily between these three levels while novices had difficulty understanding one level, let alone connecting to the other two levels. Based on this reason, many instructors thought that students would master chemistry by assisting them in learning how the three levels related. Some studies were conducted to emphasise the connection between macroscopic, submicroscopic and symbolic levels using the animation. Animations provide students with an explanation of the macroscopic and submicroscopic phenomenon, which can have a powerful affect in transforming how students make sense of the chemistry (Jones & Kelly, 2015).

A study about the effect of computer animations was conducted by Williamson and Abraham (1995). In this study, they developed eight animations on gases, liquids and solids, including gas behavior, phase transitions, intermolecular forces and London dispersion forces. The animations were used in six lectures. Some of these animations were interactive, so that students were able to alter the variable, such as pressure or temperature to see how it affected the gas. The researchers used the animation in two treatment situations: as a supplement in large-group lectures and as both the lecture supplement and as assigned individual activity in a computer laboratory. Both of these treatment group received a significant higher conceptual understanding scores on a test than did a control group. Similar findings were found for a second topic (reaction chemistry), which used five animations in four lectures. Based on these outcomes, Williamson and Abraham (1995) concluded that the animations led to increased understanding and that students developed mental models of particulate behavior that were more like those experts.

Yezierski and Birk (2006) used the Vischem animations developed by Tasker to study the effect of viewing animations on students learn. In this study, they used Vischem animations of water in different phases: liquid, solid, vapor and changing phases from solid to liquid to investigate how animations affected students' misconceptions related to the particulate nature of matter. Their findings demonstrated that students who viewed the animations performed better on a test of understanding. Thus, they recommended that class time be used to discuss and interpret the animations as they relate to macroscopic phenomena that they were observed.

Based on the findings, it can be concluded that visualisation is the key to understand chemistry. The visualisation plays an important role in constructing students' conceptual understanding of chemistry concepts. Therefore, visualisation were highly recommended to be used in teaching the abstract concept of chemistry.

2.4 Problems of Understanding Chemistry

Misconception is to be one of the main the problems in chemistry education. Misconception is known by many terms, such as alternative conception, pre-concept, alternative frameworks. Moreover, Cho, Kahle & Nordland (1985), define misconceptions as “any conceptual idea whose meaning deviates from the one commonly accepted by scientific consensus”. Due to the nature of the subject, chemistry relies on a number of models that rely on abstract concepts (e.g. models of atomic and molecular structure). These models are fundamental in understanding the more complex topics that students encounter in the later stages of their education. A means of identifying and resolving misconceptions in fundamental topics like these is an important consideration when designing a chemistry curriculum. In addition to the difficulty of interpreting representations, Keig and Rubba’s (1993) study showed that large numbers of students were unable to translate among formulae, electron configurations, and ball-and-stick models.

One possible answer to that is proposed by Nakhleh (1992) is that many students are not constructing proper understanding of basic chemical concepts from the beginning of their studies, therefore they cannot fully understand the more advanced concepts that build upon the fundamental concepts. This is also supported by the work of Taber (2009). A number of studies have shown that misconception occurs in the teaching of many fundamental topics in chemistry (Taber 2003, Gabel 1998, Rogers, Huddle & White 2000, Nakhleh 1992) (Taber 2003; Gabel; Huddle & Rogers 2000; Nakhleh 1992; Nicoll 2001). In addition to that, Taber (2009) suggested students’ prior educational experience is the primary contributory factor to misconceptions.

Based on the author’s review of the literatures, the most widely reported misconceptions relate to the following topics: the mole concept (Gilbert & Watts, 1983), element, compound and mixture (Ayas and Demirbas, 1997; Papageorgiou & Sakka, 2000), the particulate nature of matter (Abraham *et al.*, 1992; De Vos and Verdonk, 1996; Nakhleh & Samarapungavan, 1999; Valanides, 2000), atomic structure (Zoller, 1990; Harrison & Treagust, 1996), kinetic theory (Abraham *et al.*, 1992; Stavy, 1995; Taylor & Coll, 1997), thermodynamics (Abraham et al., 1992; Özmen & Ayas, 2003), electrochemistry (Garnett & Treagust, 1992; Sanger & Greenbowe, 1997), chemical change and reactivity (Zoller, 1990; Abraham *et al.*, 1992), chemical bonding (Peterson & Treagust, 1989; Taber, 2002; Taber & Coll, 2003; Coll & Treagust, 2003; Özmen, 2004; Ünal *et al*., 2006), molecular geometry (Nicoll, 2001; Sumarni 2010), electronegativity (Nicoll 2001), intermolecular forces (Winarni, 2006), (Winarni & Syahrial, 2016), Goh, *et al.* (1993); Peterson *et al.* (1989, 1993); Taber (1995, 1998); Peterson & Treagust (1989); Birk & Kurtz (1999); Griffith & Preston (1992); Coll & Taylor (2001), Schmidt (1996) and Henderleiter *et al*. (2001).

Misconceptions or alternative conceptions in chemistry can be identified using conceptual inventory for certain topics, such as the chemical concept inventory developed by Mulford and Robinson (2002), diagnostic test by Treagust (1988); Peterson, Treagust & Garnett (1989), two-tiered multiple-choice diagnostic test by Chandrasegaran, Treagust & Mocerino (2007). However, in this study, the concepts of students' common misconceptions were identified by reviewing the relevant studies published in scientific journals. The findings of the reviews were then used to develop the targeted Teaching and Learning Resources (TLRs) with a suitable format by embedding the three level of representations.

2.5 Description of General Chemistry Course (Source: Syllabus of General Chemistry 1 and 2 Course of Pendidikan Kimia, FKIP, Universitas Tanjungpura)

General Chemistry 1 and 2 are two of the compulsory courses for first year Chemistry Education Study Programme students at Department of Mathematics and Science Education, Faculty of Teacher Training and Education of Tanjungpura University, Indonesia. The aim of this programme is to prepare the future chemistry teachers for roles in junior high schools and high schools in Kalimantan Barat, Indonesia. General Chemistry 1 is taught is the first semester, while General Chemistry 2 is taught in the second semester (Tim Prodi Pendidikan Kimia, 2016). These courses are designed to provide students with an understanding of the foundations of the subject that they will need to apply in later courses such as Biochemistry, Organic Chemistry, Analytical Chemistry, Inorganic Chemistry, *etc*.

Table 2. 1 Topics and sub-topics covered in General Chemistry 1 and 2 Courses

Course	Topic	Sub-topic
General Chemistry 1	Chemistry and Measurement	An Introduction to Chemistry and Physical Measurement
	Atoms, Molecules, and Ions	Atomic Theory and Atomic Structure, Periodic Table of Elements, Chemical Substances, Chemical Reactions
	Stoichiometry	Fundamental Laws of Chemistry, Mass and Moles of Substance, Determining Chemical Formulas, Quantitative Relation in Chemical Reaction
	Thermochemistry	The Nature of Energy, Enthalpy and Calorimetry, Hess's Law, Standard Enthalpy of Formation
	Thermodynamics and Chemical Equilibrium	First Law of Thermodynamics, Enthalpy, Spontaneous Processes & Entropies, Free Energy Concept, Free Energy and Equilibrium Constant
	Acids and Bases	Acid Base Concepts, Acid Base Strength, Self-ionisation of Water
	Chemical Bonding	Basic concepts of chemical bonding, Ionic bonding, Covalent Bonding, Polarity, Molecular Geometry
General Chemistry 2	State of Matter	Changes of States, Liquid of States, Properties of liquids, Intermolecular Forces, Solid States
	Solutions	Solution Formation, Colligative Properties, Colloid Formation
	Electrochemistry	Half Reaction, Voltaic Cells, Electrolytic Cells
	Chemistry Kinetics	Form of The Rate Law, The Integrated of Rate Law, Reaction Mechanism, A Model for Chemical Kinetics, Catalysis
	Chemistry of Main-Group Elements	Chemistry of The Main-Group Metals, Chemistry of Non-metals
	Nuclear Chemistry	Radioactivity & Nuclear, Bombardment Reaction, Energy and Nuclear Reaction

An overview of the concepts covered in the General Chemistry 1 and 2 courses is presented in Table 3.1. Both courses are designed to expose the learner to macroscopic, microscopic and symbolic levels of representation of these key chemical concepts (Tim Prodi Pendidikan Kimia, 2016).

Both General Chemistry 1 and 2 courses are taught by a team consisting of two lecturers. These courses consist of 3 credits, with 2 credits allocated to theory content taught in lectures and 1 credit allocated for laboratory work. Each credit for the lectures is equivalent to 50 minutes classroom meeting, 50 minutes for structured task and 60 minutes for self-learning. Meanwhile for the laboratory work, each credit is equivalent to 160 minutes.

Teaching methods used in the course range from the didactic (e.g. lectures) to the student-centred (e.g. small-group discussion and individual and group tasks). Student understanding of the course content is assessed in two written exams (taken at the mid-point and the end of each semester). In addition to the written exams, individual and group assessed tasks are also used to help support student learning, such as writing an essay or paper related to certain topics in General Chemistry courses. The exams for these courses were designed by the course lecturers. The final course scores are calculated as the sum of the score from the exams, individual and group tasks and the laboratory work.

2.6 Topics presented in the TLRs that covered in General Chemistry course

General Chemistry is the fundamental subject for first-year students who studied science in all Universities in Indonesia.

2.6.1 Molecular Geometry based on VSEPR (Valence Shell Electron Pair Repulsion) Theory

The shape of molecules is a fundamental concept that students must understand before going on to study more complex topics. Understanding how to determine the shapes of simple molecules is a crucial first step to discuss and predict chemical properties. Molecular geometry is influenced by a number of factors including the valence electron configuration for both central atom and the substituent/s, the number of lone and/or bond pair electrons surrounding the central atoms and the repulsion between lone and bonding electron pairs.

Valence Shell Electron Pair Repulsion (VSEPR) theory is used to predict the shape of the molecule. This theory is developed by Gillespie and Nyholm in 1957. Thus, this theory also known as Gillespie-Nyholm theory. In VSEPR theory, electron pairs are arranged around the central atom of the molecule or ion as far apart as possible in order to minimise repulsion between pairs. This influences the shape of the molecule and the size of the bond angles. Basic assumptions of VSEPR as follows:

1. Pairs of electrons in the valence shell of central atom repel each other.
2. These pairs of electrons tend to occupy positions in space that minimise repulsion and maximise the distance of separation between them.
3. The valence shell is taken as a sphere with electron pairs localising on the spherical surface at maximum distance from one another.
4. A multiple bond is treated as if it is a single electron pair and the two or three electron pairs of a multiple bond are treated as a single super pair.

Three types of repulsion take place between the electrons of a molecule:

- The lone pair – lone pair repulsion
- The lone pair – bonding pair repulsion
- The bonding pair – bonding pair repulsion

To remain stable, a molecule must avoid those three repulsions. When the repulsion cannot be avoided, the weaker repulsion (i.e. the one that causes the smallest deviation from the ideal shape) is preferred. The lone pair-lone pair (lp-lp) repulsion is considered to be stronger than the lone pair-bonding pair (lp-bp) repulsion, which in turn is stronger than bonding pair-bonding pair (bp-bp) repulsion. Hence, the weaker bp-bp repulsion is preferred over the lp-lp or lp-bp repulsion.

2.6.2 Electronegativity, Bond Type and Polarity

Electronegativity

Electronegativity (EN) is one of the most important concepts in chemical bonding. EN is the ability of an atom in a molecule to attract shared electrons to itself. The greater an atom’s electronegativity, the greater its ability to attract electrons to itself. It only applies to electron in bonding pairs. The trend of EN in the periodic table is shown in Figure 2.2. The most commonly used definition of EN uses the Pauling Scale. The

Pauling scale is a numerical scale of electronegativities based on bond-energy calculations for different elements which joined by covalent bonds.

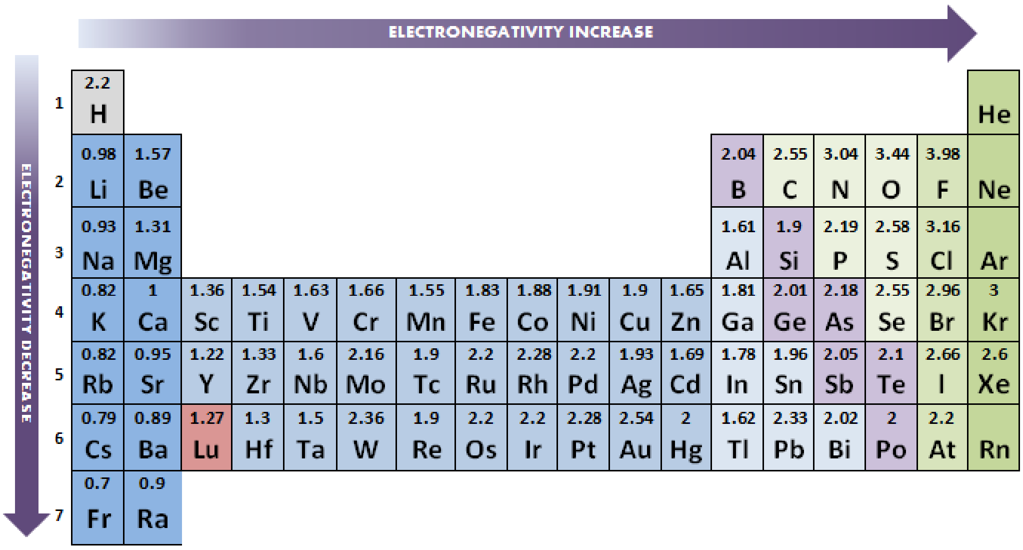


Figure 2. 2 The periodic table trends and electronegativity values (as measured on the Pauling scale).

In general, EN increases across a period and decreases down the group. As shown in Figure 2.2, the most electronegative element is fluorine (F) with 4.0, while the francium (Fr) has the least with 0.7.

Bond Character and Bond Types

A chemical bond between atoms of different elements is never completely ionic or covalent. The degree of ionic or covalent character of a bond depends on how strongly each of the bonded atoms attracts electrons. As shown in Table 2.2, the character and type of a chemical bond can be predicted using the electronegativity differences of the elements that bond.

Table 2. 2 EN Difference and Bond character

ΔEN and Bond Character	
Electronegativity Difference	Bond Character
> 1.7	mostly ionic
0.4 - 1.7	polar covalent
< 0.4	mostly covalent
0	nonpolar covalent

Electrons in bonds between identical atoms have an electronegativity difference of zero—meaning that the electrons are equally shared between the two atoms. This type of bond is considered nonpolar covalent, or a pure covalent bond. On the other hand, because different elements have different electronegativity, the electron pairs in a covalent bond between different atoms are not shared equally.

Unequal sharing results in a polar covalent bond. When there is a large difference in the electronegativity between bonded atoms, an electron is transferred from one atom to the other, which results in bonding that is primarily ionic.

Bonding is not often clearly ionic or covalent. An electronegativity difference of 1.70 is considered 50 percent covalent and 50 percent ionic. As the difference in electronegativity increases, the bond becomes more ionic in character. Generally, ionic bonds form when the electronegativity difference is greater than 1.70.

Bond types

How to identify the bond types? There are 2 ways to identify the bond types. The first approach is to use our understanding of the periodic table. This is the most common and easiest way to identify the bond types.

Here are the rules to predict the bond type:

1. **Ionic bonding** usually happens between metallic elements and non-metallic elements, such as NaCl, $MgCl_2$, MgO, etc.
2. **Covalent bonding** usually happens between non-metallic elements. For instance, O_2, Cl_2, H_2O, etc.
3. **Metallic bonding** happens between metallic elements. Examples; Al, Cu, Fe, etc.

Another way to predict the bond types is using the difference in the electronegativity (ΔEN) of the bonded atom.

Polarity

The relationship between electronegativity and bond character (Table 2.2) can also be used to identify whether a molecule is polar or non-polar covalent. By understanding the concept of electronegativity, we can explain not only the types of chemical bond but polarity as well.

Bond polarity is a measure of how equally or unequally the electrons in any covalent bond are shared. A nonpolar covalent bond is one in which the electron are

shared equally, as in Cl_2 and H_2. In a polar covalent bond, one of the atoms exerts a greater attraction for the bonding electrons than the other. If the difference in relative ability to attract electrons is large enough, an ionic bond is formed.
We can use the difference in electronegativity between two atoms to gauge the polarity of the bond the atoms form. Consider these three chlorine-containing compounds:

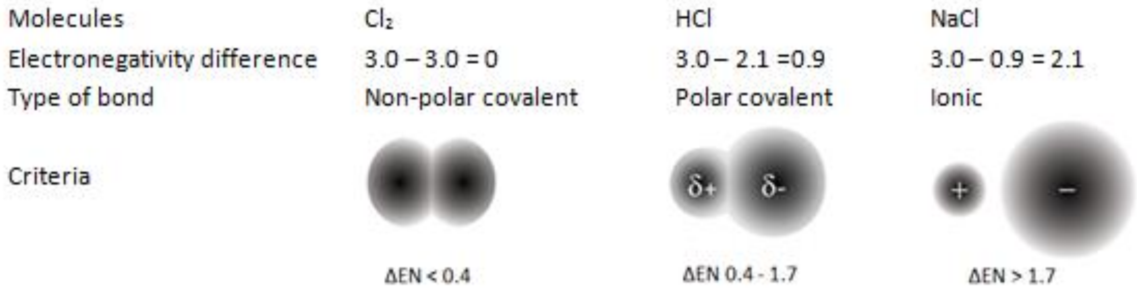


Figure 2. 3 The relationship between EN difference, Bond Types and Polarity of sample molecules.

In Cl_2 the electrons are shared equally between the chlorine atoms and, thus, the covalent bond is nonpolar. A nonpolar covalent bond results when the electronegativities of the bonded atoms are equal. In HCl the chlorine atom has a greater electronegativity than the hydrogen atom, with the result that the electrons are shared unequally, thus the bond is polar covalent.

In general, a polar covalent bond result when the atoms differ in electronegativity and tend to occur between atoms of moderately different electronegativities (0.4 - 1.7).

Polarity plays an important role in chemistry because of two reasons. First, polar and nonpolar molecules do not mix to form a solution. Second, polarity influences several physical properties of matter, such as solubility, surface tension and melting point. Polar molecules and ionic compounds are usually soluble in polar substances, but non-polar molecules dissolve only in non-polar substances.
In HCl the more electronegative chlorine atom attracts electron density away from the less electronegative hydrogen atom, leaving a partial positive charge on the hydrogen atom and a partial negative charge on the chlorine atom. We can represent this charge distribution as

$$\overset{\delta+}{H} - \overset{\delta-}{Cl}$$

The δ+ and δ- (read delta plus and delta minus) symbolize the partial positive and negative charges, respectively. In a polar bond, these numbers are less than the full charges of the ions. The relationship between electronegativity (EN), bond type and polarity can be seen om Figure 2.4.

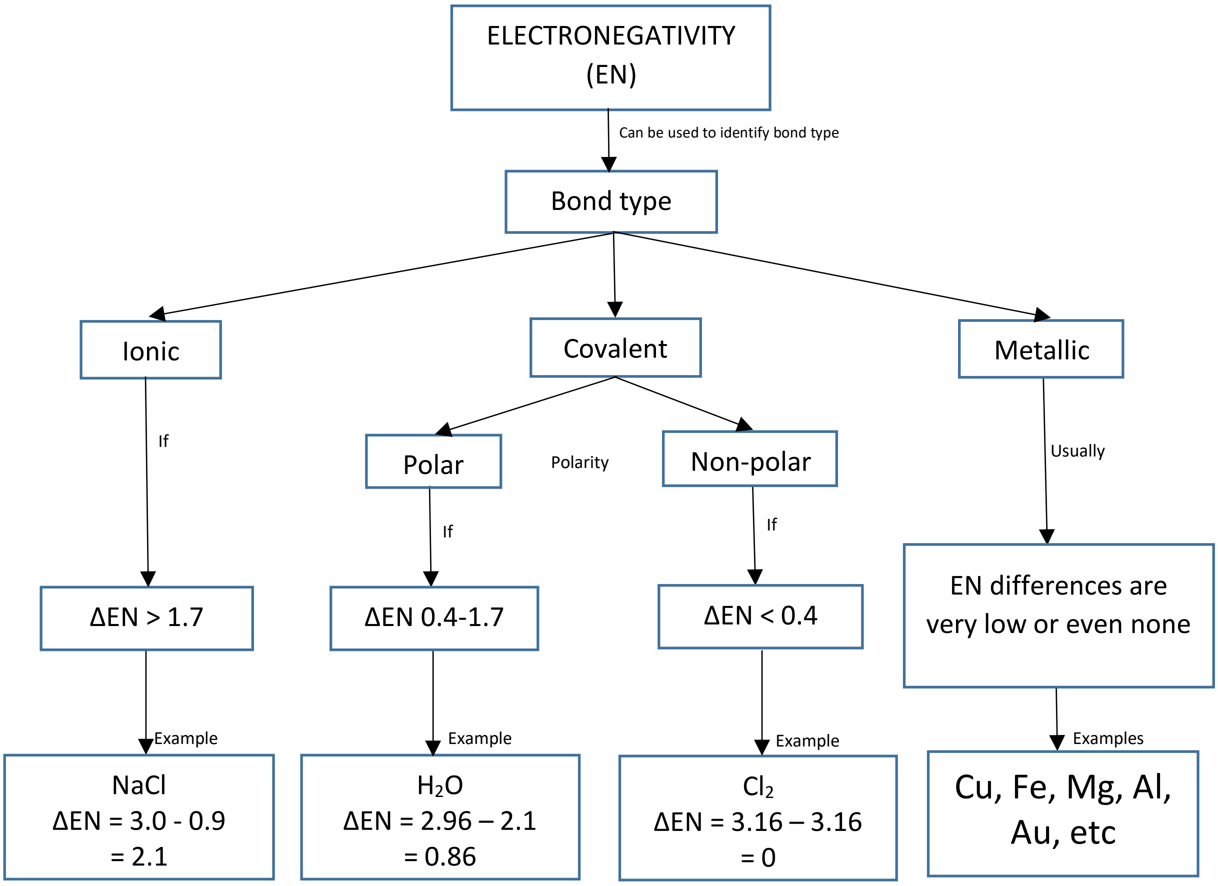


Figure 2. 4 A diagram to show the relationship between Electronegativity (EN), Bond Type and Polarity presented with example for each bonding type.

In NaCl the electronegativity difference is very large. It effectively means that one Na's valence electron is transferred to Cl to produce a pair of ions. The resultant bond is therefore most accurately described as ionic. Thus, if we considered the bond in NaCl to be fully ionic, we could say δ+ for Na is +1 and δ- for Cl is 1-. Electronegativity also give us a simple way of predicting which atom in a polar covalent has the partial negative charge and which has the partial positive charge. *In a polar covalent bond, the atom with the higher electronegativity has the partial* *negative charge, and the atom with the lower electronegativity has the partial positive charge.*

For example, the electronegativity of fluorine (4.0) is higher than for hydrogen (2.1). In an H-F bond, we predict that the fluorine atom attracts more strongly than the hydrogen atom and gets a partial negative charge.

2.6.3 Intermolecular Forces

Intermolecular Forces are the attractive force between similar or different molecules. The types of the intermolecular forces can be seen in Figure 2.5.

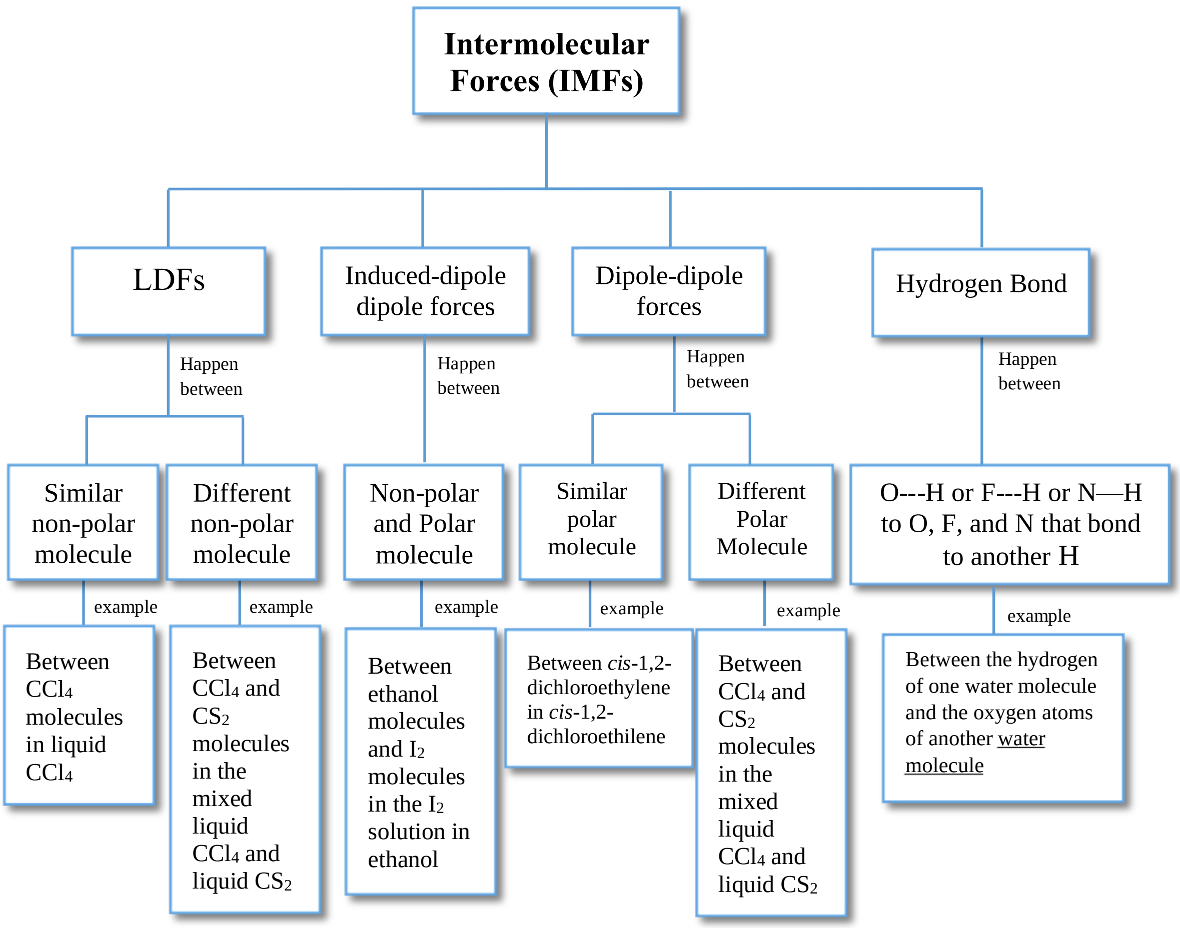


Figure 2. 5 Types of Intermolecular Forces that consists of London Dispersion Forces (LDFs), Induced-dipole dipole force, Dipole-dipole force, and Hydrogen Bond with example for each type.

London Dispersion Forces (LDFs), dipole-induced dipole force and dipole-dipole force are usually called van der Waals forces, after the Dutch scientist Johannes van der Waals who first attempted to explain them. All these intermolecular forces are electrostatic in origin and result from mutual attraction of unlike charges and the mutual repulsion of like charges.

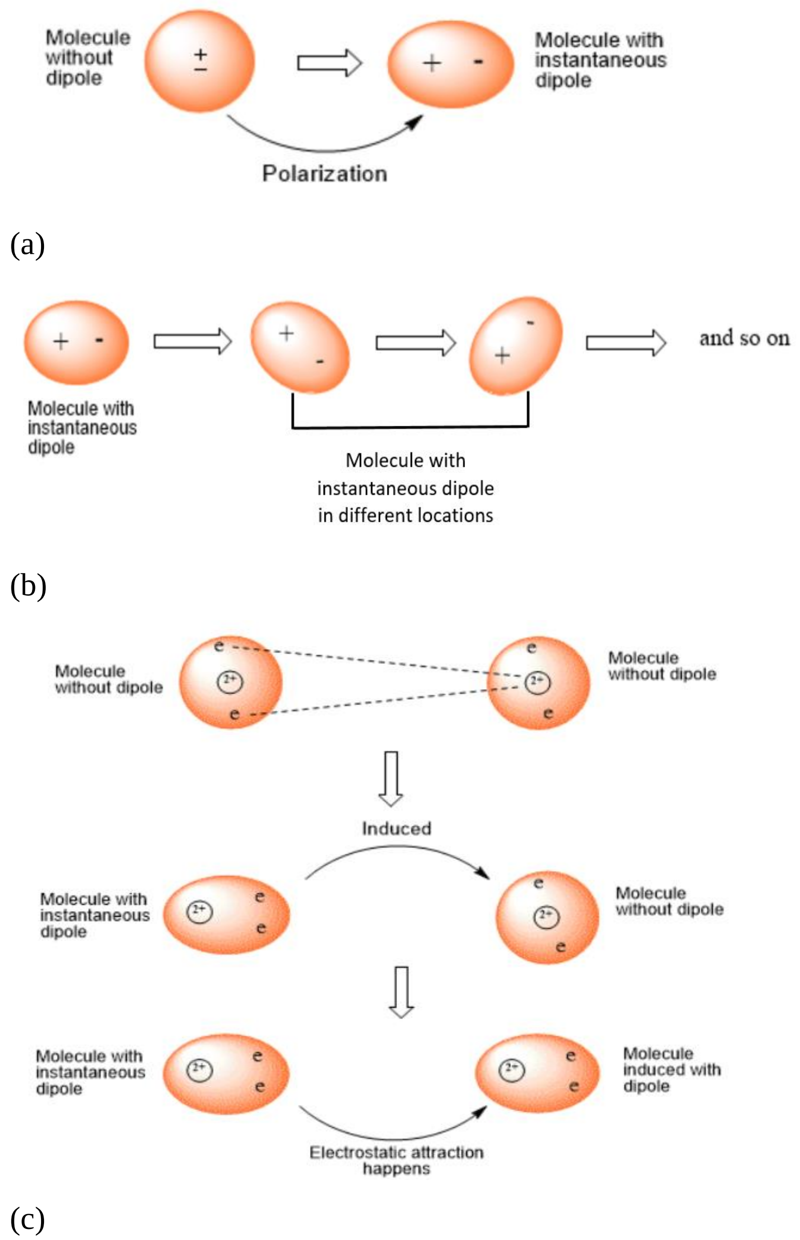


Figure 2. 6 (a) The formation of instantaneous dipole of nonpolar molecule; (b) The instantaneous dipole in different locations; (c) The occurrence of London Dispersion Forces (LDFs) between nonpolar molecules.

London Dispersion Forces (LDFs) is the attraction between 2 instantaneous dipoles and it happens between polar and nonpolar molecules. These are the weakest intermolecular forces and increases in strength as molar mass increases. *Dipole-induced- dipole forces* are the attraction between polar and nonpolar molecules by disturbing the arrangement of electrons in the nonpolar species. The induction process can be seen in Figure 2.6. The diagram shows the process of induction between polar and nonpolar molecules. The strength of dipole induced-dipole force is weaker than dipole-dipole force but stronger than LDFs. Induced dipole moments depend upon the dipole moment present in the permanent dipole and the polarizability of the electrically neutral molecule. *Dipole-dipole force* is the attraction between two permanent dipoles and it happens between polar molecules. The strength of this force is medium (stronger than LDFs and dipole-induced dipole force). This force is stronger when molecules are closer. *Hydrogen bonding* is the attraction between molecules with N-H, O-H, & F-H bonds and occurs between extremely polar bonds with very strong dipole-dipole force. Depending on the nature of the donor and acceptor atoms which constitute the bond, their geometry, and environment, the energy of a hydrogen bond can vary between 1 and 40 kcal/mol. This makes them somewhat stronger than a van der Waals interaction, and weaker than fully covalent or ionic bonds. It is called hydrogen bonding but it’s not a chemical bonding like covalent, ionic or metallic.

2.7 Theoretical framework of the study

The theoretical frameworks used in this study are based on a constructivist approach that is grounded in the belief that what a learner already knows is a major factor in determining the outcomes of learning (Ausubel, *et al*., 1968). Constructivism is a theory of learning with its origin in the cognitive sciences that eventually discussed and applied in both science education and chemistry education (Ferguson, 2007). As a theory of learning, constructivism provides a basis for understanding how a person incorporates new knowledge into existing knowledge and then makes sense of that knowledge (Nussbaum, 1989; Tobin, 1990; von Glasserfield, 1992). In addition to that, the constructivism offers a theoretical framework for thinking about how people engage with objects in the world around them and make sense of these objects (Bodner, 1986; Bodner, Klobuchar & Geelan, 2001).

The complex and abstract nature of chemistry makes the study of the subject difficult for students (Ben-Zvi *et al*., 1987, 1988; Gabel 1998; Johnstone, 1991, 1993; Nakhleh 1992; Treagust & Chittleborough 2001). As a result, students tend to hold particular uncommon views about scientific phenomena and concepts that they bring with them to science lessons. The unique conceptions about natural phenomena that are held by students are often resistant to instruction because there is a tendency for these conceptions to become firmly entrenched in students' minds as coherent but mistaken conceptual structures (Driver & Easley 1978), especially when students' conceptions are deeply rooted in everyday life experiences. As a result, when the new concepts do not make sense to them, students tend to adhere firmly to their own views (Treagust *et al*., 1996). Consequently, it is helpful to identify the conceptions held by students that are different with scientific views so that relevant strategies may be formulated that will challenge their understandings in order to help students develop more scientifically acceptable views of science concepts.

2.8 Summary

This chapter has drawn together the chemical representations, the visualisations, the problems of learning chemistry and the core ideas of General Chemistry to develop the teaching and learning resources (TLRs). The relevant works (three levels of representations, visualisations, and alternative conceptions) reported by other researcher also presented to show the importance of developing the TLRs. The chapter closed with the theoretical frameworks based on constructivist views that is used in the thesis.

Chapter 3
Research Methodology

Chapter Outline

This chapter provides an overview of the research methodology applied in this study. It initially examines all the methodological issues of the study. The first section describes the research context. The second and the third sections provide an overview of research design and research methods. The fourth section is a discussion of the participants involved in the study. The last section provides describes data collection, data analysis, validity and reliability and ethical issues respectively.

3.1 Research context

The area of focus for this study is the development of TLRs for use in general chemistry courses. This research focused on utilising chemical representations developed in the TLRs and to challenge alternative conceptions of some core topics of General Chemistry. The integration of the TLRs and chemical representations aimed to overcome challenges some students may experience when learning these topics as described in the literature. All data collection was completed at the University of Tanjungpura, Pontianak, Indonesia.

3.2 Research design

This study employed a qualitative research design. Denzin and Lincoln (2013) defined qualitative research as "a situated activity that locates the observer in the world. Qualitative research consists of a set of interpretative, material practices that make the world visible". In addition to that, they concluded that in qualitative research, "the researcher study things in their natural settings, attempting to make sense of, or interpret, phenomena in terms of the meanings people brings to them". The natural setting in this study is the General Chemistry course where the implementation of the targeted TLRs took place. The topic presented in the TLRs is implemented concurrently when the concept is taught. Participants involved in this study were the students who studied the General Chemistry 1 course. Thus, the phenomena that happened in the class were real.

Merriam (2016) describes four characteristics to identify the key to understand the nature of qualitative research: the focus is on process, understanding, and meaning; the researcher is the primary of instrument of data collection and analysis; the process is inductive, and the product is richly descriptive. As the overall purposes of qualitative research are to achieve an understanding of how people make sense out of their lives, delineate the process (rather than the outcome of product) of meaning making, and describe how people interpret what they experience. Patton (1990) argues that qualitative research is an effort to understand situations in their uniqueness as part of a particular context and the interaction there. Moreover, Merriam explains that qualitative research emphasised on understanding the phenomenon of interest from participant's perspectives, not the researchers.

Action research can be used in almost any setting where a problem involving people, tasks, and procedures that needs a solution, or where some change of feature results in a more desirable outcome (Cohen, Manion & Morrison, 2018). Action research embraces both posing and problem solving. In addition to that, McNiff (2010) stated that action research not only focus on solely problems, it can also embrace the areas of interest for development. This study aimed to develop the TLRs and investigate their impact on alternative conceptions in general chemistry held by students, thus qualitative research approaches are suited to achieve the aim. Qualitative methods used in this study to describe the process of the development of the TLRs, to understand student's perspective and views of using the TLRs, and also student's understanding after the implementation of the TLRs to challenge student's alternative conceptions on targeted concepts in general chemistry.

3.3 Research methods

This project is based on the principles of action research. Action research is used to facilitate the development of teaching and learning resources. Cohen, Manion & Morrison (2018) defined Action Research as "a small-scale intervention in the functioning of the real-world and a close examination of the effects of such intervention". Meanwhile, Bassey (as reviewed by Costello, 2011) defined action research as "a method to understand, to evaluate and to change the educational practice". The main purpose of this study is to address students' alternative conceptions of the core ideas of chemistry by developing and implementing the targeted TLRs. The development and implementation process would make a change to students' alternative conceptions. Thus, action research is suited to this study.

According to Costello (2011), action research has five characteristics; (1) a change or improvement as an aim, (2) conducted by practitioners or professionals in their own works, (3) an understanding of the process of action implementation at the same time, (4) involving action and reflection in turn, and (5) the research question is actually a problem-solving question. Moreover, as proposed by McTaggart and Kemmis, there are three characteristics of action research; it is carried out by practitioners rather than outside researchers; it is collaborative and it aims to bring about change (McTaggart & Kemmis, 1988). It is also supported by Creswell who stated that action research focus on practical; the educator-researcher's own practices; collaboration; a dynamic process; a plan of action and; and sharing research (Creswell, 2003). Somekh argues that action research is designed to bridge the gap between research and practice (Somekh, 1995). Moreover, McNiff and Elliot stated that action is the combination of diagnosis, action and reflection that focus on practical issues that have been identified by participants and which may somehow be both problematic yet capable of being changed (McNiff, 2010; Elliot, 1978). The collaboration as one of the action research was considered by involving both lecturers who taught General Chemistry module.

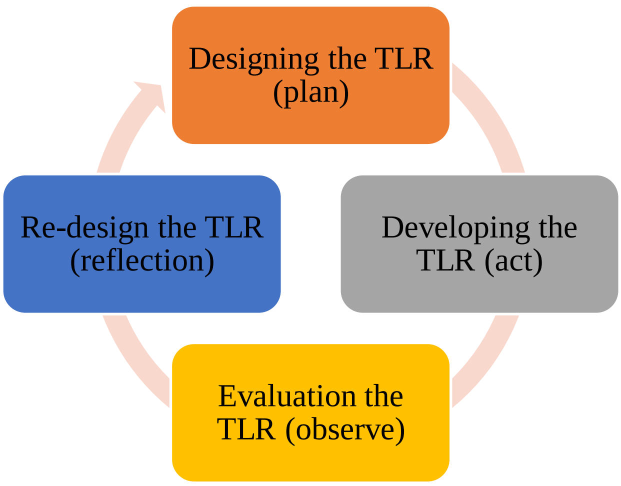


Figure 3. 1 Four steps of action research in one cycle

There are four steps of action research as suggested by Kember (2000): plan, act, observe and reflect as described on the Figure 3.1. These four stages are originally proposed by Kurt Lewin as the founder of AR (Norton *et al*., 2009). The four steps are adapted to the needs of the specific study. In the first step, planning is used to design the TLRs, in the second step, action is used to develop the TLRs, in the next step observation is used to evaluate the TLRs, and in the last step, reflection is used to re-design the TLRs based on the findings on the previous step. The last step also acted as the first step for the second cycle. Details of each step explained in the next section.

Action research in this project adapted qualitative approaches as suggested by a number of authors (Costello, 2011, McNiff, Whitehead, 2011, Patton, 1990, Stringer, 2014). These authors argued that using a positivist stance (quantitative paradigm) may not be well suited, since understanding the "change" would need a deep understanding which would be more contextual or situational. To analyse the "change" that happens during the action research needs qualitative views that focus on *how* it happens. As emphasised by Merriam that data analysis in qualitative action research studies is going to focus not only on what happens but also *how* it happens over the course of ongoing action research cycle of plan, act, observe and reflect. In this study, the "change" is students' understanding of the core ideas presented in the TLRs.

3.4 Pilot Study

Prior to the evaluation stage, a pilot study was conducted for each TLR. A pilot study is a mini-version of a full-scale study or a trial run done in preparation of the complete study. The latter is also called a 'feasibility' study. According to Blaxter, Hughes & Tight (1996), pilot study is a process of trying out all research techniques and methods, that the researcher have in mind to see how well they will work in practice. If necessary, the result of a pilot study can be used as to adapt and modify the methods or techniques accordingly.

3.5 Participants

Participants of this study were divided into two groups for the pilot study and the implementation of the TLR. The number of participants involved are presented in Table 3.1. The study focused on the first-year cohort of Chemistry Education study programme, Department of Mathematics and Science Education of Universitas Tanjungpura, Indonesia. All participants involved in this study volunteered to participate.

Table 3. 1 Summary of participation levels for the different parts of this study

Type of TLR	University		Number of Students involved		
	Pilot	Research	Pilot	Research	
				Cycle 1	Cycle 2
SoMCards & MMB	First-year Natural Sciences students of University of Leicester, UK	First-year students of Department of Chemistry Education, University of Tanjungpura, Indonesia	13	33	82
LoEN	First-year students of Department of Chemistry Education, University of Tanjungpura, Indonesia	First-year students of Department of Chemistry Education, University of Tanjungpura, Indonesia	20	33	82
VoIF	Second-year students of Department of Chemistry, University of Leicester, UK	First-year students of Department of Chemistry Education, University of Tanjungpura. Indonesia	10	82	–

Pilot study for the first TLR (SoMCards and MMB) conducted in the University of Leicester to the group of 13 first-year Natural Sciences students. Meanwhile, the first and second cycle conducted in in Indonesia. 33 students were involved in the first cycle, but only 13 of them were willing to be interviewed after the intervention. 82 students volunteered to participate in the second cycle of the project and 15 of these participated in post-intervention interviews.

The first and second TLR which are SoMCards, MMB and LoEN were evaluated in two cycles, while the last TLR (VoIF) was evaluated in a single cycle only due to research schedule constraints.

3.6 Data collection

Four methods were used to collect data in this project: questionnaires, tests to measure students' understanding before and after using the TLR (pre-test and post-test), interviews and observations.

The first method of data collection involved the use of questionnaires to collect students' feedback, comments and suggestions related to the appearance, content and value of learning experience of each TLR. The questionnaires used in this study consisted of two sections. The first section was based on closed-questions using a five-point Likert scale (strongly agree, agree, neutral, disagree and strongly disagree). The second section of the questionnaire used open-response questions to gather students' views, perceptions, comments and suggestions articulated in their own words. The questionnaires were circulated to participants at the end of each part of the study, after implementation of each TLR. All questionnaires adopted a similar format to allow comparisons to be made between questions on different TLRs.

The second data collection method employed in this study was conceptual testing. This approach makes use of pre-tests before, and post-tests after the intervention. These tests were designed to measure the conceptual understanding of participants before and after the implementation of each TLR. Both tests were aligned to the content areas presented in the relevant TLR. Both tests made use of essay-questions. The essay-type question is an examination question that requires an answer in a sentence, paragraph, or short composition (Merriam-Webster Online Dictionary). Open-questions require the student to recall the relevant factual information, organize the ideas, and write an extensive response. One of the advantages of using the open type questions is students are offer a chance to demonstrate their knowledge, skills, and abilities in a variety of ways. The tests used in this study is aimed for students to show their understanding related to the topics presented in the TLRs. The post-test made use of analogous questions to those asked in the pre-test to ensure that level of difficulty of each test was consistent. Details of each tests used in the evaluation of each TLR will be explained in chapters 4, 5 and 6.

The third method of data collection used in this study was the use of interviews. Interviews were based on a focused conversation between the researcher and the participant based on the participant's experience of the intervention (as well as any relevant background questions) (Roulston, deMarrais & Lewis, 2004). Face-to-face interviews were used in this study as this type of interviews allows the researcher to gather details information for the need of the study (Mathers, Fox & Hunn, 2002). By using this type of interview, the researcher as the interviewer can help the participant to understand the questions as well as clarify the answer of the participants.

As emphasised by Merriam (2016), gaining specific information is the primary goal of interviews. The purpose of these interviews was to gain information related to student's views, perceptions, conceptual understanding and reasoning of their understanding. The interviews focused on how students felt about the TLRs after using them in the learning process, how the TLRs helped them understand the topic, which part of the TLRs or the activity that contributed to students' understanding, and students' reasoning related to their understanding of the topics. A semi-structured interview was used to achieve the purpose. This type allows the researcher to use the questions flexibly as suggested by Merriam (2016). This type of interview also allows the researcher to ask follow-up questions. Furthermore, semi-structured interview involves asking a series of questions and then probing more deeply using open-form questions to obtain additional information (Gall, Gall & Borg, 2003).

The final method of data collection used was observation. Observation was used in order to measure student's engagement and interaction to the TLR during the implementation process. Observations were primarily used to support and/or clarify the findings of the questionnaires and interviews used as the primary means of data collection. Thus, observation was used as a supporting data set.

Developing teaching and learning resources to study the core ideas of chemistry

Qualitative data collection methods in this study involved document analysis, interview, observation, and audio-visual recording. Document analysis, in this study, refers to the module syllabus and module text books, student's answers to the pre-test and post-test as well as the worksheet.

Interviews were conducted before and after the presentation of each TLR. Students who were involved in the interview process were volunteers. All interviewees who were involved in the study excited to share their experiences after learning with the TLRs. The interviews were conducted in students' free time for their convenience.

Table 3. 2 Details of each stage of action research

Stage	Details of each stage
Design (Plan)	All TLRs were design by: 1. Identifying students' common misconceptions about core ideas in general chemistry 2. Determining subjects and format of TLRs 3. Developing plots of TLRs
Developing (Act)	All TLRs were developed by: 4. Designing and producing a prototype 5. Designing and producing the relevant research instruments: questionnaire, interview guide, test, and observation sheet 6. Piloting the prototype and the research instruments 7. Revising the prototype and research instruments following reflection on the pilot
Evaluating (Observe)	All TLRs were evaluated by: 8. Administering a pre-test to students 9. Implementing TLRs to the class and observing students' interactions 10. Administering the research questionnaire to students 11. Administering the post-test to students 12. Interviewing students
Re-designing (Reflection)	All TLRs were re-designed based on the outcomes of the data analysis, by: 13. Analysing data (test, questionnaire and interview) 14. Revising TLRs 15. Re-testing TLRs in the second cycle

Observation was conducted through field notes. This approach requires the researcher to act as the observer throughout the intervention (Gillham, 2005). To understand what really happens during the implementation a video camera was set up to record the activity. The recording was conducted with the permission of all students and lecturers who were involved in this study. The video allowed the researcher to do a thorough analysis of non-verbal expression, such as during the conversation between students while doing the activity, the tone of voice used by participants at different stages of the intervention as well as the facial expressions and body language of participants during their activities. The video recordings were used to complement the analysis of the field-notes and the interviews.

An overview of the individual steps involved in this study is presented in in Table 3.2. A detailed explanation of each step is shown below:

1. *Designing the TLR (Plan; First cycle):*

In the designing phase, a plot for the TLRs were considered first. A plot is a sequence of events for each TLRs. Several factors that must be considered at this stage are:

1) What common misconceptions will be the focus of TLRs?
2) How to present the topic to address students' common misconceptions?
3) What format of TLR will be used to challenge students' common misconceptions?
4) How to use the TLRs?

A literature review of papers related to these issues was conducted to address the questions. Then, the results were used to inform the development of the plot to design the TLRs.

2. *Developing the TLR (Act; First cycle):*

In the second stage, a design of the TLR was developed based on the plot in the first stage. The development stage started by developing the design of the TLRs based on the plot. The process continued by creating the prototypes of the TLRs along with the research instruments to collect the data. During the process of design and making the prototype of the TLRs, the researcher always discusses the progress with both supervisors to get some feedback and comments related to the presentation and the content. After all the prototypes were done, the next step is piloting both TLRs and instruments. Following the pilot study, the TLRs were then revised based on students' feedback. The next step was presented the TLRs to the instructors who taught General Chemistry in the Department of Chemistry Education, Universitas Tanjungpura, Indonesia and asked them to involve in the study. The last step was the implementation of all TLRs to first-year students who studied General Chemistry course.

3. *Evaluating the TLR (Observe; First cycle):*

Students were given a pre-test before the trial of the resources. During implementation, observation and video recording would be conducted. A month after the activities were completed, students took the post-test. Within a week, students were interviewed in a face-to-face interview.

4. *Evaluating the TLR (Reflect; First cycle):*

All data gathered in this step was used as a basis for the reflection on the impact of the TLRs on students' conceptual understanding of the specific chemical concept that was the focus of that part of the study. Based on the reflection in this first cycle of action research, the resource was revised in preparation for the next cycle of research (see stage 5 below).

5. *Redesigning the TLR (Plan; Second cycle):*

Based on the above reflection, an update of the existing plan was developed to revise any imperfections of the TLR found based on students' feedback in the first cycle. The structure this stage took was defined by the findings of the reflection stage of the first cycle (Cohen, Manion & Morrison, 2018; McNiff & Whitehead, 2011; Costello, 2011). McNiff & Whitehead (2011) stated that action research is a flexible research approach which can enable the researcher to adapt and plan the next stage based on the findings of the first cycle. Accordingly, the findings of the first cycle was be the foundation of the next cycle of research. The stages of research in the next cycle also followed the steps of the action research model as in the first stage, i.e. planning, action, observation, and reflection.

6. *Redeveloping the TLR (Act; Second cycle):*

It may not be possible for this stage of the research to involve the same student population as it may be necessary to conduct this in a different academic year. In spite of this, all other factors will, if possible, be kept constant between the first and second cycle (e.g. the same instructor will be involved in both cycles). The first (The Shape of Molecules Cards (SoMCards) and Molecular Model Building (MMB)) and the second (the Leaflet of Electronegativity (LoEN)) TLRs were evaluated in two cycles. Meanwhile, for the last TLR developed in this study which is the Video of Intermolecular Forces (VoIF) evaluated only in one cycle due to the time constraint.

7. *Evaluating revised TLR (Observe; Second cycle):*

The identical research instruments (questionnaire, tests and interview guide) as in the first cycle were used in this stage as the aims of second cycle were the same which is evaluate the TLRs

8. *Evaluating revised TLR (Reflect; Second cycle):*

In this stage, all data gathered in the second cycle is used to reflect on the impact of the TLR on students' conceptual understanding of the focus areas of content.

3.7 Data analysis

A variety of data analysis approaches were used in this study depending on the nature of the data collected. Qualitative data was analysed according to established principles of good practice. Lacey and Luff (2009) defined six stages of qualitative data analysis: familiarisation, transcription, organisation, coding, analysis and writing the report.

As a project of this nature generates a significant volume of data, the researcher regularly read through collected data, listened to (or watched) recordings and summarised data in written statements. This allowed the researcher to become very familiar with all of the data collected and helped establish connections between different forms of data. This also acted as a quality assurance process in order to ensure that all data had been successfully collected and was stored in a usable format. Therefore, transcripts were read several times, looking for the similarities, anomalies, and trends in students' response to ensure the researcher familiar with the data.

Transcription is the process of converting audio recorded data or handwritten field-notes obtained from interviews and observation into paper form to allow it to be read and further analysed. A close observation of data through repeated careful listening or watching is necessary in the process of transcriptions (Bailey, 2008). The transcripts allow researchers to develop a holistic view of the study before organisation step.

During the organisation stage, the researcher organised collected data into a logical structure, so it was easier to retrieve at a later date. At this stage the real names of participants were substituted with codes to preserve participant anonymity and facilitate data analysis.

The next step of data analysis was coding. According to Gibbs (2007) coding is a process that involves attaching one or more keywords to a text segment in order to permit later identification of a statement (Gibbs, 2007). Categorisation is a major component of qualitative data analysis by which investigators attempt to group patterns observed in the data into meaningful units or categories. Through this process, categories are often created by chunking together groups of previously coded data.

In this research open coding and axial coding were used to analyse the data. As explained by Strauss and Corbyn (1998), open coding is the process of 'sweeping' through the data and marking the text. This approach allows the researcher to make codes or label words and phrases found in the transcript or text. Open coding refers to the initial interpretive process by which raw research data are first systematically analysed and categorised. Axial coding involves creating themes or categories by grouping codes or labels given to words and phrases that emerge from the transcript (Strauss & Corbin, 1998). Saldana (2009) defines that "a code in qualitative inquiry is most often a word or short phrase that symbolically assign a summative, salient, essence-capturing, and/or evocative attribute for a portion of a language-based or visual data". The process of coding of transcripts start by tagging the text with open codes to detect reoccurring patterns. Patterns that arise from the open coding then clustered in order to generate a smaller number of categories or pattern codes (Miles, Huberman & Saldana, 2014).

Data collected through observation, video recording and interviews was analysed using the NVivo 11 software package. NVivo is a qualitative data analysis software produced by QSR International for qualitative (Hilal & Alabri, 2013). The NVivo software package was also used in the coding process. NVivo also ensures easy, effective and efficient coding which makes retrieval easier (Bazeley & Jackson, 2013). For instance, NVivo can open link a paragraph from one source to another paragraph in either the same or another source and retrieve it with less effort. This task could have been very time consuming if using manual coding.

The analysis process was categorised into two groups: quantitative and qualitative analysis. The two types of data collection used throughout this study are presented in Table 3.3. Data which is collected through tests (pre-and post-test) and questionnaires was analysed quantitatively. The score of both tests were analysed using IBM SPSS Statistics 24. *Paired sample t-test* is used to compare the pre-test and post-test score. *Paired sample t-test* was used as data of students' pre-test and post-test score in one cycle were related since the students involved are the same. According to Bryman and Cramer (2009) related or *paired sample t-test* can be used to compare the means of the same participants in two conditions or at two points. Questionnaire data was tabulated and analysed using Microsoft Excel. Microsoft Excel was chosen based on two reasons, the first Microsoft Excel offers complete features to analyse the questionnaire data, such as the mathematical formula, graph, chart, etc. Secondly, it easy to use as Microsoft Excel has been familiar to the researcher. Microsoft Excel was used to show the percentage of students' perceptions and views based on the questionnaire data. It also used to tabulate the pre-test and post-test data prior to the SPSS analysis.

The second group was data that analysed qualitatively. Students' individual answer of pre and post-test as well as interviews were grouped in this part. Both tests were analysed based on student's answer to reveal their understanding before and after they studied with each of the TLRs. Data collected through interviews were transcribed before analysed using NVivo 11.

Table 3. 3 Types of data collection

Quantitative data	Qualitative data
Score of pre-test and post-test	Student's individual answer of pre-test and post-test
Percentage of questionnaire	Student's answer on the second section of the questionnaire
Paired sample t-test	Student's interviews

3.8 Validity and Reliability

In order to improve the validity and quality of data (Anderson & Anderson, 1998, Burns, 1997, Mathison, 1988), both quantitative and qualitative data collected in the studies served as a form of methodological triangulation (Cohen, Manion & Morrison, 2018). Lewis-Beck, Bryman & Liao (2004) explained that triangulation refers to the use of more than one approach to the investigation of a research in order to enhance confidence in the ensuing findings. Triangulation is the process of strengthening the findings obtained from a qualitative inquiry by cross-checking information (Potter, 1996). The type of triangulation used in this research is methodological triangulation. Methodological triangulation refers to the use of more than one method for gathering data (Patton, 2002; Denzin, 1978). In this study, the multi methods of data collection used in this research are questionnaire, tests, interviews and observation. The quantitative and qualitative data analysis also acts as the triangulation process. By using these approaches, the validity and reliability of this research will be maximised.

3.9 Ethical Issues

As the researcher, I have given full consideration to the participants and their learning environments. The methodology adopted has been designed to effectively integrate into the natural learning environment of the participants. The project has been carefully designed to avoid interfering with or intruding on students' learning in any of the two cycles for each TLRs included in this research. While endeavouring to achieve the objectives of this study, I attempted to do so in a manner that did not interfere or conflict with any individual who involved in this study. Also, I will refer back to the ethical approval before doing the work. The students were mostly positive and interested in the research, keen to see improvements to their learning situation.

Consent

All students who participate in this research are volunteer. Before the start of each study, the researcher explained the nature of the work to students who may then choose volunteer to participate. When students volunteer to participate in the study, they are asked to give permission to be video recorded during the learning process. This work received ethical approval from University Ethics Sub-Committee for Science and Engineering and Arts Humanities.

The identity of the participants involved in this research will kept confidential throughout the study.

3.10 Summary

This chapter has examined the research methodology taken in this research to address the research questions. The research methodology has discussed the collection of quantitative and qualitative data sources and the interpretative analysis of data. The validity and reliability of data has been demonstrated by triangulation of quantitative and qualitative data analysis. The ethical aspects of the research have given full consideration to the participants and their learning environments.

Chapter 4

Understanding the Shape of Molecule Based on VSEPR Theory by Using Cards (SoMCards) and Molecular Model Building (MMB)

Chapter outline

The fourth chapter presents results of research into the use of Shape of Molecule Cards (SoMCards) and simple Molecular Model Building (MMB) activity. This chapter addresses three research questions, which are: (1) How should educators develop SoMCards and MMB in order to challenge students' alternative conceptions of shape of molecules based on VSEPR Theory?; (2) What is the impact of the SoMCards and MMB on student learning?; (3) How effective are the SoMCards and MMB at providing engaging learning experience?. The chapter also includes a discussion of their significance in teaching General Chemistry courses. This TLR focuses on helping students understand how to determine the shape of simple molecules based on Valence Shell Electron Pair Repulsion (VSEPR) theory. In VSEPR theory, the pairs of electrons that surround the central atom of a molecule or ion are arranged as far apart as possible to minimise the electron repulsion. The difference of magnitude of the repulsion depending on type of electron pair: lone pair electron/s has a stronger repulsion compared to the bond pair/s electron/s. This repulsion affects the shapes of molecules as well as bond angles. The development of these TLRs were based on action research cycles, each of which consists of four phases. Action research were done in two cycles in order to improve the reliability of the research as well as the TLRs developed. The four phases used in each cycle are: planning, action, observation, and reflection. This chapter explores the rationale for developing these TLRs and then provides a description of the development process. Both of the developed resources were piloted with first-year undergraduate Natural Sciences students at the University of Leicester in the 2015/2016 academic year prior to the first and second cycle research. The research methods employed in this part of the study and the data collected processes are presented in this chapter. The chapter concludes with a discussion of students' perceptions of the SoMCards and MMB and the impact the TLRs have had on student understanding of VSEPR theory in order to answer the three specific research questions.

4.1 Rationale of developing cards and molecular model building of Shape of Molecule based on VSEPR theory

Molecular geometry is a key topic studied in General Chemistry courses due to its important role in determination of the physical and chemical properties of compounds (Nicoll, 2001; Dale, 2006; Meyer, 2005). Hence, Gillespie (1997) suggested that this concept must be incorporated into general chemistry courses. Valence Shell Electron

Pair Repulsion (VSEPR) theory is used to predict the shapes of simple molecules based on minimising the electrostatic repulsion of electron pairs surrounding a molecule's central atom.

Previous research has shown that some students find the determination of molecular geometry to be challenging (Furio & Calatayud, 1996; Birk & Kurtz, 1999; Coll & Treagust, 2003, Gabel, 1998; Nicoll, 2001; Özmen, 2004; Pabuccu & Geban, 2006), Taber, 2003; Yilmaz & Özgür, 2012). A number of researchers have reported misconceptions related to this concept (Nicoll, 2001; Peterson & Treagust, 1989). Nicoll (2001) reported that some first-year chemistry undergraduate students cannot explain the reason why the molecules adopt a certain geometry, such as bent for water molecules. Harrison and Treagust (1989) reported that grade 12 students (age 16 or 17) experienced the misconceptions related to the shape of molecules, whereas 25% of students (N=84) thought that the shape of molecules is due to only to the repulsion between the bonding electron pairs. Meanwhile, the other 22% of students stated that the shape of molecules is due only to the repulsion between the nonbonding electron pairs. This problem was also identified in Indonesia, as reported by Sumarni (2010) who stated that 74.2% of first-year students of Chemistry Education at the University of Semarang State (UNNES), Indonesia in the 2009/10 experienced misconceptions when drawing the shape of molecule. Students tend to ignore the effect of lone pair electrons around the central atom to the shape of the molecules. Reflecting on my own three years' experience as a General Chemistry course pre-service chemistry instructor, I have found that many students struggle to predict the shapes of molecules correctly. Many students try to memorise the shape of common examples used in teaching which may mean they don't understand the factors that influence molecular geometry and are unable to derive the shapes of 'unseen' examples (Harrison & Treagust, 1996). An example of a determining factor that students often overlook is the presence of lone pairs of electrons, for example students predicting that ammonia will be trigonal planar because they ignored the lone pair electrons (Furio & Calatayud, 1996). Another common mistake made by students who don't learn the process is to ignore number of substituents around the central atom. Some students assume that molecules with similar formulae will adopt the same shapes. For example, when they asked to predict the shapes of the commonly seen example ammonia (NH_3) and the less commonly see boron trifluoride (BF_3) and some students assume they are both trigonal planar. This answer is incorrect, as ammonia has a central atom in group 15 of the periodic table (whereas boron trifluoride has a central atom in group 13 of the periodic table) so there is one lone (non-bonding) pair of electrons surrounding the central atom. This means the molecule adopts a trigonal pyramidal shape and the H-N-H bond angles are smaller than would be predicted for a shape with four bonding pairs of electrons around the central atom.

In order to be able to determine molecular geometries, students need to develop the ability to visualise molecules (including the central atom' substituents) as bonding and lone pairs of electrons. As suggested by Jones and Kelly (2015), visualisation is a way of improving students' understanding of abstract concepts in chemistry. Visualisation is known to play an important role in understanding chemistry concepts, such as chemical bonding, determination of the shapes of molecules, intermolecular forces, etc. Visualisation and modelling tools offering more accurate and informative images of the molecular (or particulate) level to be used to describe how atoms and molecules might interact and move (Jones & Kelly, 2015). Based on the work of Jones and Kelly, this study incorporated a simple molecular model building (MMB) activity that made a clear distinction between bonding pairs and lone pairs of electrons. The impact of this activity on overcoming students' common misconceptions was investigated.

The use of a card game to support of the teaching of molecular geometry was inspired by the Simulation Cards activity developed by Professor Annette Cashmore in GENIE-CETL University of Leicester for teaching (Cashmore, Hawkridge, Cramer & Suter-Giorgini, 2009). The simulation cards were used in the tutorial molecular biology undergraduate class to study how to produce a medically important protein. The cards presented the problem which students have to work on by deciding which option they chose to solve the problem. The option will lead to another problem with some options. If they chose the incorrect option, they have to go back and start again. The cards also provided the hint to help students understand the reason why the option that they chose was incorrect. The Shape of Molecule Cards (SoMCards) game-based approach was structured in such a way to guide students through the process of predicting the shapes of molecules through the use of a structured approach based on the different steps. Participants must choose the correct answers to 11 multiple choices questions based on the individual steps used to determine molecular geometry as defined by on Valence Shell Electron Pair Repulsion (VSEPR) theory. If participants make a mistake, the game is structured to give them a hint and then allow them another chance to answer the question. By structuring the game in this way, misconceptions are challenged through discussion between players. To emphasise the sequence of steps used in the VSEPR theory approach to predicting molecular geometry, students had to keep a written record of each of these steps by using their own words at the end of the game. In order to facilitate visualisation of the 3D structures of the molecule in the game, students had to build simple three-dimensional models of the molecules, clearly indicating the locations of bonding and lone pairs of electrons.

4.2 The development of the SoMCards and MMB activity

The development process of the SoMCards and MMB consisted of two stages: design and development (see Figure 4.1). The design stage started with a literature review that informed the eventual structure of the SoMCards/MMB game. The review starting by identifying the relevant studies reported in the published papers to find students' common misconceptions in core chemical concepts. The review process was conducted by considering multiple sources (online and printed papers). Finding the relevant papers through online sources (search engine and database) were done by inserting the relevant keywords such as misconceptions or alternative conceptions in chemistry, how to overcome the misconceptions, the role of representations, *etc*. Meanwhile, the sources for printed papers were found in the library of University of Leicester. Then, summarising the evidences found from those reported papers and selecting the topic and the format of the TLRs.

Findings from the review unfolded that determination of molecular geometry or shape of molecule is challenging for some students, hence they held misconceptions (Furio & Calatayud, 1996; Birk & Kurtz, 1999; Coll & Treagust, 2003, Gabel, 1998; Nicoll, 2001; Özmen, 2004; Pabuccu & Geban, 2006), Taber, 2003; Yilmaz & Özgűr, 2012). A range of teaching and learning resources reported to help students learning this topic is limited. So far, the researcher only found two resources that have been reported: the molecular game developed by Myers (2003) and modelling a TLC (Thin

Layer Chromatography) exercise for teaching Molecular Structure and Intermolecular Forces. Considering the findings of the review and the limited number of learning resources, it was decided that the topic presented in the TLRs is how to predict the shape of molecule based VSEPR theory and the format is card game supported with molecular model building activity.

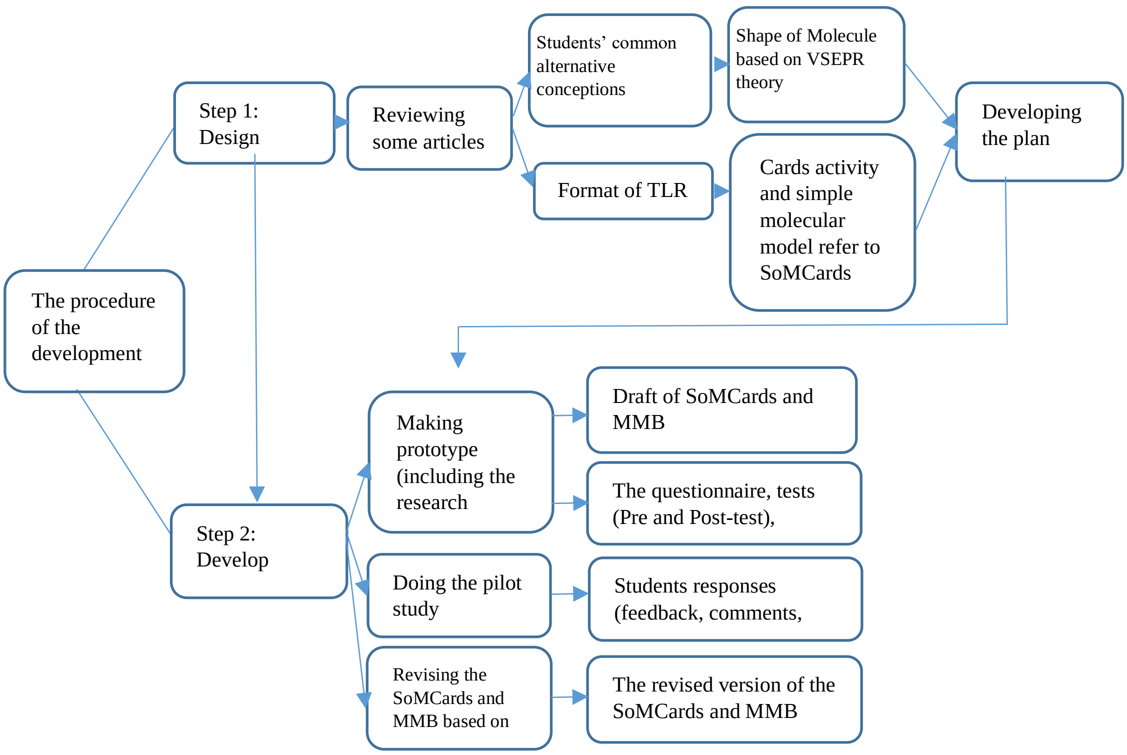


Figure 4. 1 The procedures of the development process of the SoMCards and MMB that consist of two steps; design and develop.

After the topic and the format of the TLRs were selected, the next step was to develop a plan of the resource. Developing a plan allows the researcher to audit all relevant aspects of the topic and to arrange all of them in a way that creates a meaningful student experience. The plan directly informed the structure of the card game and the model building activity. When developing the plan, the first step was designing the cards in term of the presentation, the structure of the cards, the content of the cards (what and how the questions will be presented), also combining the MMB activity, and the procedures of the activity. After the plan had been defined, the process of drafting a prototype of the SoMCards and MMB begins. The game structure must reflect the structure defined in the plan. The procedure of the implementation process shown in the Figure 4.1.

Table 4. 1 Contents of the Activity Cards for the Example of NF_3

Type of the Card	Content of the Cards	Number of the Card(s)
Introductory cards	Cover, Rules, learning objectives, a brief explanation of VSEPR theory, important terms, sample molecules	1-6
Questions cards	What is the central atom in this example?	7
	What is the total number of electrons that N has?	8
	How many valence electrons does N have?	11
	What is the total number of electrons that F has?	14
	How many valence electrons does F have?	18
	How many electrons are used by each F atom to make bonds with the central atom?	20
	What is the total number of valence electron pairs?	22
	How many bond pairs (BP) and lone pairs (LP) are there around the central atom?	26
	What is the Lewis structure of NF_3?	28
	Based on your Lewis structure, what is the shape of the molecule?	31, 33
Correct answer cards	Questions	Answer given at the start of the next question and card 35
Wrong answer cards	Feedback and Hints	9, 10, 12, 13, 15, 16, 17, 19, 21, 23, 24, 25, 27, 29, 30, 32, 34, 36

The table were adapted from the published paper on Journal of Chemical Education (Erlina, Cane & Williams, 2018).

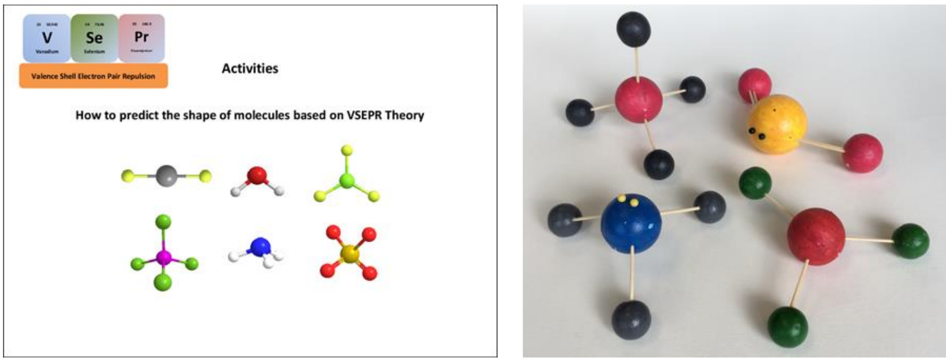
The SoMCards game resources were collected together into a game pack (see Figure 4.2). All of the necessary game cards (as well as a set of rules) and the modelling pieces necessary for the complementary MMB activity shown in Table 4.1. The wrong answer cards provide participants with hints to help them have another attempt at the questions.

As explained above, the SoMCards are accompanied by a worksheet which participants use to record the steps used to predict the shape of the molecule based on their experiences of playing the game. This step is included to give participants the opportunity to reflect on the geometry determination they have worked through in the game. This step was also used as a means of evaluating the impact of the game on the students' understanding of the topic.

(a) (b)

Figure 4. 2 (a) A set of the SoMCards consist of the cards, periodic table, and worksheet; (b) example sets of the MMB kit with the coloured polystyrene balls, map pins, and cocktail sticks.

The SoMCards game was supported by the complementary Molecular Model Building (MMB) activity. The MMB activity asked students to build models of the molecules they had just determined the shape of (in the SoMCards game) using different size polystyrene balls (to represent atoms), cocktail sticks (to represent bonds) and map pins (to represent lone pair electrons) as shown in Figure 4.3. To allow the players to differentiate between the central atom and its substituents, the polystyrene balls were painted in different colours.



(a) (b)

Figure 4. 3 (a) Cover of SoMCards; (b) The assembled MMB.

An additional requirement for this project was to keep costs to a minimum for the user (so schools without access to significant amounts of funding can still use the game). In order to achieve this, a simple modelling kit was created using cheap materials. The kit developed for this game is cheap and allows lone pairs of electrons to be represented by placing the map-pins in the regions of space they occupy. Students can therefore visualise how lone pairs of electrons around the central atom influence the shapes of molecules as well as the magnitude of the bond angles. Participants are asked to assemble the MMB at the end of each round of the game in order to reinforce the key learning points from the activity and to help them visualise the three-dimensional structure of the molecule they have been working on.

4.3 Pilot study of the SoMCards and MMB

The development of this resource integrated a pilot study. This pilot was conducted to gain an initial insight into the effectiveness of the TLRs and to identify any issues that would need to be addressed ahead of the full research phase. The pilot study was conducted at the University of Leicester. The participants in this study were 13 students from the first-year cohort of the Natural Sciences undergraduate degree programme. The Natural Sciences programme is designed around a core set of interdisciplinary modules that is delivered using a Problem Based Learning (PBL). The participants all voluntarily agreed to take part in the study. The study took place at the end of a general chemistry PBL session. At the time of the pilot, students had just been introduced to the topics of chemical bonding, shapes of molecules and the principles of reactivity. The pilot phase participants were asked to organise themselves into small groups (two groups of four students and one group of five students) in order to do the activity. This pilot of the activity lasted approximately 30 minutes in which included completion of the evaluation questionnaire.

Evaluation of the pilot was conducted through a two-section questionnaire. Section one of the questionnaire consisted of eight statements about the presentations and contents of the SoMCards and MMB Participants were asked to state their level of agreement with these statements on a Likert scale with five options (strongly disagree, disagree, neutral, agree and strongly agree). Section two consisted of open-ended questions which asked participants to suggest improvements that could be made to the activity and to state which part of the SoMCards game they found most least useful. Details of the Likert statements used in section one and the open-ended questions used in section two are shown in Table 4.2. During the pilot, the students' activities and interactions during the activity were observed and recorded by taking notes.

Table 4. 2 Statements and questions presented in the questionnaire

No	Statements and Questions	
	Section 1 (Likert scale)	**Section 2 (Open-ended questions)**
1	The card-game instructions are clear and understandable	Which parts of the card game were most useful?
2	Answering the questions in the card-game helped me understand the topic	Which parts of the card game were less useful?
3	I understand how to predict the shape of molecule after playing the game	What changes would you like us to make to the card game?
4	The questions in the card-game are challenging	
5	I enjoyed playing the card-game	
6	The presentation of the card-game is interesting	
7	Making the molecular model using polystyrene balls and cocktail sticks was useful	
8	Making the molecular models helped me understand the influence of lone pairs of electrons on the shapes of molecules	

The table shows the 8 statements on the first section of the questionnaire and the 3 questions in the second section.

4.3.1 Pilot Methodology

Each group was given a set of the SoMCards and MMB kit (see figure 4.2). The first step was to read the instructions then for players to briefly discuss their approach to the game (so each player knew what their role was). Participants stared the game by answering the questions presented on the cards. The questions adopted a multiple-choice format and the chosen answer option directed the participants to the next card. Students were told to discuss the question in their teams and work together to determine the correct answer. In order to successfully be directed to the next question card, students had to correctly answer the preceding question. If students answered the question incorrectly, they were directed to a wrong answer card that provided them with a hint and then redirected them back to the same question for another attempt. Once all questions have been correctly answered, the final card instructed students to assemble a molecular model of the correct structure using the MMB kit. The final step is for students to record the steps they used to predict the shape of the molecule in their own words on the worksheet provided.

The game-playing process used in the pilot study is summarised as follows:

1. Students were assembled into groups of four or five.
2. Students were instructed to start playing by following the instructions from the first card.
3. Students' activities and interactions during the activity were observed and documented.
4. The evaluation questionnaire was distributed to all students.
5. All evaluation data were analysed.
6. Revisions were made to the SoMCards and MMB activities based on reflection on the game-playing process and analysis of the evaluation responses.

The researcher observed students' interactions with other members of the team while playing the game. Evaluation questionnaires were given to all students in the end of the activity and collected in for analysis. All data collected from the questionnaires and observations were analysed by quantifying and classifying participant attitudes towards the activity. The findings from the pilot study were used to revise the activity (see discussion in section 4.3.3).

4.3.2 Results of the pilot study

The data presented in Figure 4.4 is an overview of student responses to the Likert statements in section one of the evaluation questionnaire. The text-based feedback collected in section two of the questionnaire is summarised in Table 4.3.

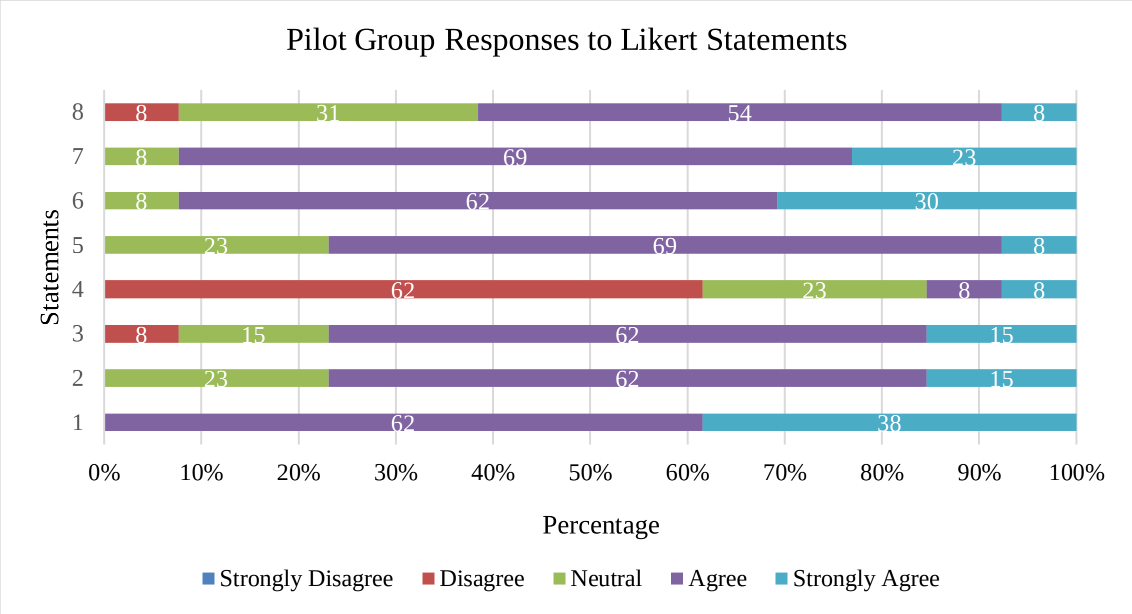


Figure 4. 4 The proportion of students' responses to the SoMCards and MMB (N=13). Detail of all statements refer to Table 4.2.

The figure describes the proportion of students' responses of the SoMCards and MMB on the first section of the feedback questionnaire given in the pilot study that consist of 8 statements with 5 options of agreement based on Likert scale. The 8 statements presented in the questionnaire are: 1= The card-game instructions are clear and understandable; 2= Answering the questions in the card-game helped me understand the topic; 3= I understand how to predict the shape of molecule after playing the game; 4= The questions in the card-game are challenging; 5= I enjoyed playing the card-game; 6= The presentation of the card-game is interesting; 7=Making the molecular model using polystyrene balls and cocktail sticks was useful; 8= Making the molecular models helped me understand the influence of lone pairs of electrons on the shapes of molecules.

Figure 4.4 shows that majority of students either agreed or strongly agreed with all the items except for statement four. Statement four ("*The questions in the card-game are challenging*"). 62% of respondents (N=13) disagreed with this statement. This outcome was in line with expectations as the questions presented in the cards covered basic chemistry concepts that students in the pilot group would have previously encountered. Students who were involved in the pilot study had already studied the topic at university (and possibly earlier) meaning they all had at least some experience of how to predict the shapes of simple molecules. Meanwhile, students who were involved in the evaluation stage (the first and second cycle) have not learned the topic yet. Due to this prior exposure to the topic, the pilot group were able to provide feedback on the quality of the learning experiences provided by the SoMCards and MMB activities.

Table 4. 3 Students' responses to the Likert statements in section one of the questionnaire (N=13).

No	Statements on the first section of the questionnaire	Percentage (%)				
		SD	D	N	A	SA
1	The card-game instructions are clear and understandable	-	-	-	62	38
2	Answering the questions in the card-game helped me understand the topic	-	-	23	62	15
3	I understand how to predict the shapes of molecules after playing the game	-	8	15	62	15
4	The questions in the card-game are challenging	-	61	23	8	8
5	I enjoyed playing the card-game	-	-	23	69	8
6	The presentation of the card-game is interesting	-	-	8	62	30
7	Making the molecular model using polystyrene balls and cocktail sticks was useful	-	-	8	69	23
8	Making the molecular models helped me understand the influence of lone pairs of electrons on the shapes of molecules	-	8	30	54	8

The table describes the percentage of students' responses to 8 statements in the first section of the questionnaire. SD=Strongly Disagree; D=Disagree; N=Neutral; A=Agree; SA=Strongly Agree.

100% of respondents to the questionnaire agreed that the instructions for the activity were easy to understand. 93% of respondents agreed that the SoMCards game makes the topic interesting to participants. 77% of respondents agreed to statements 2, 3 and 5. 92% of respondents agreed that the molecular model building activity was a useful learning experience. Detail of each percentage can be seen on Table 4.3.

The average level of agreement for the Likert statements was 74%, it can be concluded that student attitudes towards the activity were generally very positive. The next stage of the evaluation was to analyse the student comments provided in response to the section two questions (see Table 4.4. for summary).

The first question of section two asked participants which part of the game they found most useful and 5 respondents responded stated that the process of answering the step-by-step questions was the most useful part of the game. 4 respondents stated that the entire process of playing the game the most useful aspect of the experience. This suggests that the design process was successful in developing a multi-component learning experience Most respondents (11) failed to respond to the question asking for the least useful part of the game, because they loved it and thought it was useful. Eleven students' respond by answering "no changes" for the last question asked about "What changes would you like us to make to the card game?". However, 1 respondent suggested changing the colours and size of the cards to improve the clarity and the readability of the cards. This probably because the colour of the cards was in contrast with the text and images presented in the cards. Also, the size of the cards was too big, while the text and images presented did not required those size. Further discussion of these changes is presented in the reflection section.

Table 4. 4 Summary of students' comments and suggestions on the second section of the questionnaire (N=13).

Comments or suggestions		Number of students
Part of the games that most useful	The cards/questions	5
	Writing the steps used to predict the shape of molecules on the worksheet	2
	Making Molecular models of the structures	2
	The whole experience of playing the SoMCards including assembling the molecular model	4
Less useful	The cards/questions	1
	The brief explanation of VSEPR theory	1
	Making Molecular models by assembling polystyrene balls, map pins and cocktail sticks	0
	None	11
Changes	The colours and the size of the cards	1
	Incorporate more molecules	1
	No suggested changes	11

One student suggested expanding the scope of molecules included in the game. Further, S/he explained that one example molecule for one group was not enough to be played. Thus, having a complete set of molecular geometry would help them comprehend the whole concepts. Comments and suggestions related to the size and colour of the cards as well as adding more sample of molecules were considered when revising the resource for use in the main research phase of the project. The outcomes of this evaluation showed, that with some minor modifications, the SoMCards and MMB activities were ready to move on to the research phase.

4.3.3 Reflection of the pilot study

Some minor changes were made to the activities based on student feedback from the pilot evaluation. The size and the colour of the cards was changed to make them easier to read. The prototype version of the resource (used in the pilot) had cards printed on paper of dimensions 21 cm x 10.8 cm. Student feedback indicated that this was too big, so it was hard to hold. So, aesthetically, the appearance of the cards will be more interesting. The size of the cards was reduced to 14.8 cm x 10.4 cm for the research phase of the project. Reducing the size of the cards made them easier for players to hold. More molecules were added to the SoMCards game in order to give students more unseen examples which allowed them to determine the shapes of different examples with lone pairs and double bonds surrounding the central atoms. Also, each molecule added to represent different shapes. Seven new example molecules were included in the activity following this initial feedback giving a total of eleven molecules.

The last change that has been made was the number of students per group. Small group of 4-5 students was not effective as only 2-3 of students were fully participated in the game. Thus, to make sure every student had a role in the game, the number of students in each group was limited to two or three students. Detail of all changes is shown in Table 4.5.

Table 4. 5 Details of the changes made based on findings of the pilot study

Findings	Changes	Rationale
The size of the cards: initially 21 cm x 10.8 cm	Change into 14.8 cm x 10.4 cm	To make it easier to hold the SoMCards
The colour of the cards: initially only 2 colours used (yellow and blue) and the yellow colour were quite dark	Change into 7 bright colours: yellow, blue, green, pink, orange, purple and pink	To make the cards easier to read and to reinforce a key learning point
Incorporate more molecules: initially only four set of the SoMCards and MMB were developed	Adding another 7 sets of the SoMCards and MMB to represent each shapes of the molecules	To give the students more experience of determining the shapes of a range of structure types.
Number of students PER group: initially 4-5 students	Change to 2-3 students per group	To help ensure that everybody had a role to play in the game.

Based on the observation of student interactions in the pilot implementation, it was decided that using groups of four of five was an ineffective way of running the activity as only two or three students per group tended to be actively involved in the activity (with other group members acting as ‘passengers’). A summary of the observation can be seen on Table 4.6.

Table 4. 6 A summary of observation during the activity of the pilot study

<table>
<tr><td colspan="2">Researcher's Note during students' activity</td></tr>
<tr><td colspan="2">Before doing the activity:</td></tr>
<tr><td>- A brief descriptionof the study was given to all students.
- Students were asked to arrange themselves into groups of 4-5.
- The researcher explained the rules of the activity (how to play the SoMCards and MMB).
- Sets of the SoMCards and MMB activities were distributed to each group.</td><td>- Students listened to the description of the study.
- Students self-organised into to a small group.
- Students listened to the explanation of the rules.</td></tr>
<tr><td colspan="2">During the activity:</td></tr>
<tr><td>- Only 2 or 3 of students actively discussed how to answer the questions while the other 2 or 3 students did not participate in the game
- The researcher noted that no one were asked about the clarity of the questions presented in the SoMCards.</td><td>- Students started to play the activity by opening-up the bag of the SoMCards. Students read the introduction cards (the rules, the objectives of the activity, important terms used, a brief explanation of VSEPR theory).
- Then, students began to answer the first question. The questions were effective at triggering group discussion
- All groups had to have a second attempt at the first question as they initially chose the wrong answer. Students seemed surprised to find out they chose the wrong answer, but then realised they made a mistake after reading the hints given on the wrong answer card.
- Students seemed to enjoy answering the questions (and playing the game).
- The students enjoyed the process of assembling the simple molecular models.</td></tr>
</table>

	- Students used the periodic table provided when answering the questions. - Students followed the game procedures given. - The game was completed quicker than the researcher expected (15 minutes). Each group played the game for one round.
After doing the activity:	
A feedback questionnaire was distributed to all students	Students provided feedback related to the SoMCards and MMB by answering all of the questions.
Conclusion: Overall, the students enjoyed the process of playing game especially assembling the simple molecular models (MMB part of game). One student said that the SoMCards and MMB game was an interesting approach to learning this topic. The student really enjoyed doing the activity as they were enthusiastic. In addition, during the activity some of them said that "I loved or liked this game", "We did it, we have chosen the correct answer", "I really like assembling the molecular model, as I can see the 'actual' shape of the molecule", "I wish this game can be played for another concept/topic". Even though, students enjoyed the activity, the researcher realised that the activity is ineffective for groups of 4 or 5 students, as only 2 or 3 of them were actively involved in the process of answering the questions. Thus, the rules were changed so students work in groups of 2 or 3.	

The Table describes the researcher's notes of observation during the implementation process of the SoMCards and MMB in the pilot study.

Even though only 1 student suggested to incorporating more molecules into the game, the researcher decided to make this change by adding seven more sets of the SoMCards. Therefore, 11 sets of SoMCards in total to allow a range of different types of molecules to be included in the game. The pilot version of the SoMCards game was emphasised the effect of lone pairs of electrons on the shape and bond angles of molecules. The four molecules included in the original version of the game included two molecules with lone pair electron/s around the central atom (NF_3 and ClF_3) and two molecules with no lone pair electron/s around the central atom (BF_3 and CCl_4). This allowed students to compare the shapes of molecules with lone pair electron/s with analogous structures without lone pair electron/s. These additional SoMCards sets (PCl_5, SF_4, SF_6, BrF_5, XeF_4, $SnCl_2$, and NO_3^+) enhanced the learning experience by giving students more opportunities to practice determining the shape of a wider range of molecules. This revised version of the SoMCards game was then used in the first cycle of the evaluation stage.

4.4 Evaluating the SoMCards and MMB: first cycle of research

The evaluation of the SoMCards and MMB activities took place in the Department of Chemistry Education, Faculty of Teacher Training and Education of Tanjungpura University, Pontianak Indonesia. The SoMCards and MMB were implemented as part of the General Chemistry 1 course.

4.4.1 The context of the first cycle of research

The University of Tanjungpura is a publicly funded university in Pontianak, the capital city of West Kalimantan, Indonesia. The university has nine faculties including the faculty of teacher training and education. The faculty has 5 departments including the Department of Mathematics and Science Education, where Chemistry Education Study Programme was held. The Chemistry Education study programme was established in 2003 to produce chemistry teachers to teach junior (age 13-15) and high school (age 15-18) students.

The first cycle of research was conducted between May and June 2016. The students involved in this study were year one students from Chemistry Education study programme during the 2015/2016 academic year. At this point in their education, students were studying General Chemistry 1 module, but had not studied the topic (i.e. molecular geometry) covered in this activity. The SoMCards and MMB activities were implemented in the classroom at the same time that the topic was taught in the course. Thus, the activities were implemented as integral parts of teaching in the module as suggested in qualitative research for keeping the natural setting of the research (Denzin and Lincoln (2013). The way the lecturer taught the topic was changed to make it similar to the way of the activity works.

4.4.2 Procedures of the implementation of SoMCards and MMB in the first cycle

A demonstration of how to play the SoMCards and complete the simple MMB activity took place two days prior to implementation in the class. This was done by a live demonstration of the activity being acted out. The aim of this demonstration was to train the lecturer who taught this topic. In the simulation, both lecturers played together as a pair. The simulation designed to familiarise staff with the activity and to give them the opportunity to anticipate the types of questions that students were likely to ask when doing the activity themselves. This demonstration also allowed any potential technical issues to be identified before the activities were used in the class, such as the procedure or the rule of the game. Both the lecturers followed the procedure as defined by the author. The demonstration run well. The outcome of demonstration was no technical issues were found during the simulation process. The only issue raised was what if student cheated during the game by looking the correct shape of the molecule in the end of the card. This issue will be prevented by emphasising the procedure and observing all the group during the activity. Both lecturers were confident that the implementation will run smoothly.

On the first day of research, all students completed the pre-test prior to the instructional intervention (playing the SoMCards and assembling the MMB). After finishing the pre-test, students were asked to play the SoMCards and MMB in pairs or groups of three. A total of 33 students participated in the study. The students self-organised into 15 pairs and one group of three. Each group was given a set of the SoMCards and a set of the MMB kit as shown in Figure 4.2. Before they started playing the game, the instructor explained the rules of the activities. The activities took 35 minutes to complete. The researcher observed the interactions between students while they were doing the activity. In order to make sure that the students were following the required steps, the lecturers and the researcher facilitated the process by giving a brief explanation about the game, distributing the SoMCards and MMB for each group, going around to answer the technical questions related to the activity and observing the whole process. An overview of the procedures of implementing the SoMCards and MMB activities in the class are shown in Figure 4.5.

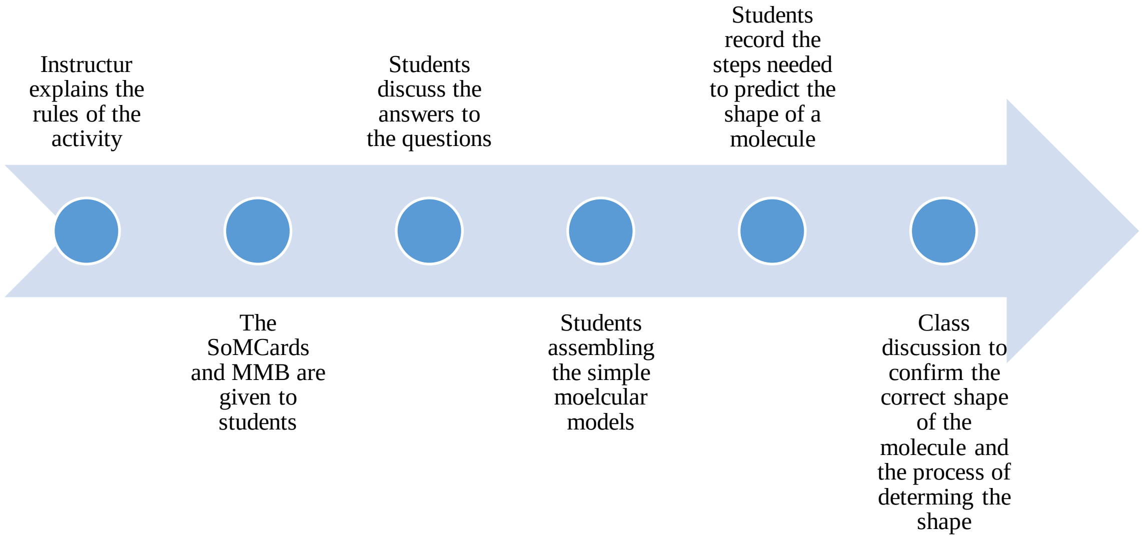


Figure 4. 5 The procedures of the implementation process of the SoMCards and MMB activities in the general chemistry class for one round.

After successfully completing the SoMCards game, students built a molecular model of the correct answer using a simple modelling kit consisting of polystyrene balls, cocktail sticks and map pins. Then, it continued by recording their understanding of these steps on the worksheet provided. The last step in the procedure was discussion of the correct shape of the molecule in teams and as an entire class. The class discussion was led by the instructor. At the end of the activity, students were asked to fill in the feedback questionnaire. Interviews were scheduled a week before and two weeks after the instruction. The first interview was intended to gather the information on students' initial understanding before the intervention while the second interview was held to get students' feedback and understanding after the intervention. The timescale of research activity presented in Table 4.7. It was intended that analysis of these interviews would reveal the impact of the activity on student learning and perceptions of the topic.

Table 4. 7 Timescale of Research Activity of SoMCards and MMB in the First Cycle

Activity	May				June				
	1	2	3	4	1	2	3	4	5
Preparation: The set of the SoMCards and MMB, the worksheet and the periodic table (Demonstration of how to do the activity to the Lecturers)									
Pre-test									
Pre-intervention interview									
Learning with the SoMCards and MMB									
Post-test									
Post-intervention interview									

The timescale scheduled on weekly basis.

4.4.3 Findings of the evaluation: first cycle of research Students' Conceptual Understanding of Molecular Geometry

Individual interviews were conducted with 13 volunteer participants from the cohort prior to the intervention. All interviews were conducted in Bahasa (Indonesian language), the students' native spoken language. These interviews were recorded and the interview records were later transcribed and translated into English. The questions given in the interview directly follow-up based on students' answer in the post-test. Participants were provided with a sheet of paper and a pencil in order to allow them to provide illustrations to support their answers to interview questions where necessary. In the course of each individual interview, the researcher presented two molecules (BF_3 and NF_3). As discussed earlier, the first molecule has no lone pair of electrons surrounding the central atom while the other molecule has one lone pair of electrons surrounding the central atom. Then asked them about the shape of the molecules and along with the reason. The structure of the pre-intervention and post-intervention interview describes in Table 4.8 and 4.9.

Table 4. 8 The structure of the pre-intervention interview

Themes	Key questions	Prompts	Duration
Personal data	How would you describe yourself?	• Name • Term/class • Place of origin • Previous high school	5-10 minutes
Learning style	How do you typically learn?	• Preferred learning style • Preferred learning resources	
Difficulties in learning chemistry	What obstacles do you facing in learning chemistry?	• Terminologies and concepts • Teaching methods • Learning resources • How to deal with the obstacles	
Contents	What concepts do you learn throughout chemistry course?	• Scope of content • Sequence of concepts • Expectations of learning chemistry • Different experiences with learning chemistry in high school	15-20 minutes
Concepts	How would you describe your understanding about the shapes of molecules?	• Concept of VSEPR theory, electron configuration, central atom, substituent, lone pair, bond pair, repulsion,	
	Based on your answer on the pre-test, what are the shapes of molecule BF_3 and NF_3	Student's understanding of the concepts VSEPR theory	
Reason	Why do those molecules adopt the shapes you have stated?		
Responses	What types of learning resources do you use to support your learning of the subject	Type(s) of learning resources (textbook, internet/website, video, lecture's note, etc)	5 minutes

Table 4. 9 The structure of the post-intervention interview

Themes	Key questions	Prompts	Duration
Concepts	How would you describe your learning experience of shape of molecule with the SoMCards and MMB?	• Concepts of shape of molecule • The game-activity • Assembling the MMB	15 minutes
	Based on your answer on the post-test, what is the shape for BF_3 and NF_3?	Concept of VSEPR theory, electron configuration, central atom, substituent, lone pair, bond pair, repulsion,	
Reason	Why those molecules (BF_3 and NF_3) adopt a certain shape?		
Response	In what ways do the SoCards and MMB helped you to understand the shape of molecule concept?	• Which part of the SoMCards and MMB's activity is the most useful part? • Which part is less favourite	15 minutes
	What will you do to improve SoMCards and MMB to support you in learning the concept of shape of molecule?	• Technical aspects • Content presentation	
	How the following task-activity help you to understand the concept of shape of molecule?	Kind of difficulty in doing the activity	

NF_3 (trigonal pyramidal) and BF_3 (trigonal planar) adopt a different shape as NF_3 has 1 lone pair electron around the central atom while BF_3 has no lone pair electron. Based on VSEPR theory, the electron (lone pair and bond pair electron/s) will repel each other to get a stable position. The repulsion will affect the shape and bond angle of the molecule. Based on the results, 12 students (N=13) answered that the shape of both molecules is trigonal planar and 12 of the interviewees were unable to support their answers with scientifically valid explanations. Only one interviewee is successfully determined the shapes of both molecules, but this student was unable to provide a scientifically correct justification for her answers. 11 of the students' explanations were related to the similarity in the formulae of the two structures. There was an assumption that this similarity indicated that both molecules would adopt the same shape. One interviewee stated that BF_3 was linear and that NH_3 was trigonal planar. Both of these answers are incorrect and the prediction of a linear structure for BF_3 implies the student hadn't engaged with the principles of VSEPR theory. This interviewee was unable to provide a scientific rationale for his answer ("I don't know, it just popped-out of my head"). The same interviewee also said that he had no memory of learning this topic high school, but that he may have encountered it when doing private study. This topic is compulsory for high school as part of chemistry curriculum in Indonesia. None of the interviewees successfully demonstrated an understanding of the effect of lone pair electron/s on the shape of a molecule.

When they were asked about, why the molecules adopt a certain shape, students responded by saying "I don't even know the reason why the molecules have a different shape…all I know is they have a different shape because they (molecules) have a different formula." Other student' explanation is: "……although I've read about the VSEPR theory in my chemistry textbook, I don't understand the relation between repulsion with the electron and the shape of molecule." One student gave an interesting quotation which is "I used to memorise all the shape of molecule given in the textbook." Based on the explanations given it could be concluded that all students did not have a proper understanding of the topic. Students seem to memorise the shape of the molecule given in the textbook and without understanding the reason why that shape is adopted. This may be due to the teaching and learning processes emphasising the name of the shape but not the reasons why the molecule adopts a given shape.

The explanation of why students have the poor understanding was then revealed in the interviews, most of them said that they have not studied the topic in the high school or their teacher never explains about the topic although this concept was mandated in the high school curriculum to be taught. Some of students' arguments are presented below.

"…. I never learn about the concept (shape of molecule based on VSEPR theory) when I was in high school as my teachers never explain about this." Other student said that "My chemistry teacher only asked us (high school students) to read the topic in the textbook…perhaps because too many concepts to be taught while the time is limited". The other student gave the elucidation which was "I don't understand at all about the concept even though I've read the topic in a text-book when I was in high school". This response implies that the teacher did not explain the concepts due to the limited time which resulted students only learning the concept by reading the textbook by him/herself. Based on interviewees responses it is clear why all of them do not have a decent understanding on the topic due to this issue. The findings of the student interviews are consistent with students' pre-test score that is very low.

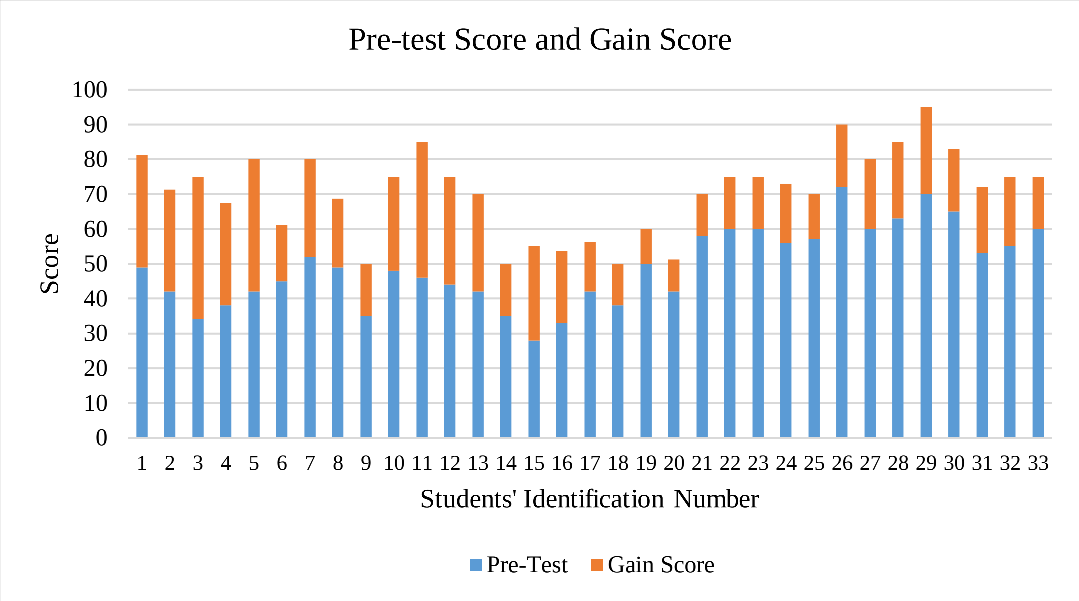


Figure 4. 6 Comparison of students' pre-test and gain score in the first cycle

In order to assess student understanding of the concepts, students were tested both before (pre-test) and after (post-test) the intervention, using the same set of questions. The format of the tests is the single tier short answer type questions, consist of 3 questions. The questions asked the students to predict the shape of different molecules and to provide their reasoning. Details of the comparison of students' score on pre-test and post-test can be seen on Figure 4.6.

Figure 4.6 shows that students' performance on the test improved following the intervention. The average of pre-test and post-test were 49.18 and 70.73 (both out of 100 points), respectively (*N* = 33) giving a 21.5 point increased in the average following the intervention. The relatively low average score of on the pre-test signified students' insufficient understanding of the concept. Students often answer the questions by drawing the Lewis structure or writing the name of the shape without explicitly working through the VSEPR process (see examples shown in Table 4.13). The average score for both pre-test and post-test was then classified into six different ranges. The proportion of students achieving scores in each of these ranges is presented in Table 4.10. What is striking in this table is the proportion of students achieving scores of below 49 points on the pre-test (87.9% of students were in this category). As shown in table 4.10 only 6.1% of students achieved scores between 70-79 points in the pre-test and nobody scored higher than 79 points.

Analysis of the post-test scores immediately reveal that no students achieved a score of under 49 points. Table 4.10 also shows there was a marked increase in the proportion of students who got scored between 70-79 (66.7% of the cohort achieving scores in this range). Despite this increase, nobody achieved scores of greater than 79 in the post-test.

Table 4. 10 Percentage of students' pre and post-test score range

Score range	% Pre-test	% Post-test
<49	87.9	0
50-59	21.2	21.2
60-69	15.2	12.1
70-79	6.1	66.7
80-89	0	0
90-100	0	0

The pre-test and post-test data were analysed using a paired samples *t*-test (using IBM SPSS 24) which demonstrated a statistically significant difference between the pre-test and post-test scores (*p value <0.001*). The results indicate that the activity of playing SoMCards and assembling molecular model can effectively support student learning of this concept. Details of the *t*-test results are reported in Table 4.11.

Table 4. 11 Result of Paired Samples t-test

Score	**Mean**	***N***	**SD**	***Correlation***	***t Value***	***p Value***
Pre-test	49.1818	33	11.19837	.732	-14.467	.000
Post-test	70.7273	33	12.06822			

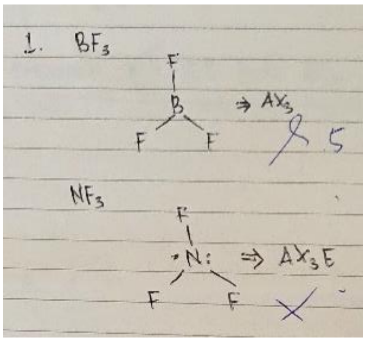
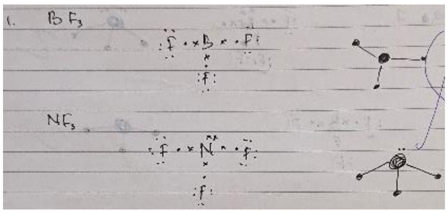
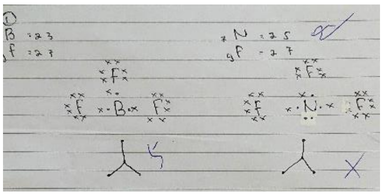
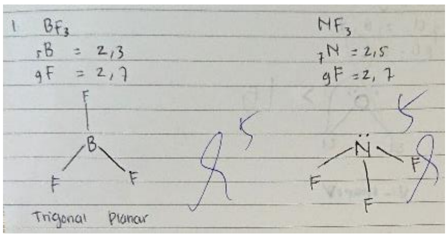
The findings from the analysis of the pre-test and post-test data were supported by the outcomes of a series of interviews conducted after the intervention. The increase in the average score following the intervention suggested that the students' understanding of the concept may have improved. Individual interviews were conducted with 13 volunteer participants. In order to verify this, the post-intervention interview, included a section which required the interviewees to talk to the interviewer through the structure determination of molecules given in the pre-test as the questions given in the interview directly follow-up question based on students' answer in the post-test. Interviewees successfully determined the different shapes of BCl_3 and NH_3 and correctly explained why they were different. A summary of the key findings of the interviews is presented in Table 4.12. It can be concluded that the SoMCards and MMB learning resources were effective at enhancing students' understanding of the concepts that were tested.

Table 4. 12 The summary of types of students' responses to the per-intervention and post-intervention interviews.

Students' understanding before playing the game		**Students' understanding after playing the game**	
Responses	Given reasons	Responses	Given reasons
Students who determined correct shape of BF_3 but the incorrect shape of NF_3	Both molecules have a similar formula therefore their shape must be the same.	No students gave an incorrect answer.	-
Students who gave correct shape of both molecule BF_3 and molecule NF_3	Interviewee wasn't able to justify their answer. The shape had been memorised from content in a chemistry textbook	All students gave the correct answer for both molecules.	As NH_3 has a lone pair of electrons and three bond pairs around the central atom it must be trigonal pyramidal. BCl_3 has no lone pair and just three bond pairs therefore its shape is trigonal planar.

The apparent improvement of students' understanding was also analysed by analysing students' answer to the pre-test and post-test questions. Both tests comprise of 3 questions. A summary of students' answer for both tests were tabulated on Table 4.13, 4.14 and 4.15.

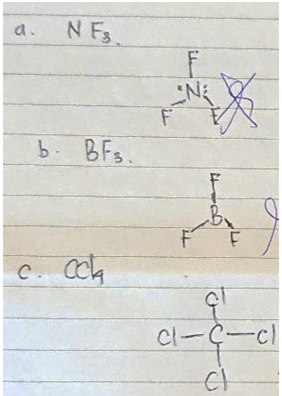
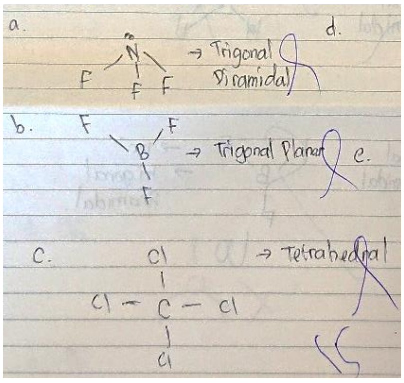
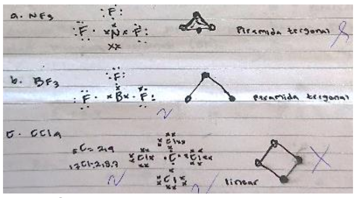
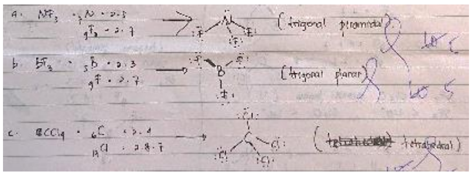
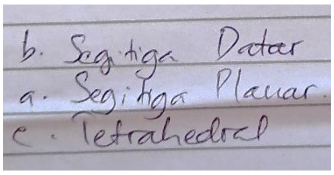
Table 4. 13 Examples of students' answer to question no 1 for both pre-test and post-test

Question 1: The molecules BF_3 and NF_3 have similar formulae, but completely different shapes. Draw diagrams to show the shapes of the two molecules and explain carefully why they are different.	
Pre-test	**Post-test**
1. 	1. 
2. 	2. 
Explanation: the shape is different because NF_3 has one lone pair electron.	*Explanation*: both have a different shape as shape of molecule affected by the lone pair and NF_3 has one lone pair electron while BF_3 has no lone pair.

28 (out of 33) students drew the Lewis structures of the molecules without providing any further explanation as shown in the examples in Table 4.13. Some students provided an explanation of the geometry without drawing the Lewis structure or the shapes of the molecules. Drawing the Lewis structure is the way the topic is taught in Indonesia. Some students started their answers by determining the valence electron configurations of the bonded atoms (as shown in post-test answer 2). 30 (out of 33) students drew a Lewis structure for the molecule even though the question did not ask them to do that. This suggests that students think the Lewis structure is a representation of the shape of the molecule. Students were not used to draw the three-

dimensional representations of molecular geometry (as shown in Table 4.13). They tended to draw two-dimensional representations of the structures (as shown in Table 4.13). Students also gave a proper explanation and drawing the lone pair around the central atom in ammonia, but still ultimately drew molecular geometries that looked the same (e.g. pre-test answer 2 in Table 4.13).

Table 4. 14 Examples of students' answer to question no 2 for both pre-test and post-test

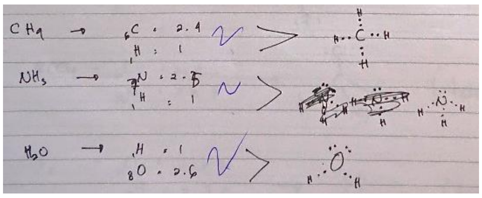
Question 2: Work out the shapes of NF_3; BF_3; CCl_4	
Pre-test	**Post-test**
1.  The shape of NF_3 and CCl_4 are incorrect while the other BF_3 is correct.	1.  The Lewis structure for NF_3 and BF_3 are correct, while CCl_4 is incorrect. All the names of the shape are correct.
2.  Even, for NF_3, he/she already mentioned the correct name but, the shape was wrong.	2.  Already using a proper way to answer the question; starts with valence electron configurations, drawing the Lewis structure and mention the name of the shape correctly
3.  Only mention the name of the shape without further explanation.	

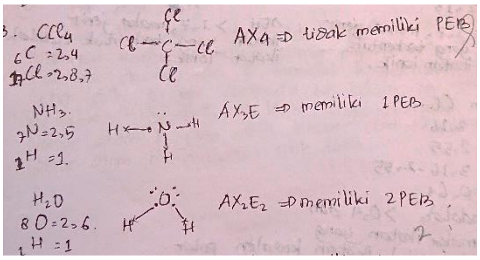
In the post-test, 25 out of 33 students correctly explained why both molecules adapt a different shape. Students seemed to have a better understanding on the post-test and drew the Lewis structure to show the shape for both molecules, although they did not give full explanation including full electron counts. Moreover, they also drew the molecular geometry, the Lewis structure stated the name of the shape. Sample students' answer to the pre-test and post-test questions are presented in Appendix 6.

Table 4.14 presents examples of student answers to question two for both the pre-test and post-test. Some answers only state the name of the shape without further explanation (electron configuration, Lewis structure or the geometry of the molecule). Student answers to the post-test tend to demonstrate a better understanding of the process as they include relevant valence electron configuration, Lewis structures and mentioned the name of the shape (no 2 of students' post-test answer). Even though, students' post-test answer was not fully correct, as they only provide the Lewis structure to illustrate the shape of the molecules, but they provide the correct name of the shape.

Based on Table 4.15, the answers for question no 2 of the pre-test were categorised into three types. The first type is the correct answer with further explanation. Student presented diagrams to differentiate the shapes of the molecules. Students who adapt this type of answer demonstrates an understanding of the concepts, although they only draw the Lewis structure to show the shape of molecule. The second type answer only provides an incorrect explanation without including diagrams. Students proposed the number of atoms bonded affect the shape of the molecule as the reason why CH_4, NH_3 and H_2O has a different bond angles, which is not fully correct, as the repulsion between lone pair electron and the bond pair electrons is considered affecting the bond angles as well as the shape of the molecules. The third type is not answering the question. The last 2 types of students' answer describe students' lack of understanding of predicting the shape of the molecule concepts.

Table 4. 15 Examples of students' answers to question no 3 for both pre-test and post-test.

<table>
<tr><td colspan="2">Question 3: In the molecules CH_4, NH_3 and H_2O, the bond angles are as follows: H-C-H = 109.5° H-N-H = 107.5° H-O-H = 104.5°. All of these molecules have four pairs of electrons arranged around the central atom in a tetrahedral arrangement. Explain why the bond angles are different.</td></tr>
<tr><td>Pre-test</td><td>Post-test</td></tr>
<tr><td>1. 

Reason:
The bond angles are different because each molecule has different numbers of lone pairs of electrons and bond pairs of electrons. CH_4 has no lone pairs of electrons.
2. Due to the number of atoms. The more the number of atoms the smaller the bond angle.
3. Did not answer the question</td><td>1. 

Reason:
Because each molecule has different lone pair electron. CCl_4 has no lone pair electron, NH_3 has 1 lone pair electron and H_2O has 2 lone pairs electron.
2. The number of lone pair electron for CH_4, NH_3 and H_2O are different. The more the number of lone pair electron the smaller the bond angle. The bond angle for each molecule can be described as CH_4>NH_3>H_2O
3. Because each molecule has different number of lone pair electron. If the molecule has more lone pair electron compare to other, so the bond angle will be smaller as lone pair need more space than bond pair electron. Based on that, CCl_4 has no lone pair electron and the shape is tetrahedral so the bond angle is bigger than NH_3 and H_2O. NH_3 has 1 lone pair electron and the shape is trigonal pyramidal so, the bond angle is slightly smaller than CCl_4 and bigger than H_2O. H_2O has 2 lone pairs electron and the shape is bent (V-</td></tr>
</table>

	Shaped) so, the bond angle is smaller than NH_3 and CCl_4.

The three types of answer given in the post-test represent students' understanding of the concepts of shape of molecule. All types of the students' responses to the post-test have shown that they made use of the electron configuration and Lewis structure to support their answers. Students also given further explanations which is correct, although they did not mention the magnitude of repulsion between lone pairs in their explanation. It appears that some students fail to appreciate the significance of the relative magnitudes of repulsion of electron pairs (i.e. lone pair-lone pair > lone pair-bond pair > bond pair-bond pair).

Students' perception and responses of the SoMCards and MMB

The result presented in this section based on the result of feedback questionnaire and pre and post interviews. Students' responses on the SoMCards were tabulated in the graph and table. The graph describes the proportion of students' responses on the first section of the questionnaire while tables depict students' comments and suggestions on section of the questionnaire. Details of students' responses can be seen on Figure 4.7.

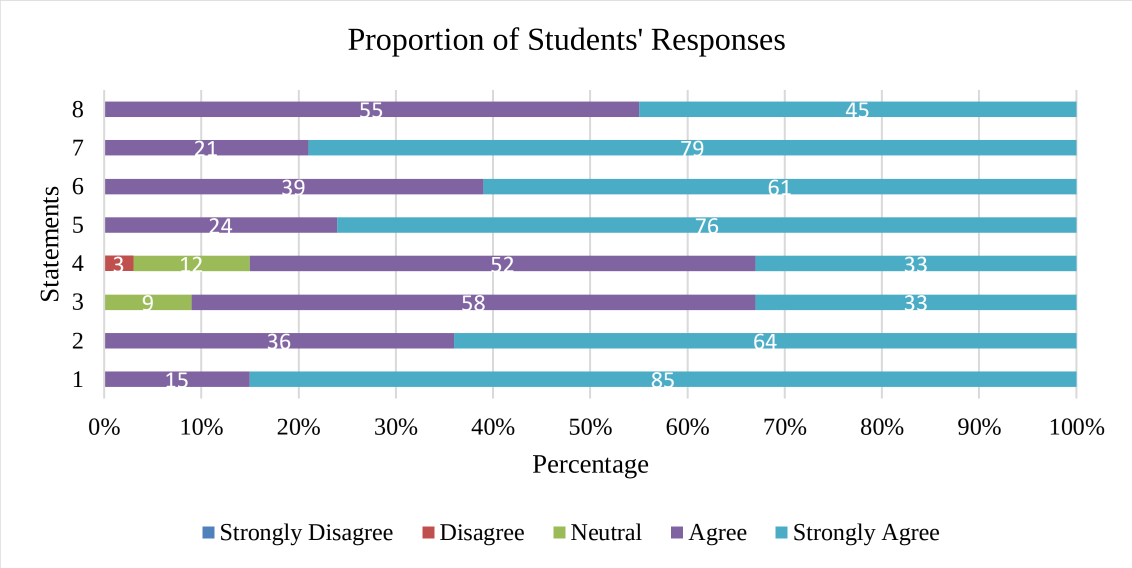


Figure 4. 7 Proportion of students' responses to the SoMCards and MMB on the first cycle (N=33).

The figure illustrates the responses of students in the first sections of the questionnaire. The 8 statements presented in the questionnaire are: 1= The card-game instructions are clear and understandable; 2= Answering the questions in the card-game helped me understand the topic; 3= I understand how to predict the shape of molecule after playing the game; 4= The questions in the card-game are challenging; 5= I enjoyed playing the card-game; 6= The presentation of the card-game is interesting; 7=Making the molecular model using polystyrene balls and cocktail sticks was useful; 8= Making the molecular models helped me understand the influence of lone pairs of electrons on the shapes of molecules.

The most satisfying response with 85% of students strongly agreed and the rest are agreed that the rules of the game were clear and easy to follow. The engaging nature of the SoMCards, the presentations and the usefulness of the simple molecular model were also noted by students. Furthermore, 100% of students ($N = 33$) responded that they either agree and strongly agree that the instructions were easy to follow; 100% of them enjoyed doing the activity; and 100% of students reported that they either agree or strongly agree that the molecular model could help them visualise the shape of molecules. As shown in Figure 4.7, vast majority of students also responded that they agree or strongly agree with each statement except for statement 'the question in the SoMCards are challenging' with only 3% of students disagree to this statement.

The notion of enjoyment of playing the SoMCards game and assembling simple molecular model shown in the questionnaire responses was also a theme raised by students in the post-intervention interview (e.g. *"It's really fun, I didn't feel bored at all. I hope this activity could be implemented to other topics as well"* and *"I really* *enjoy the whole activity"*). Some student interview responses referred to the benefits of playing the game to their conceptual understanding "The activity really helps me to grasp the concept and writing the steps in the worksheet also support my understanding".

The molecular models used in the activity helped students to visualise the shape of the molecules, thus students understand the effect of lone pair electron around the central atom to the shape of the molecules. This statement was supported by students' responses to the post-intervention interview (e.g. *"I know how to predict the shape of the molecule after playing the game, as I can see the 'real' shape by assembling the molecular model" and "having the map pin to show the effect of lone pair electron surround the central atom to the shape of molecule was a great idea, as I can visualise how it works"*). In addition, the SoMCards and the MMB supports the integration of three levels of representations in the study of chemistry. The evidence supported this assertion was the students' responses in the post-intervention interview (e.g. *"by assembling the molecular model, I can understand why the molecule of BF_3 adopt shape of a trigonal planar and NF_3 adopt a shape of trigonal pyramidal as putting the map pin visualise the lone pair around the central atom"*).

Table 4. 16 Students' comments and suggestions (N=33)

Statements		Percentage
Which part of the games that most useful?	The cards/questions that leads to the correct shape	24.2
	Writing the steps how to predict the shape of molecules in the end of the game on the worksheet	6.1
	Making the molecular models by assembling the polystyrene balls, map pins and cocktail sticks	24.2
	The whole experience of playing the SoMCards including assembling the molecular model	45.5
Which part of the games that less useful?	None	100
What changes do you want to make related to the SoMCards and MMB?	None	100

Table 4.16 presents an overview of student feedback on the SoMCards and MMB activities. It is interesting to note that almost half of the participants stated that the whole experience of playing the SoMCards and assembling the molecular models were the most useful part of the activity. Interestingly, for the last two statements 100% of them were agreed that there is no part of the activity is less useful and no changes were needed to be made to the SoMCards including the molecular model. Thus, it can be concluded that the participants believe the SoMCards and MMB activities are effective ways of supporting their learning of this topic.

4.4.4 Reflection of the first cycle

The initial evaluation of the SoMCards and MMB activities was time-consuming and logistically challenging as it required a thorough preparation (e.g. assembling the sets of cards and the components of the molecular models). The supports of the head of Chemistry Education Study Programme and my colleagues were essential. They allow me to access the room in the laboratory for conducting the interview, the printer for printing out the pre-test and post-test. The level of student enthusiasm during the intervention and the observed learning gains made the experience enjoyable for myself as an educator. The analysis of students' conceptual understanding of molecular geometry determination provided some very useful insights, such as using a different approach for teaching general chemistry will impact to students' understanding and perhaps improve their motivation for learning. This approach can also address students' alternative conceptions. This would be advantageous to the teaching and learning process as it may help students to develop deeper understanding of the topic. Thus, identifies students' common misconceptions is recommended to accelerate the teaching and learning process. Initial student feedback and instructor observation led to the small group format being replaced with students working in groups of two or three. This helped students engage with the activity more effectively. The instructors observed that some students immediately look to the last card to see the correct shape of the molecule. In order to avoid that, a teaching assistant is needed to help the researcher observing and wandering around the students during the activity. The key observations made during this phase of the research are summarised in Table 4.17.

Table 4. 17 A summary of observation during the activity of the first cycle

<table>
<tr><th colspan="2">Researcher’s note on students’ activity</th></tr>
<tr><td colspan="2">Before doing the activity:</td></tr>
<tr><td>- A brief explanation of the study was given to all students.
- Then, students were asked to work in a pair or a group consist of three students
- The researcher explained the rules of the activity (how to play the SoMCards and MMB).
- A set of the SoMCards and MMB was given to each group.</td><td>- Students listened to the explanation.
- Students self-organised to work in pairs or small groups.
- Students listened to the explanation.</td></tr>
<tr><td colspan="2">During the activity:</td></tr>
<tr><td>- 5 groups asked the instructor or the researcher for help during the activity.
- 3 groups were observed to cheat by looking at the last card to check the correct answer.</td><td>- Students started to play the activity by open-up the bag of the SoMCards, periodic table and worksheet. They read the introduction cards (the rules, the objectives of the activity, the important terms used, a brief explanation of VSEPR theory, and example molecule).
- Then, students answered the first question. Peer discussion occurred during the activity.
- All groups have to go back to the previous cards as they chose the wrong answer. They seem surprise when they chose the wrong answer, but they realised they made a mistake after reading the hints given in the wrong answer card.
- Students were excited if they chose the correct answer.
- Students were disappointed if they chose the wrong answer.
- Students also refer back to the important term to confirm their understanding
- Students enjoy answering the questions.</td></tr>
</table>

	- Students really enthusiastic to assembling the MMB. - Students use the periodic table provided constantly to answer the questions. - Students follow the procedures given. - The activity was done in time 30 minutes as expected.
After doing the activity:	
- A discussion within the class to confirm the correct shape of molecule and comparing the answer between the pair. - A feedback questionnaire was distributed to all students	- Each pair of students showed their molecular model based on their answer. They also explained why the molecule adapt those shape. - They answered all the questions and giving a feedback related to the SoMCards and MMB
Conclusion: Overall, students enjoy the process of doing the activity especially assembling the MMB. A small group (2-3 students) were proved to be effective, as all students in the group were fully participated in the game activity (one student read the question, the other check the periodic table or write their answer). The group size was changed based on researcher observations. This change resulted in a higher level of engagement. To prevent students from cheating (looking the correct answer card), the lecturer suggests to involve another lecturer to observe the activity.	

The changes that have been made based on students' feedback in the pilot study had an impact on students' responses in the questionnaire in later cycles. The average percentage of students who agrees with all the statements in the questionnaire (Table 4.2) increased from 74% to 97%. In addition to that, no students suggested any further changes to the SoMCards and MMB in the first cycle. All of them seemed pleased with all the changes suggested in the pilot study.

4.5 Evaluating the SoMCards and MMB: second cycle of research

To confirm the findings from the first cycle, the SoMCards and the simple molecular model building (MMB) were re-evaluated. The second cycle occurred after the reflection stage of the first cycle. The only difference in the research approach used in the first cycle was the use of an assistant observer. The assistant observer involved in the second cycle was the junior lecturer of the Chemistry Education Study Programme of Department of Mathematics and Science Education, University of Tanjungpura.

4.5.1 The context of the second cycle of research

The second cycle of research was conducted in October-December 2016 in the Chemistry Education Study Programme of Department of Mathematics and Science Education of Faculty of Teacher Training and Education of University of Tanjungpura, Pontianak, Indonesia. 82 students from 3 classes were involved in the study. The number of students for each class presented in Table 4.18. Although they are in a different class, they were all taught by the same lecturer. All students were in the year 1 term of the 2016/2017 academic year. At the time students were studying general chemistry 1, but they have not studied the topic these activities focused on at this time. The SoMCards and MMB were implemented in the classroom at the same time that the topic is taught.

Table 4. 18 Number of students in each class during the second cycle of research

Classes	Number of students	Number of pairs/groups
Chemistry Education A1	31	14 pairs and 1 group of 3 students
Chemistry Education A2	30	15 pairs
Chemistry Education A3	21	9 pairs and 1 group of 3 students

4.5.2 Procedures of the Implementation of the SoMCards and MMB in the Second Cycle

In order to expedite the implementation of the SoMCards and MMB in the classroom, a brief demonstration was given to the lecturers and teaching assistant involved in the study. 15 students volunteered to participate in a pre-intervention interview. The individual interview was conducted for both pre-intervention and post-intervention interview. The aim of these pre-intervention interviews was to measure students' initial understanding of how to predict the shape of the molecule based on VSEPR theory as the topic had previously been taught at high school. The interview was scheduled a week before the intervention. The structure of the pre-intervention interview and post-intervention interview in the second cycle similar to those in the first cycle (see Table 4.8 and 4.9).

On the day of the study, a pre-test was given before students start the activity. The format of the pre-test is short answer questions, comprise of 3 questions. The same pre-test was used as that used in the first cycle of research. The test took 20 minutes from start to finish. After the pre-test students were asked to arrange themselves into pairs and each pair were given a set of the SoMCards and MMB (Figure 4.2). The instructions and rules of the activity were then explained by the lecturer. The students worked on the activity for 35 minutes. During the activity, the researcher and the teaching assistant observed students' behaviour and circulated to ensure that students followed the correct process and to answer any questions they may have related to the activity. The implementation procedure is shown in Figure 4.5.

Students started the activity by reading the brief explanation of the theory. They then answered each question. After correctly identifying the shape of the molecule, students worked on assembling a molecular model. Students then recorded a log of the steps needed to predict the shape of molecule in their own words. The last step of the process was a discussion of the molecular model with the instructor. Each pair then presented their model to the other students. The instructor provided feedback on whether the model was correct or not. A questionnaire was given to students after the activity was done. The questionnaire consists of two sections. The first sections adapted Likert scale type with 5 options to gather students' responses related to the appearance and the content of the SoMCards and MMB. The second section consist of three open-ended questions to collect students' comments and suggestions related to both TLRs. A post-intervention interview was scheduled two to three weeks after the instruction. Based on the suggestion given by the audience in the STEM Horizons 2016 that it would be best if the post-test given in the end of the semester to measure students' understanding of the concepts. This suggestion supported by Brown, Irving & Keegan (2008 who stated that students would not be able to remember the questions and their answers from the pre-test if a long enough interval was used. In addition to that, Campbell and Stanley (2015) suggested that the best times to administer the post-tests are a month, 6 months and a year after the implementation. This was suggested to measure the long-term impact of the learning experience. Therefore, the post-test was scheduled as an integral part of the mid semester exam. This took place 5-6 weeks after the implementation. Students received no further tuition on this topic between the intervention and the post-test. Table 4.19 shows the timescale of research activity on weekly basis.

Table 4. 19 Timescale of Research Activity of SoMCards and MMB in the Second Cycle

Activity	October				November				December			
	1	2	3	4	1	2	3	4	1	2	3	4
Preparation: The set of the SoMCards and MMB, the worksheet and the periodic table (Demonstration of the activity to the Lecturers)												
Pre-test												
Pre-intervention interview												
Learning with the SoMCards and MMB												
Post-test												
Post-intervention interview												

The timescale scheduled on weekly basis.

4.5.3 Findings of the evaluation: second cycle Students' Conceptual Understanding of Shape of Molecules Concepts

Face-to-face interviews were conducted in Bahasa. The interview records were transcribed and translated into English. Paper and pencil were provided to write or draw in the process of predicting the shape. The researcher starts the interview by presenting two molecules, BF_3 and NF_3. Then the researcher asked them about the shape of each molecule along with the explanation. The questions and the procedures used in the second cycle are identical with those used in the first cycle.

Using the responses of students in the interview as a basis, most of them showed a similar trend to the interview of first cycle. Well over half of those participants agreed that the shape of both molecules is trigonal planar. The answer is half correct as the shape of NH_3 is trigonal pyramidal. A third of them claimed that the shape is trigonal planar and trigonal pyramidal which is the correct answer. The rest declared linear and trigonal planar that is incorrect. Each of them cannot provide the correct explanation, even those who come up with the correct answer. The explanation of given by student are “I don’t know why they have a different shape” or “I don’t understand, I thought they have the same shape as both molecules have a similar formula.” Other student declared that “I just know that they have a different shape.” Students’ responds on this question demonstrated that they don’t understand the effect of lone pair/s electrons around the central atom to the shape of molecules and bond angle.

The interview also exposed the reason why students do not understand the topic as majority of them implied that the topic was never explained by their teacher. Despite of the high school curriculum cover this concept to be taught, teacher did not explain the topic to students. Students proposed some arguments related to it. “… My teacher never explains the topic, so I thought the topic was not important enough to be learned.” Other student come up with “She (chemistry teacher) asked us (high school students) to just read the topic in the textbook.” One student suggested that “I’ve read the topic in the textbook when I was in high school, but honestly I don’t understand.” Notwithstanding the fact that the topic is incorporate in the chemistry high school curriculum chemistry teacher seem to disdain to teach the topic to students. As a consequence, students have a lacking understanding of the concept.

Pre and post-test were given to assess students’ understanding of the concepts. The question give is identical to the first cycle. The questions asked the students to predict the shape of different molecules along with the reasons. Details of the comparison of students’ score on pre-test and gain can be seen on Figure 4.8.

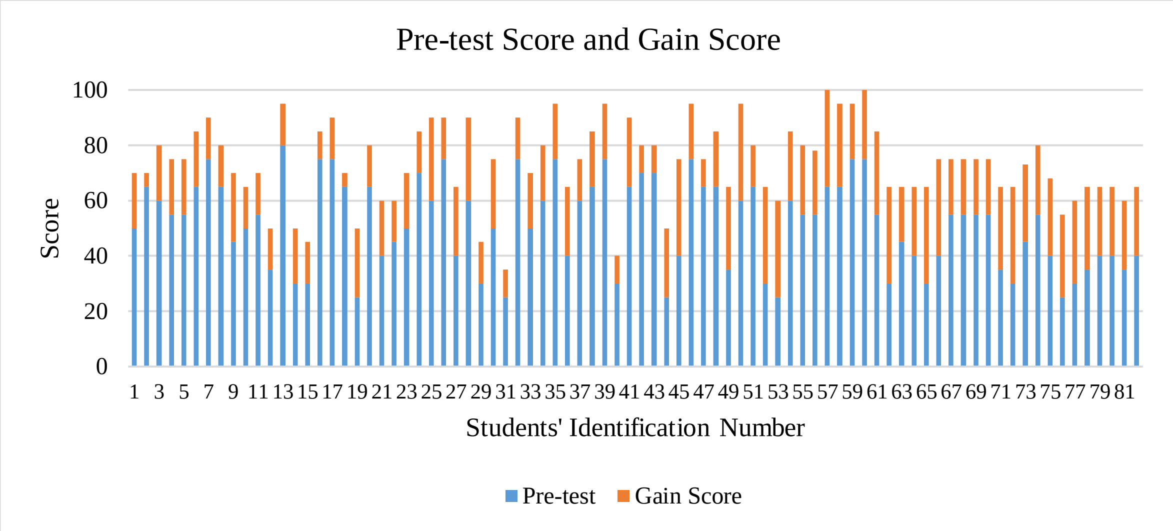


Figure 4. 8 Students' Pre-test and Gain Score on the second cycle.

The graph shows that there has been a steady increase of students' pre-test and post-test score. All students' scores had increased with the average score 21.88 points (maximum score = 100). The average score of pre-test and post-test were 51.77 and 73.65, respectively (N = 82). Even though the average pre-test score is slightly better than the pre-test score on the first cycle, the low average score is evidence of inadequate understanding of the concept. The average score for both pre-test and post-test was then classified into 6 different ranges. The proportion of students' range score for both tests is presented in Table 4.20. What is interesting in this table is the low score on pre-test with 40.2% of them had below 49 in score. 1.2 % of them got between 80-89 score and none of them got higher than 89.

On the contrary, the percentage of post-test score range below 49 was declined to 4.9% only. Meanwhile, the percentage of students who got 80-89 was increased to 19.5%. It is also notable that in the post-test, 19.5% of students got between 90-100. The result indicates the evidence that SoMCards and MMB assisted students in learning the concept.

Table 4. 20 The range of pre-test and post-test score

Score range	% Pre-test	% Post-test
<49	40.2	4.9
50-59	18.3	6.1
60-69	23.2	25.6
70-79	17.1	24.4
80-89	1.2	19.5
90-100	0	19.5

To verify the findings, both pre-test and post-test data were analysed using a paired samples *t*-test. The result confirms that there is statistically significant between pre-test and post-test score with *p value <0.001*. This can be used as evidence that the activity cards can effectively support student learning of this concept. Details of the *t*-test results are reported in Table 4.21.

Table 4. 21 Result of Paired Sample t-test

Score	**Mean**	***N***	**SD**	***Correlation***	***t Value***	***p Value***
Pre-test	51.77	82	15.993	.882	-26.224	.000
Post-test	73.65	82	14.396			

Both interviews' result aligned with the findings on paired sample *t-test*. The average scores of post-test signify the improvement of students' understanding. All of them could provide correct shape of the molecule given along with the reason in the post-interviews. Students could explain the different shape of BCl_3 molecule and NH_3 molecule although they possess a similar formula. Summary of students' responses on pre and post-interviews is presented in Table 4.22. Based on the table, it can be concluded that SoMCards and MMB could enhanced students' understanding of the concepts that were tested.

Table 4. 22 The summary of students' pre- and post-interviews

Students' understanding before playing the game		**Students' understanding after playing the game**	
Responses	Reasons	Responses	Reasons
Students who gave correct shape of molecule BF_3 and incorrect answer for molecule NF_3	Both molecules have a similar formula therefore their shape must be the same.	There is no student who gave the incorrect answer.	-
Students who gave correct shape of both molecule BF_3 and molecule NF_3	Students' cannot provide the explanation as they only memorise or guessing all the shape given in the chemistry textbook	All students come up with the correct shape for both molecules.	As molecule NH_3 has one lone pair electron around the central atom while BCl_3 has no lone pair therefore the shape of NH_3 is trigonal pyramidal and BCl_3 is trigonal planar. As electron will repel each other to get a stable position.

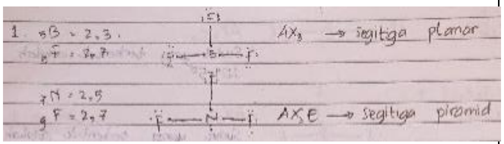
Moreover, the improvement of students' understanding was also observed by analysing students' answer on pre-test and post-test. Both tests comprise of 3 questions. A summary of students answer for both tests were tabulated on Table 4.23, 4.24 and 4.25.

For the pre-test, there was one student who answered the question correctly, he/she also provide the correct explanation. Meanwhile, some students did not answer the question or provide any further explanation. Some of them also start the answer by electron configuration like students' answer no 1 on the pre-test. Interestingly, one student (example no 3 of pre-test in table 4.23) wrote the number of lone pair and bond pair electron correctly to answer the question, even though without electron configuration.

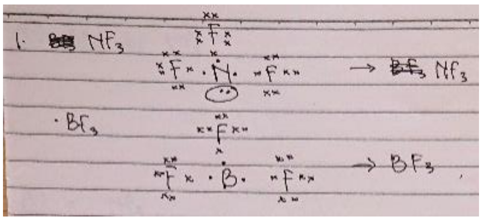
Table 4. 23 Examples of students' answer to question no 1 for both pre-test and post-test.

<table>
<tr><td colspan="2">Question 1:

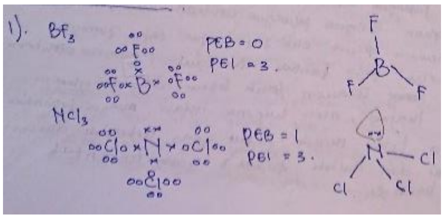
Pre-test: The molecules BF_3 and NF_3/NCl_3 have similar formulae, but completely different shapes. Draw diagrams to show the shapes of the two molecules and explain carefully why they are different.

Post-test: The molecules BF_3 and NF_3/NCl_3 have similar formulae, but completely different shapes. Draw diagrams to show the shapes of the two molecules and explain carefully why they are different.</td></tr>
<tr><td>Pre-test</td><td>Post-test</td></tr>
<tr><td>1. 

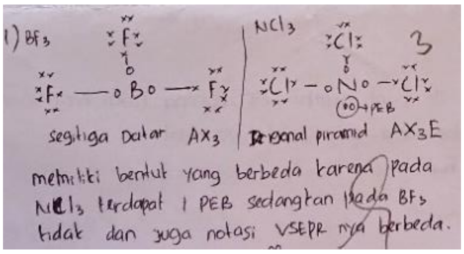
The shape is different due to NF_3 molecule has 1 lone pair electron while BF_3 has no lone pair

2. 

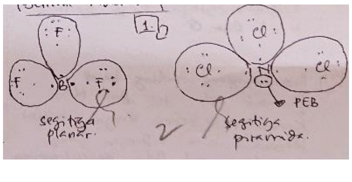
Did not provide further explanation

3. Did not answer the question</td>
<td>1. 

The shape is different due to BF_3 has no lone pair electron while NCl_3 has 1 lone pair electron

2. 

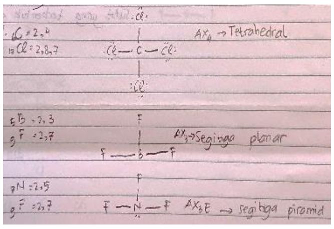
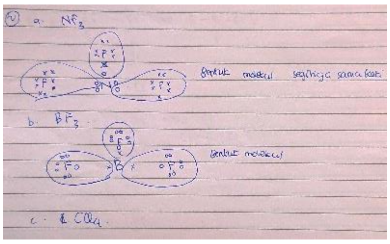
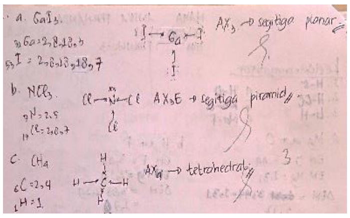
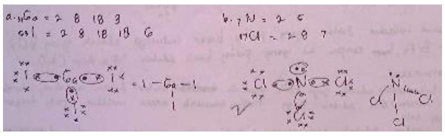
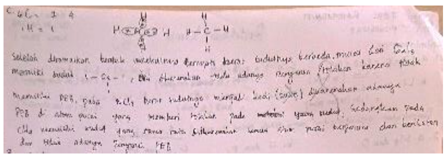
Even though both molecules have a similar formula, but they have a different shape due to the number of bonding pair (BP) and lone pair (LP). NCl_3 has 1 lone pair and 3 BP, so the shape is trigonal pyramidal. Meanwhile BF_3 has no lone pair electron and 3 BP so the shape is trigonal planar.

3. 
</td></tr>
</table>

	He/she drew the Lewis structure and mentioned the name of the shape correctly, but no explanation provided.

For post-test, majority of students give a further correct explanation why both molecules adapt a different shape. Students seemed to have a better understanding on the post-test as they already drew a correct shape for both molecules. Moreover, they also draw the shape after the Lewis structure and put the correct name of the shape.

Table 4. 24 Examples of students' answer to question no 2 for both pre-test and post-test

<table>
<tr><td colspan="2">Question 2:
Pre-test: Work out the shapes of NF_3; BF_3; CCl_4
Post-test: Work out the shapes of GaI_3; NCl_3; CCl_4</td></tr>
<tr><td>Pre-test</td><td>Post-test</td></tr>
<tr><td>1. 
The answer is correct, already used electron configuration and Lewis structure.
2. 
Incorrect answer.</td><td>1. 
The answer is correct, already using electron configuration and drew the Lewis structure to show the shape of the molecules.
2. 
The answer for the shape of GaI_3 is incorrect, even though. Meanwhile the answer for NCl3 and CH4 are correct. He/she used electron configuration,</td></tr>
</table>

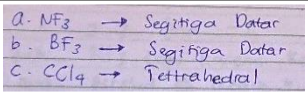
3.  a. NF_3 → Segitiga Datar b. BF_3 → Segitiga Datar c. CCl_4 → Tettrahedral Only wrote the name of the shape.	drew the Lewis structure and the shape of the molecule He/she even add further explanation about the steps needed to predict the shape of the molecule.

Table 4.24 describes the type of students' answer on question no 2 of the pre-test. The first type is the correct answer. This type of answer showing students' understanding of the concepts. He/she already used the electron configuration and drew the Lewis structure to answer the question. Meanwhile, the second type is the incomplete and incorrect answer. He/she only drew the Lewis structure to show the bond pair/s electrons between the atoms. For the last type, he/she only wrote the name of the shape (the shape for NF_3 and BF_3 were wrong). The second and the third type of the answer shows students' lack of understanding on these concepts.

Based on Table 4.24, there are two types of students' answer on the post-test. Both types are correct, except the shape of GaI_3 which they drew the wrong Lewis structure (the answer should be trigonal planar not the T-shaped) but the second type provided a further explanation. He/she added the steps used to predict the shape of the molecule. Both types used the electron configuration and Lewis structure. It is noted that no students answer using this type on the post-test. These 2 types of students' answer shown that students have a proper understanding related to the concept.

Students' have a various explanation to answer the third question of pre-test. The first answer is the correct answer. He/she also used the diagram to support the explanation. Whilst, for the last three answers students provide the incorrect explanation, even some of them did not answer the question. Again, the incorrect explanation indicates students' poor understanding of the concepts.

Table 4. 25 Examples of students' answer of question no 3 for both pre-test and post-test

<table>
<tr><td colspan="2">

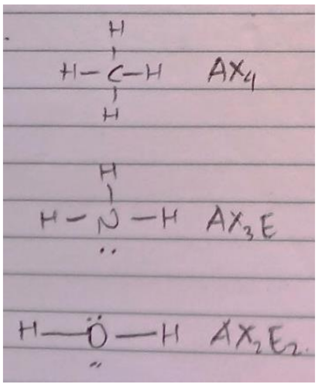
Question 3:

Pre-test: In the molecules CH_4, NH_3 and H_2O, the bond angles are as follows: H-C-H = 109.5° H-N-H = 107.5° H-O-H = 104.5°. All of these molecules have four pairs of electrons arranged around the central atom in a tetrahedral arrangement. Explain why the bond angles are different.

Post-test: In the molecules CCl_4, NH_3 and H_2O, the bond angles are as follows: Cl-C-Cl = 109.5° H-N-H = 107.5° H-O-H = 104.5°. All of these molecules have four pairs of electrons arranged around the central atom in a tetrahedral arrangement. Explain why the bond angles are different.

</td></tr>
<tr><td>Pre-test</td><td>Post-test</td></tr>
<tr><td>

1.

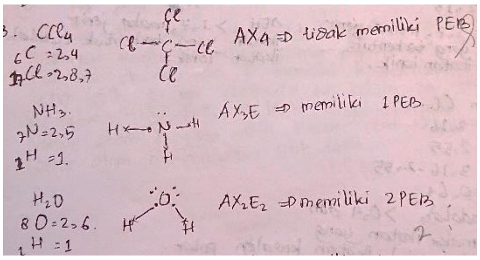


The bond angles of each molecule are different due to the number of lone pair electron. Each molecule has different number of lone pair electron. The more the lone pair electron the smaller the bond angle of a molecule. The lone pair will repel the bond pair electron.

2. Because each molecule has a different central atom
3. Because the electronegativity of each molecule is different
4. Did not answer the question

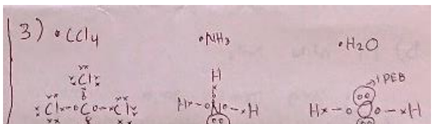
</td><td>

1.



CCl_4, NH_3 and H_2O has a different size of bond angle because the effect of repulsion between lone pair electron and bond pair electron. The more bond pair and lone pair electron the smaller the bond angle.

2.



The bond angles are different because each molecule has a different number of lone pair electron (see diagram).

</td></tr>
</table>

	3. Because each molecule has different number of lone pair electron. The more the number of lone pair electron, the smaller the bond angle as the lone pair repel the bond pair electron.

On the contrary, students could provide a proper explanation to answer this question. Students also use the diagram to support their explanation. It is interesting that students even use the term of “repulsion” and “repel” which cannot be found in the pre-test. Based on this answer, it can be concluded that students have an adequate understanding to the concepts.

Students’ perception and responses of the SoMCards and MMB

The findings in this section is presented based on the result of the questionnaire, pre-interviews and post-interviews. The graph describes the proportion of students’ responses on first section of the questionnaire while the summary of the second section of the questionnaire presented in table. Pre and post interviews are presented as quotation to show students’ answer to the questions.

Figure 4.9 depict the proportion of students’ responses to the first section of the questionnaire. Majority of students are either agree or strongly agree to all items. The most notable is item no 5 with 52% and 48% stated that they are strongly agree and agree that the activity was enjoyable. The clarity of the instruction and the good presentation of the SoMCards also regard by students with 96% and 94% respectively agree or strongly agree. Answering the questions and assembling the molecular model could elevate their understanding is notice by students with 90% and 89% of them agree or strongly agree to the item. Students’ responses to item no 4 is quite different as 70% of them agree or strongly agree while 30% of them chose neutral to the item. Overall students showed a positive response toward the SoMCards and MMB.

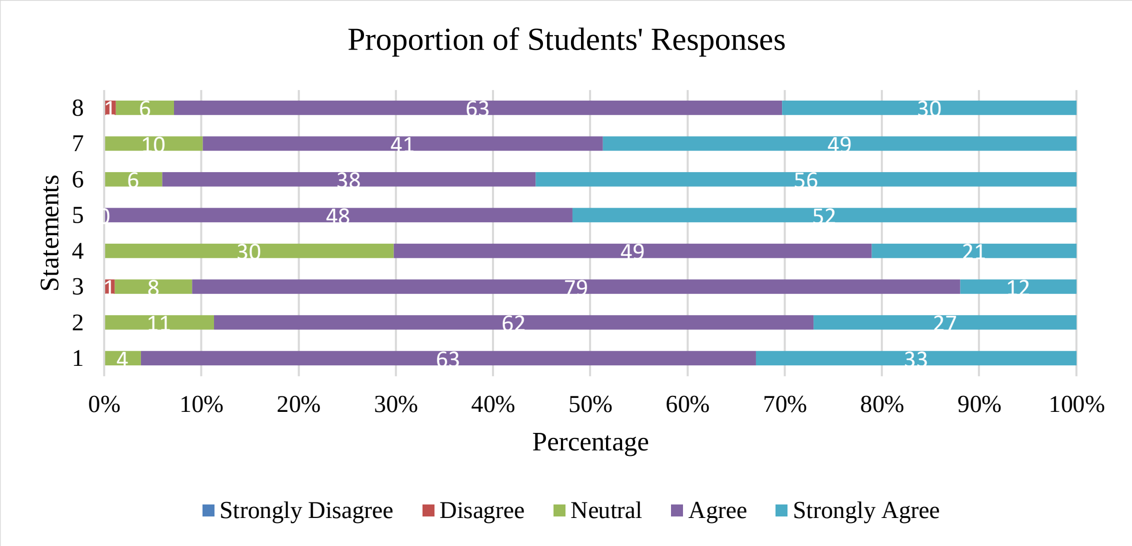


Figure 4. 9 Proportion of students' responses (N=82) to the SoMCards and MMB in the second cycle. Detail of all statements refer to Table 4.2.

The figure illustrates the responses of students in the first sections of the questionnaire. The 8 statements presented in the questionnaire are: 1= The card-game instructions are clear and understandable; 2= Answering the questions in the card-game helped me understand the topic; 3= I understand how to predict the shape of molecule after playing the game; 4= The questions in the card-game are challenging; 5= I enjoyed playing the card-game; 6= The presentation of the card-game is interesting; 7=Making the molecular model using polystyrene balls and cocktail sticks was useful; 8= Making the molecular models helped me understand the influence of lone pairs of electrons on the shapes of molecules.

On section two, more than half of students (52.4%) stated that the whole experience of playing SoMCards and assembling the simple molecular model is noted as the most useful part of the activity. 100% of them concur that there is no less useful part of the activity and express that no changes need to be made to the activity. Details of students' responses on each item can be seen on Table 4.26.

Table 4. 26 Students' comments and suggestions (N=82)

Statements		Percentage
Part of the games that most useful	The cards/questions	6.1
	Formulated the steps of how to predict the shape of molecule on the worksheet	4.9
	Making Molecular models by assembling polystyrene balls, map pins and cocktail sticks	36.6
	The whole experience of playing the SoMCards including assembling the molecular model	52.4
Less useful	None	100
Changes	None	100

In the post-interviews, students clarify that they enjoy doing the activity and constructing the simple molecular model as well. Here are some of students' quotations that "I usually get bored in the class but today was a great fun." "I love the assembling the molecular model as it helps me visualise the effect of the lone pair/s electrons to the shape of the molecules." "I love the process of going back to the previous card if we choose the wrong answer." "I thought the idea of providing the hint was brilliant." The findings confirm that students really enjoy the activity of playing SoMCards and building simple molecular model.

4.5.4 Reflection

Evaluating SoMCards and MMB in the second cycle is to ensure the reliability of the findings in the first cycle. As the result of the second cycle is consistent to the first cycle, thus it can be concluded that SoMCards and MMB could improve students' understanding on the shape of molecule topic. The involvement of the teaching assistant in the second section was effective. The findings of the observation were similar to those in the first cycle. Students enjoyed the process of answering the question given in the card. Involving another observer to help the researcher observe the whole process proven to effective as no group attempted to be cheated by seeing the correct answer in the last card. The key observations made during this stage of the research are summarised in Table 4.27.

Table 4. 27 A summary of observation during the activity of the second cycle

<table>
<tr><td colspan="2">Researcher's note on students' activity</td></tr>
<tr><td colspan="2">Before doing the activity:</td></tr>
<tr><td>- A brief explanation of the study was given to all students.
- Then, students were asked to work in a pair or a group consist of three students
- The researcher explained the rules of the activity (how to play the SoMCards and MMB).
- A set of the SoMCards and MMB was given to each group.</td><td>- Students listened to the explanation.
- Students self-organised to work in pairs or small groups.
- Students listened to the explanation.</td></tr>
<tr><td colspan="2">During the activity:</td></tr>
<tr><td>- 5 groups asked the instructor or the researcher for help during the activity.
- 3 groups were observed to cheat by looking at the last card to check the correct answer.</td><td>- Students started to play the activity by opening the bag of the SoMCards, periodic table and worksheet. They read the introduction cards (the rules, the objectives of the activity, the important terms used, a brief explanation of VSEPR theory, and example molecule).
- Then, students answered the first question. Peer discussion occurred during the activity.
- All groups have to go back to the previous cards as they chose the wrong answer. They seem surprised when they chose the wrong answer, but they realised they made a mistake after reading the hints given in the wrong answer card.
- Students were excited if they chose the correct answer.
- Students were disappointed if they chose the wrong answer.
- Students also refer back to the important term to confirm their understanding
- Students enjoy answering the questions.
- Students really enthusiastic to assembling the MMB.
- Students use the periodic table provided constantly to answer the questions.
- Students follow the procedures given.</td></tr>
</table>

	- The activity was done in time 30 minutes as expected.
After doing the activity:	
- A discussion within the class to confirm the correct shape of molecule and comparing the answer between the pair. - A feedback questionnaire was distributed to all students	- Each pair of students was showing their molecular model based on their answer. They also explain why the molecule adapt those shape. - They answered all the questions and giving a feedback related to the SoMCards and MMB
Conclusion: Overall, students' engagement to the SoMCards and MMB were similar to those in the first cycle. Students enjoy the process of doing the activity especially assembling the MMB. Again, a small group (2-3 students) were proved to be effective, as all students in the group were fully participated in the game activity (one student read the question, the other check the periodic table or write their answer). Involving another observer to help the researcher observe the whole process proven to effective as no group was observed to be cheated by seeing the correct answer in the of the card.	

The changes that have been made to the SoMCards and MMB based on students' feedback from the first cycle had impact on students' responses towards the SoMCards and MMB. The average percentage of students who agreed to all the statements in the questionnaire (Table 4.2) were above 90% (97% for the first cycle and 91% for the second cycle). Furthermore, 100% students stated that no changes needed to be made to the SoMCards and MMB in the second cycle. These findings suggested that all students were satisfied with all the changes made in the pilot study and the first cycle.

4.6 Summary

The study of development SoMCards and MMB aimed to address three specific research questions. These research questions were extracted from the research questions of this thesis (Chapter 1, section 1.3). The connection between the specific research questions and the sources of data are described in Table 4.28. The four stages of AR, in the cyclic form used in this study, were successful in developing and evaluating the SoMCards and MMB to challenge students' alternative conceptions of the shape of molecules concepts. This finding is based on a review of the development and evaluation processes in the first and second cycles for the SoMCards and MMB. The four modified stages of AR used in this study provided the opportunity for the researcher to design, develop, evaluate and reflect (the whole process) the SoMCards and MMB continuously through each cycle. The AR approach used in this study has been successful in addressing students' alternative conceptions of shape of molecules concepts, as this approach allowed the researcher to design and develop the TLRs based on students' problems. In addition, the literature review process also enabled the researcher to identify the main reason for the problem. Therefore, the researcher has the opportunity to deal with the problem by designing and developing the suitable TLRs.

Data collected through pre and post-tests and interviews were used to assess the impact of SoMCards and MMB to students learning. The increased score on both cycles provided evidence that SoMCards and MMB had improved students' understanding on the shape of molecule topic. Also, the findings of students' answer analysis (pre- and post-test) in both cycles had shown that students had a better understanding after learning with SoMCards and MMB. The SoMCards and MMB were found to have a significant impact in supporting students' understanding of the shape of molecules concepts.

Meanwhile, the findings from the questionnaires, interviews and observations were used to answer the third research question. Based on the findings of the questionnaire and interviews, students find that SoMCards and MMB is a good way to learn. A positive response towards SoMCards and MMB confirmed that the resources were effective at providing engaging learning experience.

Table 4.28 The Connection between the specific Research Questions and Data Sources

Research Questions	Data Sources				
	*Researcher Notes	Pre- and Post-test	Questionnaire	Interviews	Observation
How should educators develop the SoMCards and MMB in order to challenge students' alternative conceptions of Shape of Molecule based on VSEPR theory?	√	√	√	√	
What is the impact of the SoMCards and MMB on student learning?		√		√	
How effective are these SoMCards and MMB at providing engaging learning experience?			√	√	√

*Researcher notes were made based on the review of the literatures

Chapter 5.

Enhancing Students' Understanding of Electronegativity, Bond Type and Polarity by Using Leaflet

Chapter outline

The fifth chapter discusses the findings of the Leaflet of Electronegativity (LoEN) developed to enhance students' understanding. This is the second teaching and learning resource (TLR) developed as part of this study to help students grasp the concept of electronegativity, bond type and polarity. The first TLR is Shape of Molecule Cards (SoMCards) and Molecular Model Building (MMB). This chapter addresses the three specific research questions, which are: (1) How should educators develop LoEN in order to challenge students' alternative conceptions of electronegativity, bond type and polarity?; (2) What is the impact of the LoEN on student learning?; (3) How effective are the LoEN at providing engaging learning experience?. The explanation of the rationale of developing the LoEN is presented first in this chapter. The chapter then continues by detailing the development process of the LoEN. The context in which the research took place in is described in detail. The next section provides a description and explanation of the pilot study which was conducted prior to the first and second cycles. The exploration of the methods employed in this study, including participant backgrounds, research instruments, data collection and analysis methods are presented in this chapter. Findings for each cycle focusing on students' conceptual understanding and their perceptions and views of the LoEN are included in this chapter in order to address those three research questions.

5.1 Rationale of Developing LoEN

Electronegativity is a concept central to a myriad of other basic concepts taught in chemistry curricula including chemical bonding (Nicoll, 2001). Nicoll (2001) reported that some undergraduate students have misconceptions related to electronegativity and bonding. Peterson *et al*., (1989) reported that some grade-11 and grade-12 students held misconceptions related to the influence of electronegativity and the resultant unequal sharing of l electron. They thought that the unequal sharing of 1 electron is not affected by electronegativity. Moreover, Nicoll (2001) found that whilst some students may be familiar with the concept of polarity, but they have difficulty explaining the relationship between polarity and electronegativity.

Another study by Ardiansah, *et al.* (2013), reported that 5 out of 12 participating chemistry teachers in Bengkayang District (one of the Districts in West Borneo, Indonesia) experienced misconceptions related to the determination of bond types based on the electronegativity difference of the bonded atoms. The authors reported that the factors that may cause these misconceptions include students’ prior knowledge, the associative thinking and textbooks. In addition, Ardiansah (2018) reported that around 40% of college students (out of 75 students who participated in this study) in Indonesia who had already studied chemical bonding experienced misconceptions related to identifying the bond types in the sample molecules given in the test. He used an online test to gather the students’ answers. Moreover, he reported that some of the participants involved in this study determined the bond type based on the metallic or non-metallic character of the bonded elements. These findings suggested that the way the relationship between electronegativity, bond types and polarity is taught may need to be reconsidered in order to support students’ understanding of chemical bonding.

Chemistry textbooks are one of the main teaching and learning resources available to many educators and students of the subject. However, the number of General Chemistry textbooks available for students in the library of University of Tanjungpura is limited (25 books for General Chemistry). This forces some students to rely on their high school chemistry textbooks as the main resource for studying General Chemistry 1 and 2 courses. The primary disadvantage of high school textbooks is the limited explanation of concepts. Based on a review of the three most popular high school chemistry textbooks that are disseminated by different publishers in Indonesia (Erlangga, Yudhistira and Grafindo), none of them provide an explanation of the relationship between electronegativity, bond type and polarity that would be suitable for a university level course. This topic can only be found in Indonesian chemistry textbooks written specifically for university students. Therefore, there is a need for the explanations of these concepts and the relationships between them to be provided in a more widely accessible format.

Booklets or leaflets were the two formats that were considered to present this topic. A booklet is a small, thin book with paper covers, typically giving information on a particular subject (Efendi & Makhfudli, 2009). Meanwhile, a leaflet is a printed sheet of paper containing information and is usually distributed free of charge. Comparing these two formats, a leaflet is easier to produce than a booklet. In addition, the concepts presented in this topic could be explained in two pages of paper. Therefore, leaflet is the best option to present the topic. The accessibility of the leaflet can be further broadened by making it available digitally. According to Ewles & Simnett (1999) the advantages of leaflets include their effectiveness for providing concise summaries of information, their simple and cheap production and the fact that each student could have their own copy to learn from. Students can read leaflets at a time and location that suits them and can make use of visual representations of an idea which may be difficult to explain verbally. Students and educators may decide to use leaflets in a learning session as a prompt for discussion or teamwork. The disadvantages of leaflet include the fact that they may be easily lost or damaged and the fact that an educator is not necessarily on hand to provide further explanation if needed. In addition, the leaflet could be recycled.

Despite the limitations of the leaflet format, presenting the topic in this format has numerous advantages described above, and helps overcome the limited availability of chemistry textbooks in some locations. It was therefore decided that a leaflet would be developed as a teaching and learning resource (TLR) focused on the concepts of electronegativity, bond types and polarity as well as the relationships between these concepts.

5.2 The development of the leaflet of electronegativity

The development process of the LoEN consisted of two stages: design and development as presented in Figure 5.1. The first stage (design) covered the determination of topics/concepts to be presented in the TLR and the format of the TLR. Both of these decisions were informed by reviewing the literatures. The review started by identifying the relevant studies reported in published papers to find students' common misconceptions in core chemical concepts. The review process was conducted by considering multiple sources (online and printed papers). Finding the relevant papers through online searches was done by inserting the relevant keywords such as misconceptions or alternative conceptions in chemistry, how to overcome the misconceptions, the role of representations, *etc*. Meanwhile, the sources for printed papers were found in the library of University of Leicester. Then, the evidence (the findings) from these papers was summarised and the topics and the format of the TLRs selected. Once the topic had been selected, the next step was to determine the format of TLR, which is leaflet in this case.

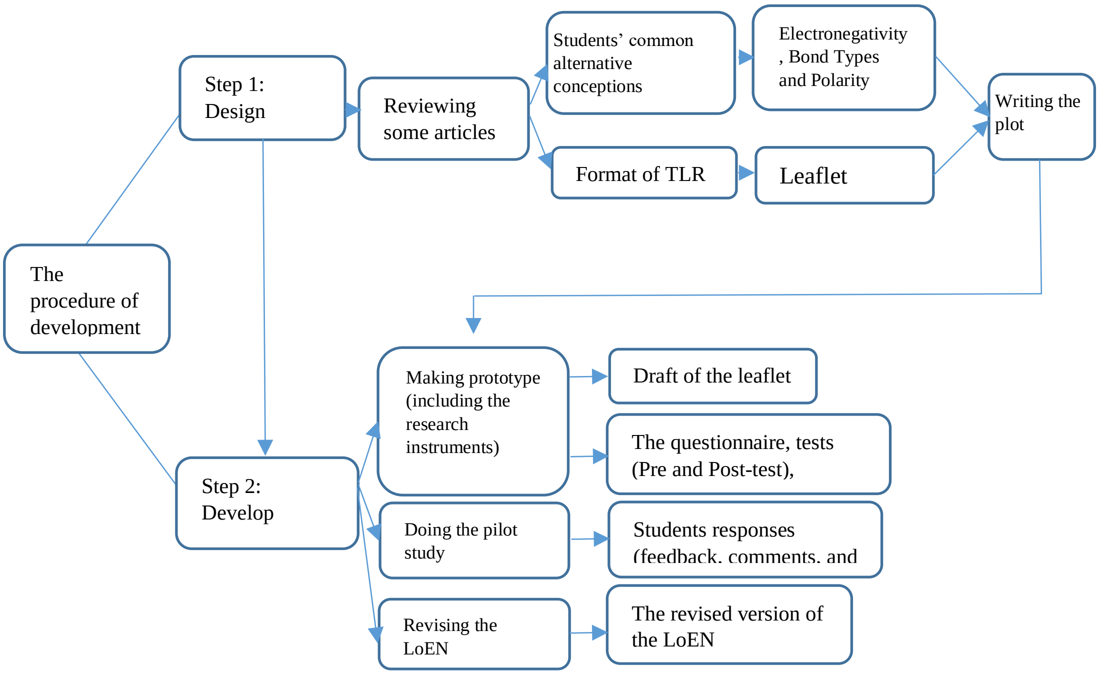


Figure 5. 1 The procedures of the development process of the LoEN.

The figure provides an overview of the whole development process of the LoEN that consists of two stages, design and develop.

The developing process consisted of four stages. The process begins with making a prototype of the leaflet. Compiling the content in term of concepts presented in the leaflet is the initial step of drafting process. The next stage was to arrange the appearance of the leaflet, decide which colour scheme to be used and what diagrams, figures and tables needed to be included to support the learning process.

The software used for designing the LoEN is Microsoft Word 2013. As the LoEN did not require any complicated template or diagrams, a word processing software package like Microsoft Word was the most suitable option. The 'Review' feature on Microsoft Word 2013 allowed supervisors to give feedback, comments or suggestions on the draft of LoEN. Microsoft Word allowed images to be presented in high resolution. To 'lock' the final position of the diagram and figures, the final version of the LoEN was converted to pdf format.

The appearance of the developed LoEN is shown in Figure 5.2. The cover of the LoEN shows the title and the logos of the institutions involved in its development and use. The next pages provide an explanation of the concepts of electronegativity, bond character, bond type, polarity and the key conclusions. The full LoEN can be seen in the appendix 2.

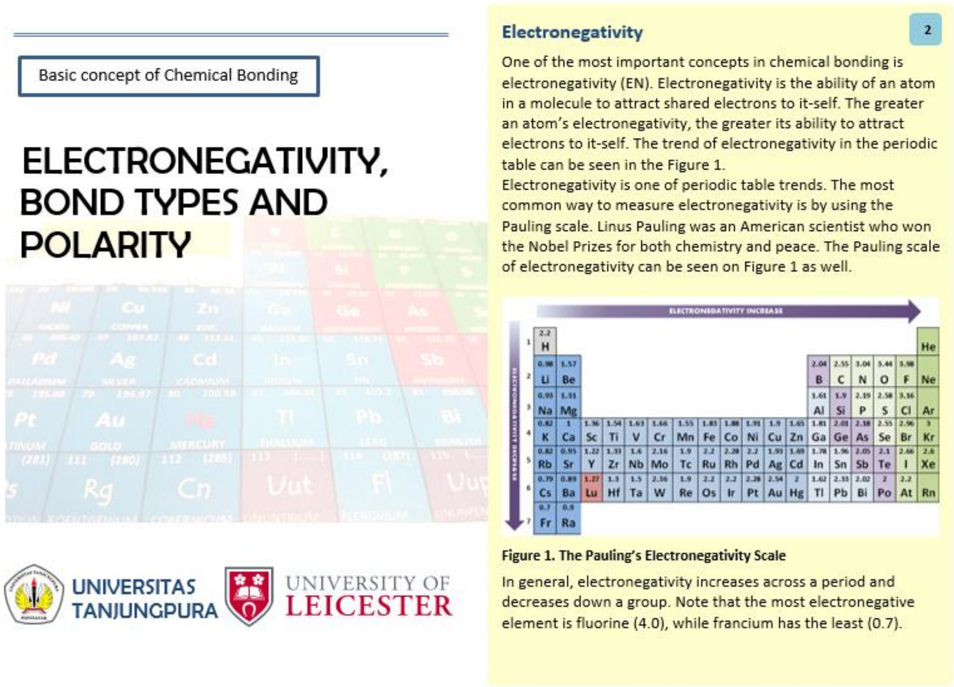


Figure 5. 2 The Appearance of the LoEN.

The figure shows the appearance of the LoEN by presenting the Cover and the First page as an example.

The LoEN was produced in full colour and the information was presented in a simple, easy to follow format, tables and diagrams (examples are shown in Figures 5.3 and 5.4) were used to explain the topics clearly and reduce the number of words needed. The LoEN was printed in A4 paper in 2 columns and then folded into four parts. The LoEN consists of three sections, which are the cover, explanations of the sub-topics and a summary.

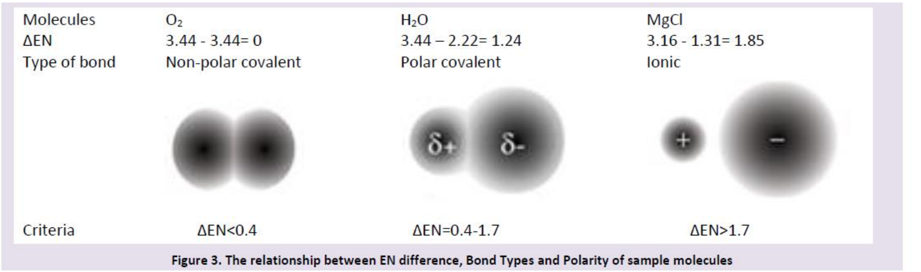


Figure 5. 3. Sample of the images presented in the LoEN.

The figure describes the relationship between the Electronegativity (EN) difference with bond types and polarity of sample molecules.

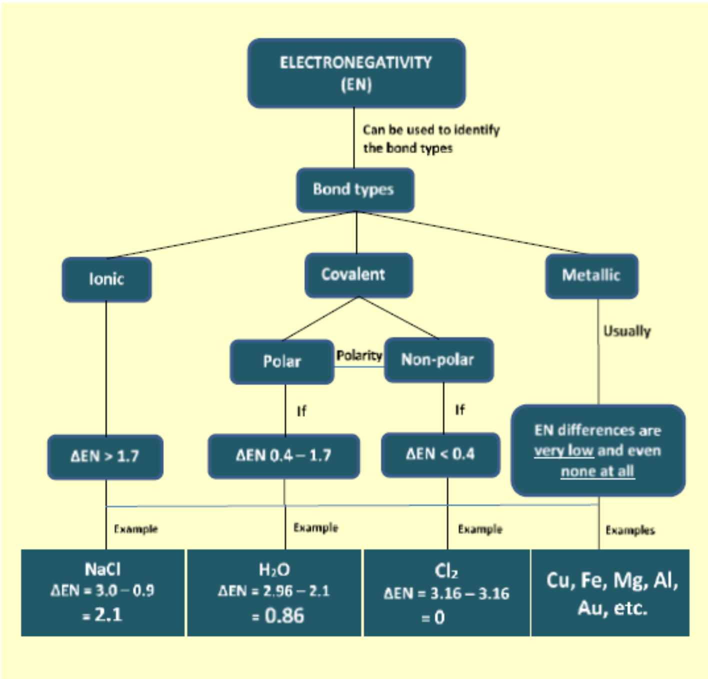


Figure 5. 4 Diagram presented in the LoEN.

This diagram was used to summarise the concepts discussed in the LoEN. The diagram shows the relationship between EN, bond types and polarity.

The first section is the cover that consists of the title of the leaflet. The second section is the explanation. The explanation begins with the definition of electronegativity and is supported with a diagram illustrating the trend in electronegativity of elements in the periodic table (figure 5.2). The explanation then continues by describing the bond character, followed by the relationship between electronegativity difference, and bond character is then presented in a table. The next section is the description about bond types. Two ways to identify the bond types are explained in this section, which are identifying the type of elements involved in a compound and using the electronegativity difference. The first is the common way taught by teachers to identify the bond type, while the second is less common in Indonesia. Then, a definition and explanation of the polarity of diatomic molecules is presented. These explanations also covered the relation of bond character, electronegativity and polarity. An image was included to illustrate the relationship (see Figure 5.3). The LoEN closes with a summary which was presented in the form of a scheme of the relationship between electronegativity, bond types and polarity. The scheme also presents an example of molecule for each bond type, included to facilitate students' understanding of the concepts (see Figure 5.4).

The second stage of the process was development of the research instruments which consisted of a questionnaire, conceptual tests (pre and post) and an interview guide. A pilot study for testing the LoEN was run before it was revised the LoEN based on students' comments, suggestion and feedback from the pilot.

5.3 The context of pilot study of LoEN

A pilot study was conducted prior to the implementation of LoEN in the General Chemistry 2 classroom. The aim of this study was to evaluate the feasibility, amount of time spent on the task and the quality of the presentation of the leaflet prior to the first and second cycles of research. 20 first year cohort students of the Chemistry Education study programme of the Department of Mathematics and Science Education at the University of Tanjungpura voluntarily participated in the pilot study during the 2015/2016 term. The pilot study took place in the second semester of their first year. The LoEN used in the pilot study was translated into the Indonesian Language to allow students to understand the concepts presented.

5.3.1 Methods

At the start of the session, the process and procedures of the pilot study were explained to all participants. As the LoEN was designed to be used individually, each student was given a copy of the LoEN. All students were given 15 minutes to read the LoEN and then to discuss the topic with the student sat next to them. The participants were told that they could ask questions related to the topic to the lecturer if they did not understand anything on the LoEN (se later on Table 5.5). After that, a feedback questionnaire was given to all of the participants. The questionnaire consisted of two sections. The statements and questions from both sections of the questionnaire can be seen in Table 5.1.

Table 5. 1 Statements and questions presented in the first and second section of the questionnaire.

No	Statements and questions	
	Section 1 (Likert Scale)	**Section 2 (Open-ended questions)**
1	Contents of the leaflet are clear and understandable	Which parts of the leaflet were most useful?
2	Learning with leaflet help me understand the topic	Which parts of the leaflet were less useful?
3	I know how to predict the bond types and polarity through concept presented in leaflet	What changes would you like us to make to the leaflet?
4	Concepts presented in leaflet are complete	
5	I enjoyed learning with the leaflet	
6	The presentation of the leaflet is interesting	
7	Learning with the leaflet is effective	
8	Leaflet is easy to use and practical	

The table shows the 8 statements on the first section of the questionnaire and the 3 questions in the second section.

The first section was based on eight closed-questions to collect student's opinions about the content and the appearance of LoEN. All questions were based on the agreement with the statements using Likert scale. The second section of the questionnaire consisted of three open-ended questions asking the participants to state their opinions in their own words. The entire session took 40 minutes to complete. The procedure of the pilot study is summarised as follows:

1. Students were instructed to start reading the LoEN and discuss the topic with a friend sat next to them.
2. Students' activities and interactions during the activity were observed and documented by taking the notes.

3. The evaluation questionnaire was distributed to all students.
4. All evaluation data were analysed.
5. Revisions were made to the LoEN activities based on reflection on the observed process and analysis of the evaluation responses.

The researcher also observed students' interactions during the implementation. All data collected from the questionnaires and observations were analysed by quantifying and classifying participant attitudes towards the activity. The findings from the pilot study were used to revise the activity (see discussion in section 5.3.3).

5.3.2 Result of the pilot study

Data collected from both sections of the questionnaire were analysed and presented in graph and table. Students' responses to the first section of the questionnaire is presented in Figure 5.5. Meanwhile, student opinion, comments and suggestions collected in the second section of the questionnaire is depicted in Table 5.2.

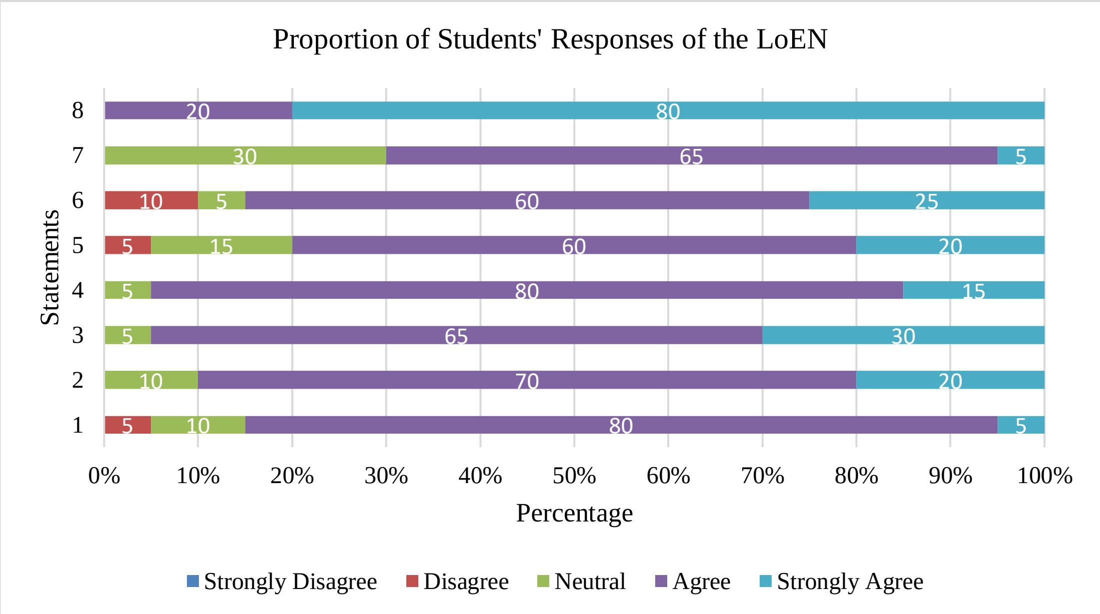


Figure 5. 5 Students' Responses of the LoEN on the first section of the questionnaire (N=20).

The figure describes the proportion of students' responses of the LoEN on the first section of the feedback questionnaire given in the pilot study that consist of 8 statements with 5 options of agreement based on Likert scale (refer to Table 5.1).

Based on the chart, 85% of students agreed that the contents presented clearly in the LoEN. 90% of students agreed that the LoEN helped them understand the topic. Interestingly, 95% of students noted that the contents presented in the LoEN were complete and reading the LoEN help them understand how to predict bond type and polarity. 80% of students were enjoying learning with the LoEN. Details of each percentage can be seen in Table 5.2.

Even though 10% of students disagreed that the presentation of LoEN was interesting, the majority of them (85%) agreed with the statement. Only 70% of them agreed and strongly agreed with the notion of the effectivity of learning with the LoEN on the seventh item, while the rest had chosen neutral to describe their views. Interestingly, 100% of students either agreed or strongly agreed for the last item, which is the use and practicality of the LoEN.

Table 5. 2 Students' responses to the statements in section one of the questionnaire (N=20).

Statements on the first section of the questionnaire	Percentage (%)				
	SD	D	N	A	SA
Contents of the leaflet are clear and understandable	-	5	10	80	5
Learning with leaflet help me understand the topic	-	-	10	70	20
I know how to predict the bond types and polarity through concept presented in leaflet	-	-	5	65	30
Concepts presented in leaflet are complete	-	-	5	80	15
I enjoyed learning with the leaflet	-	5	15	60	20
The presentation of the leaflet is interesting	-	10	5	60	25
Learning with the leaflet is effective	-	-	30	65	5
Leaflet is easy to use and practical	-	-	-	20	80

The table shows the percentage of students' responses to the 8 statements in the first section of the questionnaire given in the pilot study.

The three open-ended questions in section two are presented in Table 5.3. The first question asked about the most useful part of the LoEN. Student's comments and suggestions related to this question related to four different parts of the LoEN. 5% of students stated that table, graph, and pictures presented in the LoEN are the most useful part. Meanwhile, the figure of Bond Triangle, diagram of conclusions and the whole part of LoEN were noted as the most useful part with 20%, 15% and 60% respectively of students stated the answer.

Table 5. 3 A summary of students' comments and suggestions related to the LoEN (N=20).

Questions	Comments/suggestions	Percentage (%)
Which part of the LoEN that is most useful?	Table, graph and pictures presented in the leaflet	5
	Figure of Bond Triangle	20
	Conclusions	15
	The whole part of leaflet	60
Which part of the LoEN that is less useful	The picture of bond triangle	20
	None	80
What changes do you want to make related to the LoEN?	Adding page number	10
	Reducing the sentences	30
	How the leaflet fold	10
	The clarity of the picture of bond triangle	30
	None	20

Data presented in the Table is the summary of students' comments and suggestions with the percentage in the second section of the questionnaire that consists of 3 open-ended questions.

The second question of section two asked about the less useful parts of the LoEN, with 20% of them noting the diagram of Bond Triangle which was probably due to the clarity of the figure presented. The rest of them (80%) said that there is no less useful parts in the LoEN which meant that all parts of the LoEN are found useful. The last question asking about the changes that they suggested could be made to the LoEN. 10% of them suggested that adding the page number and changing the way the LoEN is folded. They mentioned that the image of bond triangle in the LoEN was unclear. 30% students would like to reduce the quantity of text presented in the LoEN, as it was too much. 30% students noted that the diagram of Bond Triangle was not clear enough, so putting a clear diagram would be an advantage to support their understanding. The last 20% of them said that no changes need to be made to the LoEN as they said that the appearance and the content of the LoEN has been interesting enough to them.

5.3.3 Reflection on the pilot study

The feedback collected through the questionnaire in both sections during the pilot study was used to revise the LoEN. The summary of the changes and the rationale based on the findings of the second section of the questionnaire is presented in Table 5.4. All of these changes were considered in the revision process.

Table 5. 4 A summary of changes made based on findings on the pilot study (N=20).

Findings	Changes	Rationale
The order of the leaflet is a bit confusing perhaps adding the page number will help	Adding page number to describe the order of the content of the LoEN	By adding the page number students will be easier to read the leaflet
The amount of words presented in the leaflet is too high	Reducing the amount of words presented in the leaflet by rewording, condensed and combined the explanation	Students' interest to read the leaflet may decrease due to much text and leaflet is aimed to present the concepts as simple as possible in an engaging way.
The way leaflet is fold is a bit odd	No change has been made	No change has been made to the way leaflet is folded as page numbers already added to the leaflet.
The figure of Bond Triangle is hard to read	Putting the new figure of bond triangle which is clearer	The bond triangle figure is important to the illustrate bond type. Clearer diagram will help students understand the topic.

The table summarises the changes made based on students' comments and suggestions and the rationale of why the changes have been made.

Four findings based on students' suggestions and comments were found in the pilot study as described in Table 5.4. The first was that the order of the leaflet was confusing for some students, therefore they suggested to add page numbers to the leaflet as this would help them to read the leaflet in order. The second suggestion was the large amount of text presented in the LoEN. As it potentially decreases students' motivation to read the LoEN, changes were made to reduce the amount of the text.

The third comment regarded how the LoEN was folded; some of them stated that the way the LoEN was folded was a bit strange because they could not differentiate the order of the topics presented. No changes were made as this issue had been solved by adding the page numbering. The last comment was that the figure of the bond triangle was not clear enough to read. As the diagram is important to support student understanding of bond type, a clearer diagram has been put in to replace the original one.

Table 5. 5 A summary of the observer's notes during the learning activity with the LoEN.

Researcher's note on students' activity	
Before doing the activity:	
- A brief explanation about this study were explained to all students. - Administer the pre-test. - A leaflet was distributed to each student.	- Students listened to the explanation. - Students were doing the pre-test. - Students were taking the LoEN.
During the activity:	
- Students instructed to start reading the LoEN for 10 minutes. - For the next 10 minutes, students were instructed to discuss the topics presented in the LoEN with a friend next to them or asking the questions to the lecturer. - Lecturer gives the explanation related to the topic.	- They started to read the LoEN. They seem enthusiastic reading the LoEN. They were impressed with the appearance of the LoEN as some of them stated that "the leaflet is interesting and simple". - Then, they begin to discuss the topics presented in the LoEN with a friend next to them. Students also asked some questions about the topic to the lecturer. - Listening to the explanation, asking the questions, such as "Is it true that covalent bonding molecules still have the ionic character?" or "what is the relationship between EN and polarity?".
After doing the activity:	

A feedback questionnaire was distributed to all students	They answered all the questions and giving a feedback related to the LoEN.
Conclusion: Overall, they enjoy the process of reading and discussing the topic presented in the LoEN. However, the discussion was not run as expected as most of them seemed confused what they are going to discuss with their friend. They prefer asking the questions to the lecturer in the discussion. This issue leaded the researcher to add the worksheet consist of list of questions to guide the discussion section that implemented in the first cycle.	

The table describes the researcher's observation notes during the implementation process of the LoEN in the pilot study.

The first section of the questionnaire showed that a large number of students have a positive response of the LoEN. The vast majority of them agreed that the LoEN could support their learning for the addressed concepts. Moreover, three changes based on findings on the second section were addressed. The revised version of the LoEN was then used in the General Chemistry 2 classroom in Indonesia as part of the further evaluation process.

Another change that was made was adding the worksheet comprising of questions to guide students in the discussion section. This change was made based on the findings of the observer's notes on student interactions in the pilot implementation. The summary of the observation record can be seen in Table 5.5.

The changes that have been made based on students' feedback in the pilot study had an impact on students' responses in the questionnaire in later cycles. The average percentage of students who agreed to all the statements in the questionnaire (Table 5.1) was 87% and 86% respectively. In addition, in the pilot study 80% of them suggested various changes (Table 5.3), whereas only 18.2% students in the next cycle suggested further changes and these only related to the colour and the appearance of the cover of the LoEN. The fact that only 6 students (N=33) suggested further changes to those identified in pilot study showed that majority of students were pleased with the changes that had been made.

5.4 Evaluating the LoEN: First Cycle

As described in Chapter 3, action research was employed to develop the TLR. The action research is consisted of 4 stages as one cycle, which are plan (design), act (develop), observe (evaluation), and reflection (reflect). Details of each explanation can be found in Chapter 3, Research Methodology. To confirm the consistency of the results in the first cycle, the action research obliges the researcher to do the study in two cycles. LoEN was trialed as part of the evaluation process. The evaluation of the LoEN was managed in the Department of Chemistry Education, Faculty of Teacher Training and Education, University of Tanjungpura, Pontianak, Indonesia. The LoEN was used as part of General Chemistry course.

5.4.1 The context of the first cycle research

Cycle 1 was conducted between May and June 2016. Participants involved in the first cycle were students who studied General Chemistry 1 in term 2015/2016. At this point of their education students were studying General Chemistry 1 module but had not studied this topic (electronegativity, bond type and polarity) covered in this study. The LoEN was implemented as an integral part of teaching in the module.

5.4.2 Methods

Participants

The study involved 33 first-year students of the Chemistry Education Study Programme in the Department of Mathematics and Science Education, Faculty of Teacher Training and Education, University of Tanjungpura, Pontianak, Indonesia. All students involved in the evaluation of the TLR took the questionnaire and both tests (pre-test and post-test). 13 of students were also willing to participate in the interviews. Therefore, data for quantitative analysis were based on 33 students. However, the findings of qualitative analysis (interview and students' answer of both tests) presented in the evaluation were based on 13 of these students.

Procedures of the evaluation in the first cycle

Before the implementation, the pre-test was administered to all students to collect the information of students' prior understanding of electronegativity, bond type and polarity. The pre-test consisted of three questions that allowed students to determine the bond type and polarity of given molecules using Pauling scale. The duration of the pre-test was 15 minutes. After the pre-test, the LoEN was given to each student. They had 10 minutes to read the LoEN and 5-10 minutes to discuss the topic with friend/s who sat next to them. In the next 10 minutes the lecturer explained the topic to all students. They had the opportunity to ask some questions of the lecturer related to the concepts. At the end of the process students were given a questionnaire which was similar to the one in the pilot study to gather their perceptions, comments and suggestions related to the LoEN. A post-test was scheduled two weeks after the implementation due to students having another class and laboratory work for the following few days. Step by step of the procedure is illustrated in Figure 5.6.

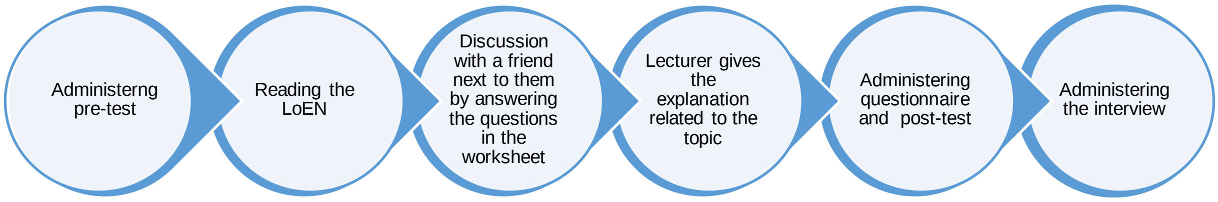


Figure 5. 6 The procedures of the implementation of the LoEN.

The figure illustrated the 6 steps of the procedures when implementing the LoEN in the classroom in the first cycle of the evaluation.

In the meantime, individual interviews were scheduled. The interviews scheduled were adjusted to students' free time. The interviews took 25-35 minutes from start to finish. 13 of students were willing to be interviewed voluntarily. The appointment for the interview agreed with each student. Thus, the individual interviews took 2 weeks to complete. Data from the pre-tests and post-tests from the 13 students who were interviewed was then linked to the data from the interview. The research timeline activity presented in Table 5.6.

Table 5. 6 Timescale of Research Activity of the LoEN in the First Cycle

Activity	May				June				
	1	2	3	4	1	2	3	4	5
Preparation: The LoEN and the worksheet, pre- and post-test									
Pre-test									
Learning with the LoEN									
Post-test									
Post-intervention interview									

The timescale scheduled on weekly basis

5.4.3 Findings of the First Cycle:

Students' Conceptual Understanding of Electronegativity, Bond Type and Polarity

The pre-test and the post-test consist of two questions. Both tests comprised similar questions. All the questions are of the open-ended type. The score from both pre-test and post-test were marked and compiled to analyse students' understanding of the concepts. Excel and SPSS Statistics version 24 were used to analyse test results. A graph of all students' pre and post-test results is shown in Figure 5.7.

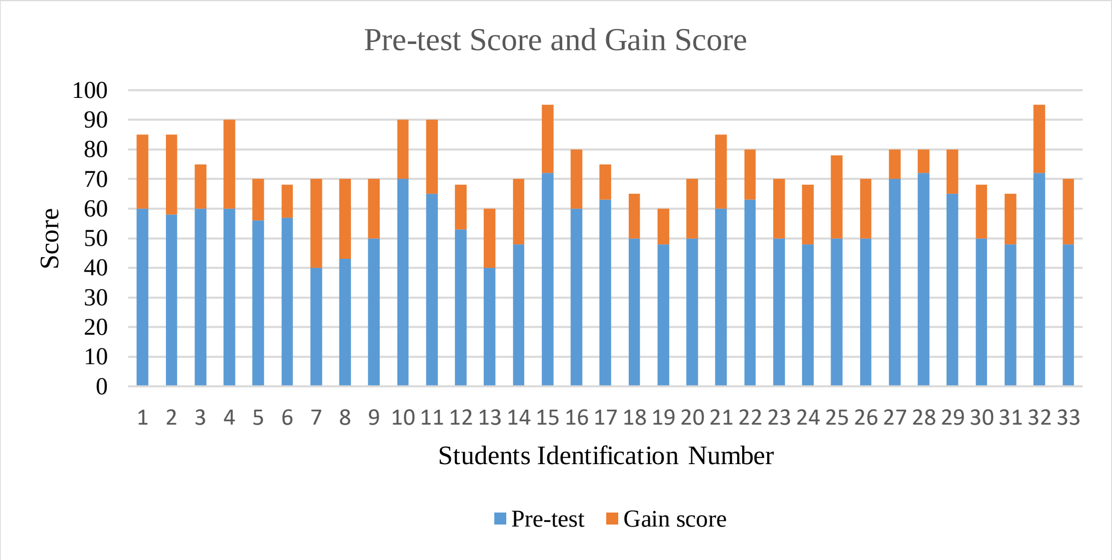


Figure 5. 7 Students' pre-test and gain score (N=33).

The figure shows the increasing score of pre-test and post-test with the maximum score=100.

Figure 5.7 shows that there has been a steady increase in the post-test score for all students compared to the pre-test. The average score for pre-test is 56.03 while the score for post-test is 75.61. The highest score for pre-test is 72 while the highest score for post-test is 95. By comparison, the lowest score for both tests are 40 and 60 respectively. The most striking observation based on these data is that 2 out of 33 students got almost full marks in the post-test at 95.

Students' score in pre-test and post-test were classified into 6 different categories as shown in Table 5.7. What stands out in this table is that no student either got a score below 59 in the post-test. In contrast, 24.2% and 33.3% of students got score below 49 and between 50-59 for the pre-test. In the third category, that is range score between 60-69, 27.3% and 24.2% of students were in this category for pre-test and post-test respectively. For the fourth category, 15.2% of students in pre-test and 36.4% post-test got the score between 70-79. Interestingly, for the last two categories, no student got score above 80 for the pre-test. On the contrary, 24.2% and 15.2% of them got the scores between those ranges. The better score for post-test indicated that the LoEN helped them understand the topic. However, these findings were further analysed by comparing qualitative analysis for each question to the interview data to get a final conclusion.

Table 5. 7 Pre-test and Post-test Range Scores.

Score range	% Pre-test	% Post-test
<49	24.2	0
50-59	33.3	0
60-69	27.3	24.2
70-79	15.2	36.4
80-89	0	24.2
90-100	0	15.2

The table depicts the 6 ranges of students' pre-test and post-test score.

The score of both tests were analysed using *a paired sample t-test* in IBM SPSS Statistics 24 to compare the pre-test and post-test scores. A *paired sample t-test* was used as data of students' pre-test and post-test scores in the same cycle were related since the students involved are the same. As suggested by Bryman and Cramer (2009) the related or *paired sample t-test* can be used to compare the means of the same participants in two conditions or at two points. The summary of the results is presented on Table 5.8. As can be seen, the result was that the difference was statistically significant between pre-test and post-test scores with *p value* < 0.001. This result is consistent with the findings based on the analysis using Excel which showed that all the scores increase following the activity. Both findings indicated that the LoEN had helped students understand the topic.

Table 5. 8 The result of Paired-sample t-test

Tests	**Mean**	***N***	**SD**	***t Value***		***p Value***
Pre-test	56.03	33	9.299	-19.465	19.576	.000
Post-test	75.61	33	9.630			

The table shows the result of *paired-sample t-test* of students' pre-test and post-test scores.

Students who provided the incorrect answer did not show an understanding of how to use the electronegativity values presented in the question (Table 5.9). Students who gave the incorrect answer to the question were guessing or using the type of the elements involved (metallic or non-metallic) to differentiate the polarity. Among 13 students whose answers on both tests were analysed and who were involved in the interview, only 1 of them used the electronegativity values to answer the first questions. Meanwhile, the rest of them used the type of elements and the bond type (covalent, ionic or metallic) to answer the question. Samples of students' answers can be seen on in both tables 5.9 and 5.10.

Sample of students' answer for the pre-test in Table 5.10 comprises of 2 types which are correct and incorrect. The first category for the pre-test is the correct answer, but students still use the type of the elements (metallic and non-metallic element) to identify the bond type. This is the general way to identify the bond type. The explanation of this concept can also be found in most of the chemistry textbooks. Thus, students are accustomed to use this technique. Interestingly students who answer incorrectly using the electron configuration to predict the bond type.

Based on data shown in Table 5.10, both students who answered correctly and incorrectly were not showing an understanding of or did not know how to use the electronegativity values to answer the question. By comparison, students' sample answers on the post-test indicated that they now have showed an understanding of how to use the electronegativity values to identify the bond type.

Table 5. 9 Examples of students' answers to the first question of the pre-test and post-test

Question 1: Rank the following bonds in order of increasing polarity based on the Pauling scale of electronegativity given in the Table.

a. Na-Cl d. H-F
b. Li-H e. Rb-O
c. H-C f. H-Cl

Elements	**Electronegativity values based on Pauling scale**	**Elements**	**Electronegativity values based on Pauling scale**
Na	0.9	H	2.1
Cl	3.0	F	4.0
Li	1.0	Rb	0.8
C	2.5	O	3.5

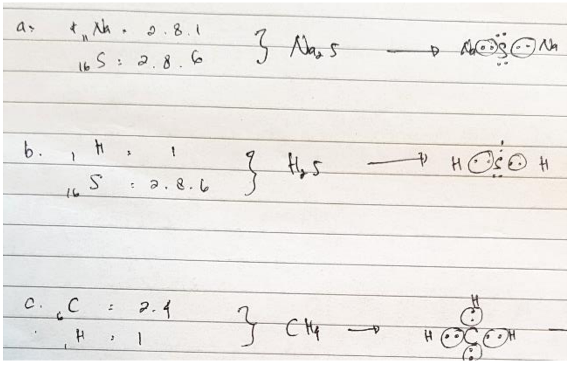
Please order by referring to no 1= the least polar and no 6= the most polar

Pre-test	**Post-test**
Incorrect answer, as they did not use the electronegativity values to identify the bond type as they just guessing to answer the question. **Sample of students'** urutan dari paling polar ke paling tidak polar. Li-H ; Na-Cl ; Rb-O ; H-C ; H-Cl ; H-F	***The correct answer***, already used the electronegativity values to answer the question **Sample of answer:** 1. e. Rb-O = 3,5 - 0,8 = 2,7 2. a Na-Cl = 3,0 - 0,9 = 2,1 3. d H-F = 4,0 - 2,1 = 1,9 4. b Li-H = 2,1 - 1,0 = 1,1 5. f. H-Cl = 3,0 - 2,1 = 0,9 6. c. H-C = 2,5 - 2,1 = 0,4.
Did not answer	***Incorrect answer,*** even though they already use the electronegativity values Miscalculated the ΔEN. **Sample of answer:** a. Na-Cl (2,1) d. H-F (2,9) b. Li-HC (1,1) e. Rb-O (2,7) c. H-C (0,4) f. H-Cl (0,9)

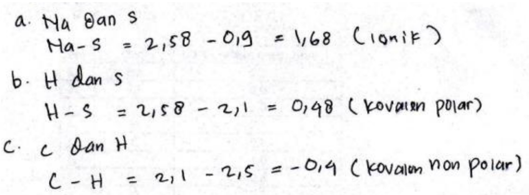
	1. d) H-F 2. e) Rb-O 3. a) Na-Cl 4. b) Li-H 5. f) H-Cl 6. c) H-C

Table 5. 10 Category of student's answer of the second question of the pre-test and post-test

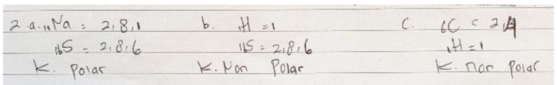
<table>
<tr><td colspan="2">Question 2: Predict the type of bond that will form between the following pair of atoms:
a. Na and S
b. H and S
c. C and H</td></tr>
<tr><th>Pre-test</th><th>Post-test</th></tr>
<tr><td>Correct answer, using the electron configuration and draw the Lewis structure to identify the bond type

Sample of student's answer:


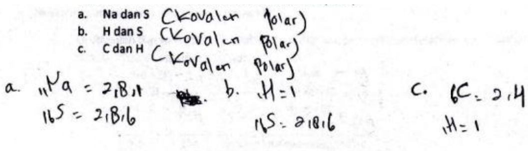
S/he mentioned that:
Na_2S is ionic bonding (she drew the wrong Lewis structure)
H_2S is polar covalent
CH_4 is non-polar covalent</td>
<td>Correct answer, already used the electronegativity values to determine the bond type

Sample of student's answer:


S/he mentioned that:
Na_2S is ionic bonding (she drew the wrong Lewis structure)
H_2S is polar covalent
CH_4 is non-polar covalent</td></tr>
<tr><td>Incorrect answer, using electron configuration to answer the question

Sample of student's answer:


</td>
<td>Incorrect answer, using electron configuration to answer the question

Sample of student's answer:


</td></tr>
</table>

Students' answers on the pre-test suggested that they do not know how to use the ΔEN to identify the bond type. This finding similar to those reported by Ardiansah, *et al*., (2014; 2018). In 2014, he reported that 10 chemistry teachers (out of 10) in Bengkayang District, Pontianak Indonesia did not used the ΔEN to identify the bond type. All of them either using the type of the element (metallic and non-metallic) or the concept that cation and anion will form ionic bonding. Moreover, in 2018, he also reported that 40% (out of 75 students) of college students (age above 17 years) were experiencing the same situation.

The trend of students' answers on the post-test was different. After learning with the leaflet, students' understanding was improved. 10 out of 13 students used the ΔEN to identify the bond type as shown in Table 5.9. Based on these findings, it can be concluded that student's understanding had changed after reading the leaflet. Even though, the leaflet used in this study cannot be categorised as an advanced TLR, the findings signified that the LoEN could support students learning about electronegativity, bond type and polarity. Samples of students' answer in both tests can be found in Appendix 6.

Students' Perceptions and Responses of the LoEN

The results presented in this section were based on the data from feedback questionnaires and interviews. Students' perceptions and responses of the LoEN were presented graphically and tabular form. The graph (Figure 5.8) describes students' responses for the first section of the questionnaire, while the table (Table 5.11) shows students comments and suggestions on the second section of the questionnaire.

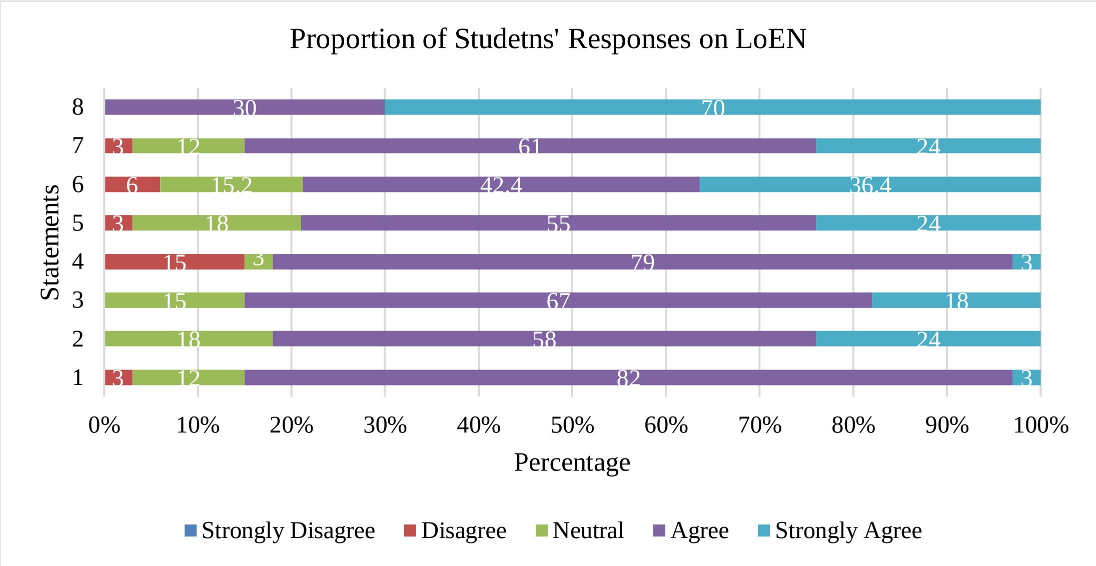


Figure 5. 8 Students' responses of the LoEN on the first section of the questionnaire (N=33).

The figure describes the proportion of students' responses of the LoEN on the first section of the feedback questionnaire given in the implementation of the first cycle which consist of 8 statements with 5 options of agreement based on Likert scale (refer to Table 5.11).

Figure 5.8 displays 8 statements (see Table 5.1) used in the first section of the questionnaire. What can be clearly seen on this Figure is that 100% of students agree with the last statement related to the use and practicality of the LoEN. The clarity of the contents was noted by students with 85% of them agreed with the statement while the rest picked neutral and disagree to describe their feeling. 82% of students agreed that the LoEN could helped them understand the topic and 85% of them believe that reading the LoEN support their understanding on predicting the bond types and polarity of the molecule. 82% of students agreed that the concepts presented in the LoEN is complete. For statement no 5 and 6, which are on enjoyment of learning with the LoEN and the presentation of the LoEN, 79% of students are in agreement. The notion of the effectivity of the LoEN as a learning resource was positively responded to by students with 85% of them in agreement with the statement. The percentage of students' responses for each statement presented in Table 5.11.

Table 5. 11 The percentage of students' responses to statements of the first section of the questionnaire in the first cycle (N=33).

No	Statements on the first section of the questionnaire	Percentage (%)				
		SD	D	N	A	SA
1	Contents of the leaflet are clear and understandable	-	3	12	82	3
2	Learning with leaflet help me understand the topic	-	-	18	58	24
3	I know how to predict the bond types and polarity through concept presented in leaflet	-	-	15	67	18
4	Concepts presented in leaflet are complete	-	15	3	79	3
5	I enjoyed learning with the leaflet	-	3	18	55	24
6	The presentation of the leaflet is interesting	-	6	15.2	42.4	36.4
7	Learning with the leaflet is effective	-	3	12	61	24
8	Leaflet is easy to use and practical	-	-	-	30	70

The table describes the percentage of students' responses to 8 statements in the first section of the questionnaire. SD=Strongly Disagree; D=Disagree; N=Neutral; A=Agree; SA=Strongly Agree.

Students' comments and suggestions on section 2 of the questionnaire are summarised in the Table 5.12. Section 2 of the questionnaire asked 3 open-ended questions. The first question is about the most useful parts of the LoEN. 27.3% responded that it was the table, graph, and pictures presented in the LoEN. Meanwhile, 12.1% of them noted that the conclusion was the most useful part in the LoEN. Interestingly, 60.6% of them stated that the whole of the LoEN was the most useful. The second question concerned the less useful part(s) of the LoEN. One hundred percent of the students agreed that there was no "less useful" part. This response indicated that the whole of the LoEN is useful. The last question asked about the changes that they would like to be made related to the LoEN, with 15.2% of students suggested to change the colour of the LoEN and 3% of them wanted to change the appearance of the cover. Meanwhile, the rest of the students (81.8%) agreed that there were no changes needing to be made. The responses to the last question supported the findings on the first and second questions.

Table 5. 12 The Summary of Students' comments and suggestions on Section 2 of the Questionnaire (N=33).

Questions	Comments/suggestions	Percentage
Which part of the LoEN that is most useful?	Table, graph and pictures presented in the leaflet	27.3
	Conclusions	12.1
	The whole part of leaflet	60.6
Which part of the LoEN that is less useful?	None	100
What changes do you want to make related to the LoEN?	Colour of the Leaflet	15.2
	The cover of the leaflet is not attractive enough	3
	None	81.8

Data presented in the Table is the summary of students' comments and suggestions with the percentage in the second section of the questionnaire that consists of 3 open-ended questions.

As part of the triangulation process to clarify the validity of the results based on the quantitative analysis (the chart and the SPSS analysis), students' answers on pre-test, post-test and interviews were then analysed qualitatively. The findings of the qualitative analysis were based on 13 students only, the students who voluntarily were involved in the interviews. The structure of the interview presented in Table 5.13. Both cycles use the similar interview structure.

Table 5. 13 The structure of the post-intervention interview

Themes	Key questions	Prompts	Duration
Personal data	How would you describe yourself?	• Name • Term/class • Place of origin • Previous high school	5-10 minutes
Learning style	How do you typically learn?	• Preferred learning style • Preferred learning resources	
Difficulties in learning chemistry	What obstacles do you facing in learning chemistry?	• Terminologies and concepts • Teaching methods • Learning resources • How to deal with the obstacles	

Contents	What concepts do you learn throughout chemistry course?	• Scope of content • Sequence of concepts • Expectations of learning chemistry • Different experiences with learning chemistry in high school	10 minutes
Responses	What types of learning resources do you use to support your learning of the subject	Type(s) of learning resources (textbook, internet/website, video, lecture's note, etc)	
Concepts	How would you describe your understanding about the electronegativity, bond type and polarity?	• Concept electronegativity, electronegativity difference based on Pauling Scale, bond type, bond character, polarity	20 minutes
	Based on your answer on the test what are the order of increasing polarity based on the Pauling scale of electronegativity given in the Table of the following molecules?	Student's understanding of the concept electronegativity, bond type, polarity	
Reason	Why you arranged those molecules like that?		
Response	In what ways the Leaflet of Electronegativity (LoEN) help you understand the concept of electronegativity, bond type and polarity?	• Which part of the LoEN is the most useful part? • Which part is less favourite?	
	What will you do to improve this LoEN to support you in learning concept of shape of molecule?	• Technical aspects • Content presentation	
	How the following task-activity help you to understand concept of electronegativity, bond type and polarity?	• Kind of difficulty in doing the activity	

The interview structure was used in both cycles.

Students' perceptions and views about the LoEN were also revealed in the interviews. The explanation of their understanding of this topic were also elucidated. The summary of students' interviews is presented in Table 5.14. As can be seen in the table, the vast majority of students stated that they never learnt this concept when they were in high school. They stated, "I have not learned this topic especially when I was in high school". Also "identifying the bond type using the electron difference also new for me". In addition to that, they stated that the explanation of this topic could not be found in their chemistry textbook, they mentioned in the interview as "I cannot find the explanation about this on the chemistry textbook". This finding is supported by Ardiansah (2018) as he explained, that students cannot determine the bond type using the electronegativity values as the chemistry textbook only discusses the determination of bond type using the type of the element. The explanation of this answer was also revealed in the interview, as all of the students stated that (for example) "my chemistry teacher never taught me about the concept of bond character and identify the bond type using the electronegativity values".

Moreover, students hold the notion that a covalent molecule will be purely covalent and an ionic molecule will be purely ionic. As they stated that "For all this time I thought that the covalent molecule will be pure covalent and ionic molecule also pure ionic". The lack of students' understanding of this concept was disclosed when students confessed that "the explanation of electronegativity only limited to the trends in the periodic table, such as electron affinity, ionisation energy and atomic radii" and "My teacher never explained the relationship of electronegativity to bond type and polarity". This kind of answer describes the reason why students cannot relate the concept of electronegativity to the concept of bond type and polarity as reported by Nicoll (2001). Furthermore, based on their answers it indicated that they don't understand the connection between the electronegativity and the concept of bond character. They have not even heard about the bond character at all until they read the LoEN; as they mentioned in the interview "I never heard about the bond character before". Also, since this topic is not explained in their chemistry textbook, they thought that a covalent molecule will be purely covalent and an ionic molecule will also be purely ionic, even though they know about the polarity as they mentioned in the interviews.

For the question asking about how the leaflet helped them understand the topic, there were 7 findings based on the student's interviews. Some of these findings also related to students' perceptions and responses to the topic presented in the LoEN and the appearance of the LoEN itself. All findings are presented in Table 5.14.

Table 5. 14 The summary of Student's perceptions, views and reason based on interviews.

Question: **Have you learned about the electronegativity, and its use to identify the bond type?**	***Question:*** **In what ways the LoEN helped you understand the concept of electronegativity, bond type and polarity?**	***Question:*** **What kind of TLR that your teacher used to teach chemistry in high school and in the university?**
Never learned the concepts before	Understand about the use of electronegativity values to determine the bond type	The chemistry textbook or/and the LKS
Cannot find the explanation of the topic in the textbook	The language use in the leaflet was easy to follow and understand	
Chemistry teacher never taught/explained about this topic	By presenting the topics in an interesting format which is a leaflet	
Never heard the term of bond character	Know about the bond character after reading the leaflet	
Only know to identify the bond type is by comparing the type of the element/atom that bonded in the molecules	By explaining the connection between the electronegativity, bond type, and polarity	The PowerPoint
The covalent molecule will be pure covalent and ionic molecule will be pure ionic	The figures, table and diagram presented in the leaflet were helped in delivering the concept	
The electronegativity topic only taught as one of the trends on the periodic table	Deliver other (chemistry) topics using the leaflet format	
The electronegativity only relates to polarity		

The table presents the summary of students' answer on the 3 questions of the interview to show students' perceptions, views and the reasons about the topic and the LoEN as the TLR.

Some of the student's response to this question by saying "after reading the leaflet I know about the term of bond character". Some other stated that "I think it's because the leaflet describes the connection between the electronegativity, bond character, and bond type as well as the polarity, which I never knew before". Meanwhile, another said that "the figures, tables and diagram presented helped in delivering the concept". These statements explicitly concur that the LoEN had an impact in improving student's understanding of this topic.

The appearance and the language used was also highlighted by some of them, for example, "in my opinion the leaflet is interesting, easy and practical. The language used make it easy to understand". Another said that "the leaflet describes the topic in quite interesting way as the leaflet is full colour and consist of figures, table and diagram not only text". These statements indicate that students have a positive response about the LoEN. This probably due to they haven't learned with any other TLR previously. As they stated that their teacher uses the chemistry textbook or the LKS (the concise version of the textbook with a brief explanation and emphasise on questions rather than the explanation itself and the presentation of the LKS is like a booklet and printed in black and white) as the main resource in the teaching and learning process. Only a few of them stated that sometimes their teacher used PowerPoint to teach. None of them stated other resources were used by the teacher in teaching.

5.4.4 Reflection of The First Cycle

Two small changes need to be addressed based on students' feedback on the second section of the questionnaire. Table 5.15 presents the summaries of changes made based on findings of the first cycle. Even though, the percentage of students who suggested the changes are only 15.2% and 3% respectively for both, but these changes were worth to be made since the changes could attract students to read the LoEN.

The first is changing the colour of the second page of the LoEN from a light yellow to a light purple to differentiate the first and the second page. The second is increasing the size of periodic table picture which used as background of the cover. By changing this the appearance of the cover, the readability of the LoEN will improve.

Table 5. 15 Summaries of Changes Made based on Findings of the First Cycle.

Findings	Changes	Rationale
The colour of the Leaflet is quite plain: initially the colour used as the background is light yellow	Adding a different colour to the second page of the LoEN, which is light purple	Changing the colour may attract students to read the LoEN and also to differentiate the first and second page
The cover of the leaflet is not attractive enough	Increasing the size of the periodic table picture on the cover	The previous cover is a bit plain, the colourful cover may increase the readability of the LoEN

The summaries of changes that had been made to the LoEN informed by students' comments and suggestion on the second section of the questionnaire.

Table 5. 16 A summary of the observation during the implementation of the LoEN in the first cycle

Researcher's note on students' activity	
Before doing the activity:	
- A brief explanation about this study were explained to all students. - Administer the pre-test. - A leaflet was distributed to each student.	- Students were listening to the explanation. - Students were doing the pre-test. - Students were taking the LoEN.
During the activity:	
- Students instructed to start reading the LoEN for 10 minutes. - For the next 10 minutes, students were instructed to discuss the topics presented in the LoEN with a friend next to them or asking the questions to the lecturer.	- Students were excited to see the leaflet for the first time. Some of them said that "it looks nice and simple" and "I like the colour of the leaflet". - They started to read the LoEN. They seem enthusiastic when reading the LoEN. - Then, they begin to discuss the topics presented in the LoEN with a friend next to them. Students also asked some questions about the topic to the lecturer. - Listening to the explanation, asking the questions, such as "why the

- Lecturer gives the explanation related to the topic.	covalent molecule still have the ionic character in it?”
After doing the activity:	
A feedback questionnaire was distributed to all students	They answered all the questions and giving a feedback related to the LoEN.
Conclusion: Overall, they enjoy the process of reading and discussing the topic presented in the LoEN. Adding the worksheet seemed to be effective as the discussion section was run as expected as most of them discussed with their friend by answering the questions on the worksheet. Students were actively participate in the activity. The discussion run smoothly.	

The table shows the researcher’s observation notes during the implementation of the LoEN in the classroom. The observation focused on students’ interaction during the activity.

The key observations made during this phase of the research are summarised in Table 5.16. Based on the observation’s note, it is noted that students shown a positive impression to see the LoEN for the first time. They said a positive comment to the appearance of the LoEN as “nice and simple” and “I like the colour of the leaflet”. Moreover, students’ interaction during the activity was improved compare to those on the pilot study. This might be due to the worksheet. Answering the questions on the worksheet seemed to be effective as students focus to have a discussion with their friend.

5.5 Evaluating LoEN: second cycle

The second cycle was intended to clarify the findings from those findings in the first cycle. The second cycle is managed after the reflection stage of the first cycle. The revised version of the LoEN is implemented in the teaching and learning process of General Chemistry 1 class.

5.5.1 The context of the second cycle

The second cycle was conducted in November - December 2016 in the Chemistry Education Study Programme, of the Department of Mathematics and Science Education, Faculty of Teacher Training and Education of University of

Tanjungpura, Pontianak, Indonesia. At this point of their education students were studying General Chemistry 1 module but had not studied this topic (electronegativity, bond type and polarity) covered in this part of this study. The LoEN was implemented as the integral parts of teaching in the module.

5.5.2 Methods

Participants

The study involved 82 first-year cohort undergraduate students of 3 classes term 2016/2017 of Chemistry Education Study Programme of Department of Mathematics and Science Education, Faculty of Teacher Training and Education, University of Tanjungpura, Pontianak, Indonesia. The first class is A1 consist of 31 students while the second class is A2 with 30 students and the last is A3 with 21 students. All students involved in the evaluation of the TLR and taken the questionnaire and both tests (pre-test and post-test). Among 82 students, 15 of them were willing to participate in the interview. Therefore, the findings of quantitative analysis presented in this study were based on 82 students. However, the findings of qualitative analysis (interview and students' answer of both tests) presented in the evaluation of the second cycle were based on 15 students.

Procedure of the second cycle

The revised version of the LoEN was used in the second cycle. Prior to the implementation, a brief description of the LoEN was explained to the lecturer who taught General Chemistry 1 in the 3 classes. The procedures of the implementation were the same to those first cycle. The session started by giving the LoEN to each student in the class. Then, they were given an opportunity to read the leaflet for 15 minutes. After they finished reading the LoEN, they discussed the topic with a friend next to him/her for 5-10 minutes. For the next 10-15 minutes the lecturer explained the topic to the class and they also had the opportunity to ask the lecturer if they had questions.

Table 5. 17 Timescale of Research Timeline of the LoEN in the Second Cycle

Activity	October								November								December							
	1		2		3		4		1		2		3		4		1		2		3		4	
Preparation: The LoEN and the worksheet, pre- and post-test					■																			
Pre-test						■																		
Learning with the SoMCards and MMB						■																		
Post-test																		■						
Post-intervention interview																				■	■			

The timescale scheduled on weekly basis.

The feedback questionnaire was then given to all students in the end of the activity. An interview was scheduled in the following days during students' free time. The interviews took 5 days to complete. 15 students volunteered to be involved and willing to be interviewed. A post-test was scheduled in the middle semester exam in the next month due to the lecturer wanting to use the result of the post-test as one of the exam scores. The research's timescale activity of the second cycle presented in Table 5.17.

5.5.3 Findings of the Second Cycle

Students' Conceptual Understanding of Electronegativity, Bond Types and Polarity

The results were analysed in the same way and supported those in the first cycle. Students' pre and gain score is described in the Figure 5.9. The graph shows that there has been a marked increase of students' pre-test and post-test score. Based on the graph, all students experienced an increasing score after the implementation of the LoEN. The maximum score for both tests is 100. The highest score for pre-test is 80, while for the post-test is 100. On the opposite, the lowest score for pre-test is 30, while for the post-test is 50. The average score for pre-test and post-test were 57.44 and 76.62 respectively. The score gain was 19.8. This result indicated that the LoEN helped students understand the topic.

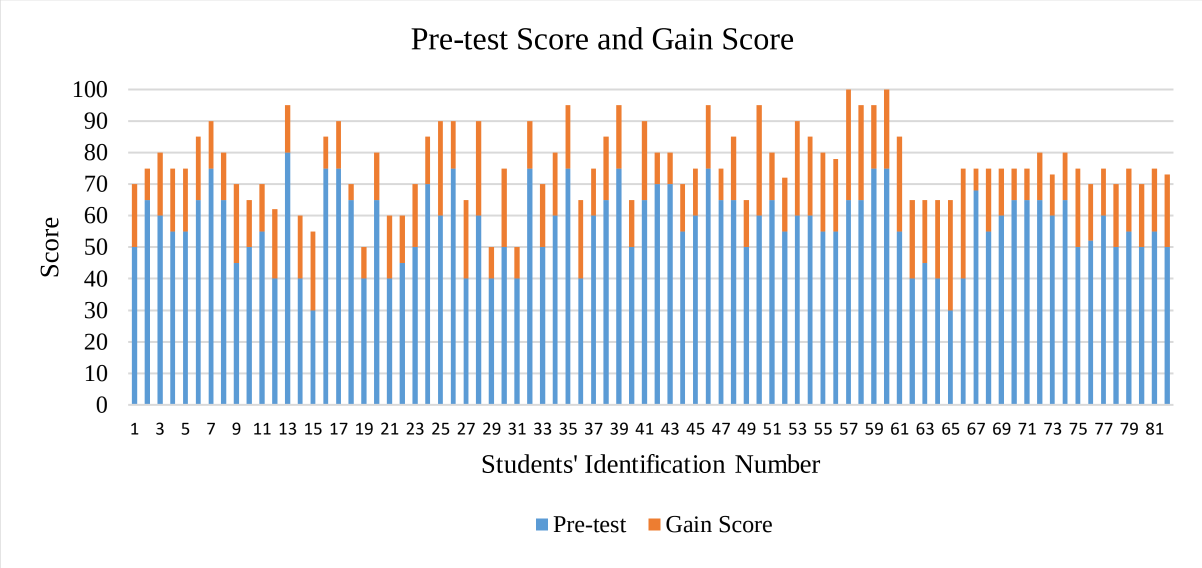


Figure 5. 9 Students' Pre-test and Gain Score (N=82).
The figure illustrates the pre-test and gain score experienced by students in the second cycle of research.

Table 5.18. shows a comparison of score range for pre-test and post-test. Both tests score was classified into 6 ranges. What is interesting in this Table is 19.5% of students got the score below 49 for the pre-test. 35.4% of students got score between 60-69 and only 1.2% of them got score between 80-89. Meanwhile, the rest of students got between 50-59 and 70-79.

On the contrary, for the post-test, only 4.9% of students got below 49. 19.5% of them got score between 80-89. It is also notable that 19.5 of them got score between 90-100. This result indicates that students' get a better score on the post-test compare to pre-test. The better post-test score implies that learning with the LoEN could improve students' understanding. This result reinforced the previous findings.

To support the findings, both scores were then analysed using IBM SPSS Statistics 24. The result presented in Table 5.19. With *p value* > 0.001, the result can be concluded as statistically significant for both tests. It means that the LoEN had impact to students' understanding of this topic.

Table 5. 18 The Range of Pre-test and Post-test Score

Score Range	% Pre-test	% Post-test
<49	19.5	4.9
50-59	28	6.1
60-69	35.4	25.6
70-79	15.9	24.4
80-89	1.2	19.5
90-100	0	19.5

The table shows the ranges of the scores for both tests. The ranges are used to classify students' scores on pre-test and post-test. The classification is aimed to emphasise the findings presented in Figure 5.9.

Table 5. 19 The Result of Paired-Sample t-test

Tests	Mean	*N*	SD	*t Value*	*Gain*	*p Value*
Pre-test	57.44	82	11.754	-25.883	19.183	.000
Post-test	76.62	82	11.589			

This table shows the findings based on quantitative analysis of pre-test and post-test scores to measure the effectivity of the LoEN.

Students' Perception and responses of LoEN

Findings on this section are based on data of questionnaire and interviews. Figure 5.7 depicts the result of the first section of the questionnaire while Table 5.8 illustrates students' comments and suggestions on the second section of the questionnaire. The interviews are presented as quotation to show students' perceptions of the LoEN.

Figure 5.10. shows the proportion of students' responses of the first section of the questionnaire. As can be clearly seen on the graph, above 95% of them were agreed to all of the statements. Even, for 5 items 100% of them either agree or strongly agree with the statements, which are item no 3, 5, 6, 7 and 8. For item no 1, 2 and 4 only 4% of them chose neutral to express their feeling. Apparently, the changes made in the first cycle also contributed to promote students' interest of reading the LoEN. Based on this result, it can be concluded that the LoEN had received a positive response. Detail of the percentage for each statement shown in Table 5.20.

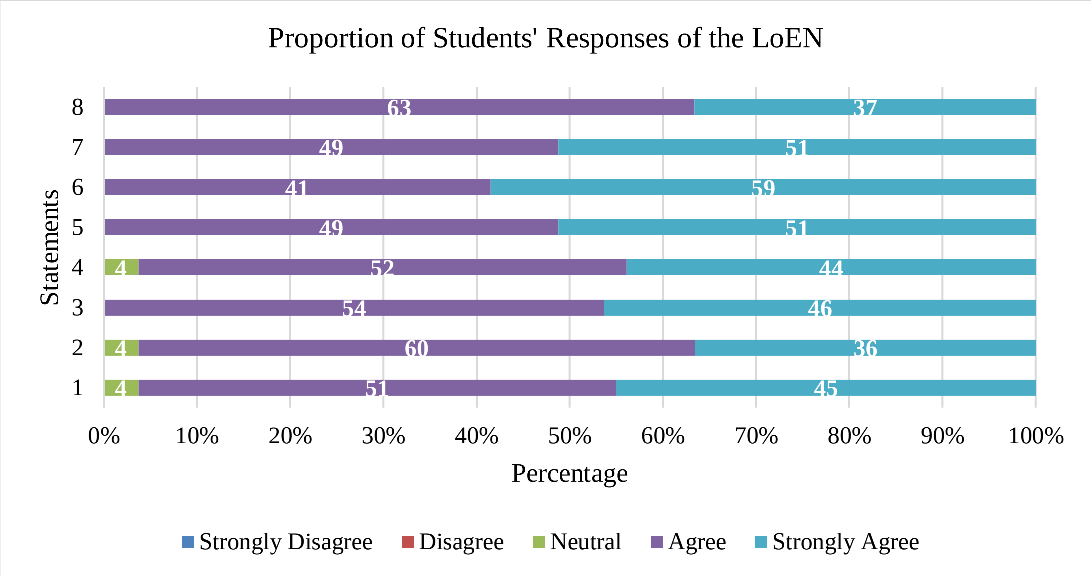


Figure 5. 10 The percentage of students' responses of the LoEN on the first section of the questionnaire (N=82).

The figure describes the proportion of students' responses of the LoEN on the first section of the feedback questionnaire given in the implementation of the second cycle that consist of 8 statements with 5 options of agreement based on Likert scale.

Table 5. 20 The percentage of students' responses on the first section of the questionnaire

No	Statements on the first section of the questionnaire	Percentage (%)				
		SD	D	N	A	SA
1	Contents of the leaflet are clear and understandable	-	-	4	51	45
2	Learning with leaflet help me understand the topic	-	-	4	60	36
3	I know how to predict the bond types and polarity through concept presented in leaflet	-	-	-	54	46
4	Concepts presented in leaflet are complete	-	-	4	52	44
5	I enjoyed learning with the leaflet	-	-	-	49	51
6	The presentation of the leaflet is interesting	-	-	-	41	59
7	Learning with the leaflet is effective	-	-	-	49	51
8	Leaflet is easy to use and practical	-	-	-	63	37

The table presents the percentage of each statement in the first section of the questionnaire given in the second cycle. Students' stated their level of agreement by choosing the 5 options: SD=strongly disagree; D=Disagree; N=Neutral; A=Agree; SA=Strongly agree

Table 5. 21 The Summaries of Students' Comments and Suggestions on Section 2 of the questionnaire (N=82)

Questions	Comments/suggestions	Percentage
Which part of the LoEN that is most useful?	Table, graph, figures	12.2
	The explanation	14.6
	Conclusions	18.3
	The whole leaflet	54.9
Which part of the leaflet that is less useful?	None	100
What changes need to be made related to the leaflet?	None	100

Data presented in the table is the summary of students' comments and suggestions with the percentage in the second section of the questionnaire that consists of 3 open-ended questions.

The second section allows students to express their perceptions of the LoEN by answering 3 questions given. Students' comments and suggestion were summarised on Table 5.21. Table, graph and figures presented in the LoEN are noted by 12.2% of students as the most useful part of the LoEN. 14.6% of them stated that the explanation (the text) in the LoEN as the most useful part. Conclusion, which is presented as diagram to summarise the concepts is chosen by student to be the most useful part by 18.3% of students. Over 50% of students considered the whole parts of the LoEN are useful. What can be clearly seen on this Table are 100% of students claimed that there is no less useful part in the LoEN and 100% of them also approved that there are no changes needed to be made. These findings confirmed that the LoEN is a useful TLR for students to teach and learn the topic.

Table 5. 22 A summary of observation during the activity of the second cycle

Researcher's note on students' activity	
Before doing the activity:	
- A brief explanation about this study were explained to all students. - Administer the pre-test. - A leaflet was distributed to each student.	- Students were listening to the explanation. - Students were doing the pre-test. - Students were taking the LoEN.
During the activity:	

- Students instructed to start reading the LoEN for 10 minutes. - For the next 10 minutes, students were instructed to discuss the topics presented in the LoEN with a friend next to them (in a pair or small group of 3) or asking the questions to the lecturer. - Lecturer gives the explanation related to the topic.	- They started to read the LoEN. All students were impressed with the simplicity of the LoEN by stating that the leaflet is "simple and practical". They also noted that the appearance of the LoEN is "interesting" and "I love the colour". - Then, they begin to discuss the topics presented in the LoEN with a friend next to them. Students also asked some questions about the topic to the lecturer. - Listening to the explanation, asking the questions, such as "how the ionic molecules still have the covalent character in it?" or "please explain more about the relationship between bond character and the EN?"
After doing the activity:	
A feedback questionnaire was distributed to all students	They answered all the questions and giving a feedback related to the LoEN.
Conclusion: Overall, the activity ran smoothly. Similar to the findings in the first cycle that students have fully participated during the discussion section. Answering the questions in the worksheet was successfully guided students in the discussion.	

5.5.4 Reflection

The reflection as part of the evaluation stage is to reflect the whole process of developing the LoEN. The purpose of the second cycle is to confirm the consistency of the findings in the first cycle as well as the effectivity of the LoEN as TLR. Whether the findings showed a similar trend to those the first cycle. Ideally the findings of the second cycle are better than the first cycle as the TLR implemented has been through some improvements based on the reflection on the first cycle.

The key observations made during the second cycle of the research are summarised in Table 5.22. Based on the observation's note, a positive impression was shown by the students when they see the LoEN. Some of them said that the LoEN is simple and practical. In addition to that, students seemed to give a positive comment to the appearance of the LoEN by saying “the leaflet is interesting” and “I love the colour of the leaflet”. Similar to those finding in the first cycle, the observation’s notes also captured that students fully participated in the discussion due to the worksheet.

The changes that have been made were based on students’ feedback from the first cycle for the LoEN. The average percentage of students who agreed with all the statements in the questionnaire (Table 5.1) were increased from 85% to 98.5%. In addition to that, all students suggested that no further changes needed to be made to the LoEN. It appears that all students delighted with all the changes suggested in the pilot study and the first cycle.

5.5.5 Summary

The study of development LoEN aimed to address three specific research questions. These research questions were extracted from the overall research questions of this thesis (Chapter 1, section 1.3). The connection between the specific research questions and the sources of data are described in Table 4.28. The four stages of AR in the cyclic form used in this study were successful in developing and evaluating the LoEN to challenge students’ alternative conceptions of shape of molecules concepts. This finding was made based on analysis of the development and evaluation processes during the first and second cycles of the LoEN. The four modified stages of AR in this study provided the opportunity for the researcher to design, develop, evaluate and reflect (the whole process) on the LoEN continuously through each cycle. The AR approach used in this study has been successful in addressing students’ alternative conceptions of electronegativity, bond types and polarity concepts, as this approach allowed the design and development of the TLRs based on students’ problems. In addition to that, the literature reviews process also enabled identification of the main reasons for the issues. Therefore, the researcher had the chance to deal with these problems by designing and developing suitable TLRs.

Data collected through pre- and post-tests and interviews were used to assess the impact of LoEN on students’ learning. The increased scores on both cycles provided evidence that LoEN had improved students’ understanding of the shape of molecules topic. Also, the findings from analysis of students’ answers (pre- and post-test) in both cycles showed that students had a better understanding after learning with the LoEN, and had a positive impact in supporting students' understanding of these concepts.

Meanwhile, the findings from the questionnaire, interviews and observation were used to address the third research question. Based on the findings of the questionnaire and interviews, students found that the LoEN was a good way to learn. A positive response towards the LoEN confirmed that the resources were effective at providing an engaging learning experience.

Table 5.23 The Connection between th specific Research Questions and Data Sources

Research Questions	Data Sources				
	Researcher Notes	Pre- and Post-test	Questionnaire	Interviews	Observation
How should educators develop the LoEN in order to challenge students' alternative conceptions of Shape of Molecule based on VSEPR theory?	√	√	√	√	√
What is the impact of the LoEN on student learning?		√		√	
How effective are these LoEN at providing engaging learning experience?			√	√	√

Researcher notes were derived from the review of the literatures

Chapter 6

Using a Video Resource to Enhance Students' Understanding of Intermolecular Forces (IMFs)

Chapter outline

The sixth chapter discusses the outcomes of the third Teaching and Learning Resource (TLR) that takes the form of a Video on Intermolecular Forces (VoIF) to enhance students' understanding of the topic. This chapter addresses the three research questions, which are: (1) how should educators develop the VoIF in order to challenge students' alternative conceptions of Intermolecular Forces?; (2) what is the impact of the VoIF on student learning?; and (3) how effective are the VoIF at providing engaging learning experience?. The chapter begins with the rationale for developing this video. This section also explains the reason for choosing the topic of intermolecular forces as well as a justification for choosing video as the format of the resource. The next section describes the process of developing the video. A discussion of the pilot study is presented, which consists of methods, findings and reflection on the outcomes. The VoIF was implemented in the General Chemistry 2 course. The implementation of the VoIF in the class of General Chemistry Year 1 Chemistry Education Programme as part of the evaluation stage is described in detail. The chapter starts by explaining the context of the research. The results and key findings are then presented from the implementation of the TLR, which includes insight into students' perceptions of the topic and the TLR. The findings presented in this chapter are based entirely on the questionnaire responses and pre and post-test results. These results have been analysed using quantitative approaches due to the limited time available to conduct this part of the study. Findings focusing on students' conceptual understanding and their perceptions and views of the LoEN are included in this chapter in order to answer these three specific research questions.

6.1 Rationale of developing VoIF

Understanding the physical basis, the principles required to describe intermolecular forces and consequences of Intermolecular Forces (IMFs) is an essential element in core chemistry education (Kind, 2004; Tarhan, *et al*., 2007; Cooper, Williams & Underwood, 2015). An understanding of intermolecular forces helps students predict a number of physical properties of substances, such as relative boiling points, changes in states of matter (Schmidt, Kauffman & Treagust, 2009) 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 (Peterson *et al.*, 1989; Birk & Kurtz, 1999; Tan & Chan, 2003). Therefore, students develop a wide range of alternative conceptions (Coll & Taylor, 2002). Chan (2003) found that some students at grade 5 and 6 (age 16-17 years and 17-18 years) had difficulty in understanding the nature of hydrogen bonding and dipole-dipole interactions. Chan found that some students find it hard to describe the intermolecular forces involved within the molecules. A number of studies have reported common misconceptions related to this concept (Kind, (2004); Goh, *et al*. (1993); Peterson *et al.* (1989, 1993); Taber (1995, 1998); Peterson & Treagust (1989); Birk & Kurtz (1999); Griffith & Preston (1992); Coll & Taylor (2001), Schmidt (1996) and Henderleiter, *et al*. (2001)) which are summarised in Table 6.1. The misconceptions described in these studies were used to inform the structure and content of the Video of Intermolecular Forces (VoIF) developed in this study.

Winarni (2006) reported that some year one chemistry students at the Islamic State University in Malang experienced misconceptions of key concepts related to intermolecular forces. Some students thought that all atoms that bonded to hydrogen atoms could form hydrogen bonds and that polarisation exists in nonpolar molecules hence dipole-induced dipole force occur. A follow up study by Winarni in 2016 established that some high school students (age 16-18) in Banda Aceh, Indonesia who studied chemistry held misconceptions about the strength of intermolecular forces. Some of the students involved in this study predicted that metallic and non-metallic atoms will form a molecule through weak intermolecular forces. This misconception indicated that students did not understand the concept of intermolecular forces.

Common misconceptions related to IMFs have also been observed when I taught the General Chemistry course for first-year students in Chemistry Education Study Programme of Faculty of Teacher Training and Education of University of Tanjungpura, Indonesia. The first reported misconception is that hydrogen bond occurs within individual molecules. For example, students referred to bonds between C-H and O-H in ethanol (C_2H_5OH) as hydrogen bonds. Another reported misconception is the existence of hydrogen bonding between any hydrogen atom in a molecule and an electronegative atom on another molecule. As an example, student predicted that hydrogen atoms in ethanol molecule will form hydrogen bonds to other hydrogen atoms in another ethanol molecule as described in Figure 6.1 below.

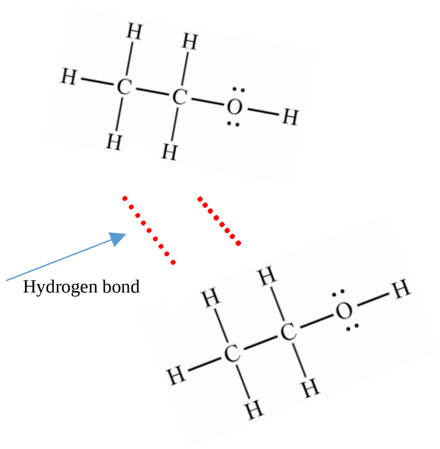


Figure 6.1. A diagram which shows a common misconception related to hydrogen bond

It has been proposed that one of the main causes of these misconceptions are the abstract nature of the topic and the inability of students to integrate the three levels of representations used when communicating chemical ideas (Gabel 1999; Nakhleh 1992; Taber 2009; Rogers, Huddle & White 2000). As stated by Herron (1996) abstract concepts are “imperceptible instances” which refers to phenomena that cannot be understood directly due to the unavailability of real-world examples that can adequately describe the attributes of these phenomena. 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 visualisation (Wedvik, McManaman, Anderson & Carroll, 1998). According to Sanger & Greenbow (1997) visualisation can help students overcome the abstract concepts.

The topic of IMFs includes a number of abstract concepts, such as the induction process of nonpolar molecules by polar molecules to form London Dispersion Force. As this topic is based on molecular scale science, the use of microscopic representations is inevitable. Many established approaches to teaching and learning in this topic require explanations that make significant use of visualisation, such as the use of molecular models, video, images, animation, *etc.* (Muchson, 2013).

Table 6. 1 Summary of common misconceptions related to intermolecular forces (adapted from Tarhan, Ayar-Kayali, Ozturk & Acar, 2007).

Students' misconceptions
• Intermolecular forces are stronger than intramolecular forces (for example hydrogen bond is stronger than covalent bond) • Intermolecular forces are present in polar molecular substances such as water • Intermolecular forces occur within a covalent molecule • Intramolecular bonds break on change of state, rather than intermolecular forces • Intermolecular forces are the forces within the molecule • Strong intermolecular forces exist in a continuous covalent (network) solid • Intermolecular forces are influenced by gravity • Intermolecular forces lead to reactions • Unpaired electrons are necessary for hydrogen bonds to form

Although many TLRs have been developed to help students visualise abstract concepts, studies on the effectiveness of these TLRs are limited. TLRs that related to computer assisted learning were reported by Muchson (2013), Burkholder and Purser (2008) and Hessley (2000). Video-based TLRs have the potential to allow students to visualise the formation of IMFs as well as the effects of IMFs on physical and chemical properties through microscopic level representations. The Oxford Online Dictionary (Accessed May 2018) defines video as the recording, reproducing, or broadcasting of moving visual images. Cruse (2006) 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 (Mayer, 2001). 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 (Gardner, 2006)

Presenting the dynamic chemical scenario required to successfully describe intermolecular forces 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 visualisation of the abstract concepts (Velazquez-Marcano, *et al*., 2004) and can attract students' attention (Talib, *et al*., 2017).

6.2 The development of VoIF

The development process of the video teaching and learning resource consisted of two stages: design and development (as described in Figure 6.2). In the design stage, the primary aim was to identify the chemical topics that would be the focus of the resource and to precisely define the format of the TLR. The first stage of the process was a review of the relevant literature. This review revealed that many students had alternative conceptions related to the topic of intermolecular forces (Tarhan, *et al*., (2007); Kind, (2004); Goh, *et al*., (1993); Peterson *et al.*, (1989, 1993); Taber (1995, 1998); Peterson & Treagust (1989); Birk & Kurtz (1999); Griffith & Preston (1992); Coll & Taylor (2001), Schmidt (1996) and Henderleiter et al. (2001)). The range of reported teaching and learning resources developed to support student learning of this topic were somewhat limited (Schmidt, Kauffman & Treagust, 2009; Tan & Chan, 2003). A video format was chosen for the learning resource used in this study as this format has the potential to allow dynamic visual representations of atomic and molecular movement to be shown. Representing these types of movement are key to ensuring that students develop an accurate representation of the topic as claimed by Vavra *et al*., (2011) that "the function of the images is to help students process and analyse information more efficiently, thus reducing the load on working memory". The video format can also potentially show simulations of vital concepts such as dipoles being induced by the presence of other nearby molecules.

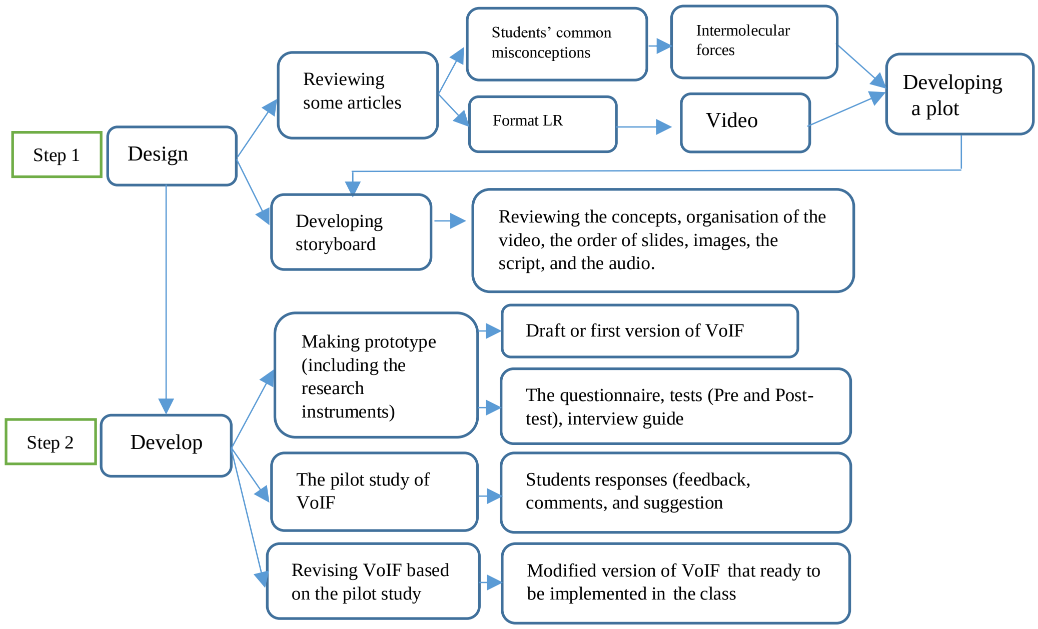
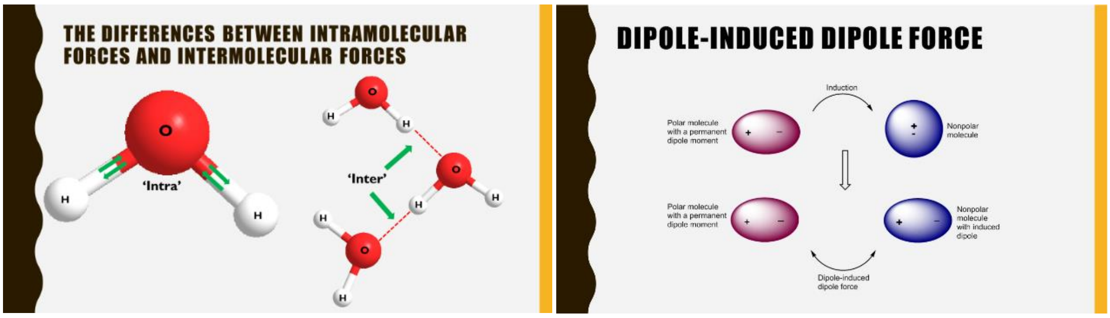


Figure 6. 2. The procedure of the development process of the VoIF

Once the format of the resource had been selected, the next step was to develop a storyboard for the video. A storyboard is a graphical representation of how the video will unfold, typically with some directions scripts for the purpose of pre-visualising an animation, motion picture, or interactive media sequence (Herrel & Fowler, 1998). The video format structured of screen-captured based on Power Point slides. Thus, the development of the storyboard involved deciding which concepts were to be covered in each slide. The concepts presented in the video aimed to challenge previously reported common misconceptions on this topic (Tarhan, *et al*., (2007); Kind, (2004); Goh, *et al*. (1993); Peterson *et al.* (1989, 1993); Taber (1995, 1998); Peterson & Treagust (1989); Birk & Kurtz (1999); Griffith & Preston (1992); Coll & Taylor (2001), Schmidt (1996) and Henderleiter *et al*. (2001)), such as Intermolecular forces are stronger than intramolecular forces and Intermolecular forces occur within a covalent molecule.

The video was recorded and edited using Movavi Video Editor 12 software. This software package was used as it offers more extensive editing features and higher resolution output formats than standard packages such as Windows Movie Maker.

Each video slide was produced using Microsoft PowerPoint. PowerPoint was used due to compatability with the chosen video editing software and the ability to create custom images and animations. The images of chemical structures used in the video were produced 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.



(a) (b)

Figure 6. 3. Examples of images presented in the video. (a) The images presented to show the differences between intramolecular and intermolecular forces, (b) The image of the induction process between polar molecule and nonpolar molecule.

The Video on Intermolecular Forces (VoIF) 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 (see Figure 6.2 for examples). Figure 6.3(a) emphasises the key differences between intermolecular and intramolecular forces. Figure 6.3(b) showing the induction process between polar molecule and non-polar molecule.

Table 6. 2 Contents of each slides of VoIF

Content of the Video	Slides' number
The title	1
The objective of the video	2
An overview of the differences between intramolecular and intermolecular forces	3-4
The diagram of the Intermolecular Forces types	5
London Dispersion Force (LDF)	6-11
Induced-dipole dipole Forces	12
Dipole-dipole Forces	13-14
Hydrogen Bonding	15-17
Ion-Dipole Forces	18
Summary of concepts	19-23

The VoIF consists of 23 slides that includes of the title, the explanations of the topic material and the summary (see Table 6.2). The arrangement of the slides presented in the VoIF were based on three sections: opening (slide 1-2), the contents (slide 3-18), and the closure (19-23). The first and second slides of the VoIF are shown in Figure 6.4. The complete set of slides used as the basis of the VoIF is shown in appendix 3.

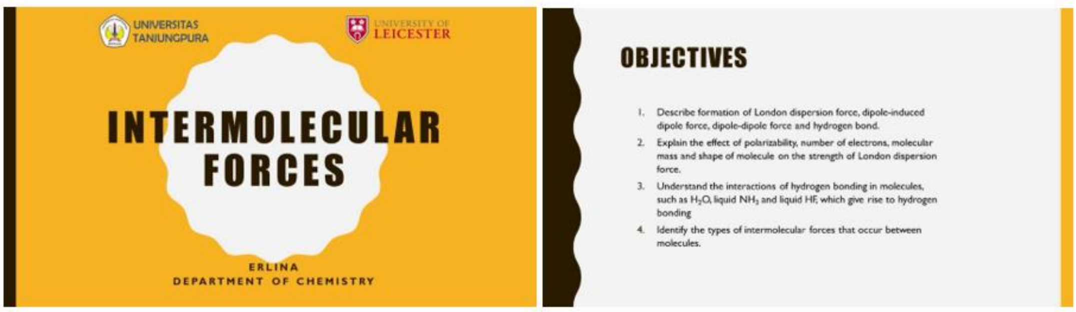


Figure 6. 4. Sample of the first and second slide of VoIF.

6.3 Pilot study: Video of Intermolecular Forces (VoIF)

A small-scale pilot study was conducted to assess the quality of the VoIF prior to full implementation and evaluation. In this case the term quality refers to the clarity of the audio-visual content and to determine whether it provided a useful learning experience and to measure how effectively students were likely to engage with the resource. The pilot study was important as the information gained was used to identify the design flaws.

Prior to the pilot study, the appearance and scientific content of the VoIF was revised based on feedback from the supervisory team. The content validation of the VoIF ensured by the arrangement of the slides, the images, explanation, and the audio. Following this initial quality control process, the VoIF was piloted with 10 second-year undergraduate students from the Department of Chemistry, University of Leicester term 2016/2017. This group of students was involved due to all students involved in the pilot had previously studied the topics covered in the resource, thus they can give a valuable feedback. All students were recruited as a volunteer. During the pilot, the activity took the students 35 minutes to complete including filling out the questionnaire.

6.3.1 Procedures of the Pilot Study

At the start of the pilot study, participants were asked to watch the VoIF (13 minutes in duration) and to provide feedback afterwards using a questionnaire designed by the researcher. The feedback questionnaire consisted of two sections: a section based on seven closed statements requiring students to state their agreement on a five-point Likert scale (strongly disagree, disagree, neutral, agree and strongly agree) and a second section consisting of four open-ended questions asking participants to provide detailed feedback in their own words (see Table 6.3). The questions of questionnaire were consistent in style to those previously used in the evaluations of the SoMCards and LoEN resources.

6.3.2 Outcomes of the pilot study

The first section of the questionnaire aimed to measure students' responses to the appearance of the resource as presented in Table 6.3. Based on the Figure 6.5, majority of students were either agreed or strongly agreed to the statements, except for statement 5 “This video did not help me in understanding the concepts of intermolecular forces”. This statement was mentioned to clarify students’ responses to other statements. 90% of students (9 out of 10) disagreed (strongly disagree or disagree) that with the statement. The first question asked participants whether they enjoy watching the video or not. Based on their feedback, students enjoyed watching the video. Interestingly, students noted that all pictures and figures presented in the video were clear, the explanations could help them to understand the concepts and the video helped them to visualise the process of IMFs (9 out of 10). Students also acknowledged that the presentation of the video of intermolecular forces is interesting, and the pictures presented in the video are useful (8 out of 10 students). Overall, students showed a positive response towards the use of VoIF in learning the topic.

Table 6. 3 Statements and questions presented in the questionnaire

No	Statements and questions	
	Section 1 (State level of agreement)	**Section 2 (Open-ended)**
1	I enjoyed watching the intermolecular forces	Which parts of the video were most useful?
2	All pictures and figures presented in the video were clear	Which parts of the video were less useful?
3	The explanations helped me to understand the concepts	What changes would you like us to make to the video?
4	The video helped me to visualise intermolecular forces	Any general comments
5	This video did not help me in understanding the concepts of intermolecular forces	
6	The presentation of the intermolecular forces is good	
7	The pictures presented in the video are useful	

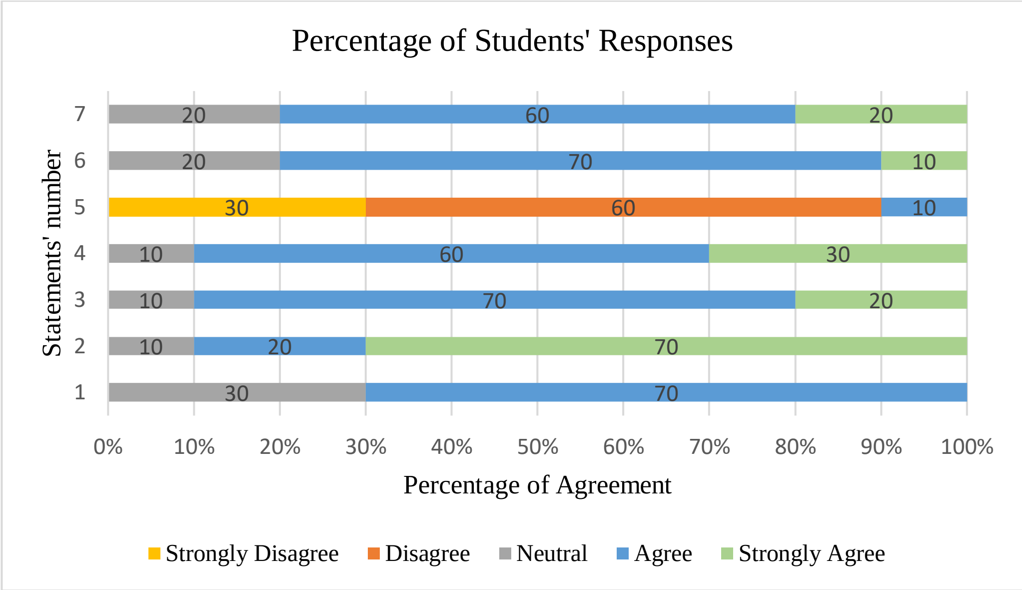


Figure 6. 5. Percentage of students' feedback of VoIF on the pilot study (N=10).

The second section of the questionnaire was based on four open-ended questions in order to gain a deeper insight into specific aspects of the student experience of the VoIF resource. A summary of responses to the questions in the second section is shown in Table 6.4. In response to the first question "Which parts of the video were most useful?", 5 students fed back that the diagrams and 2 students noted that the information and the explanation presented in the video as their responses. Student responses to the next question ("Which parts of the video were less useful?") focused on the large amount of text presented in a some slides in the video noted by 7 students, the flowchart shown in the third slide was highlighted as being hard to read by 1 student and the summary tables in the last slide also noted by 1 student. When students were asked to suggest changes they would like to see made to the video, the responses focused on reducing the amount of text used in the video (3 students), adding more animations to show dynamic processes (1 student) and improving the clarity of the audio narration (1 student). When asked for the general comments on the resource, students reflected that it is a useful learning resource, that the data tables and summary slides were helpful, the images were supported their learning by helping them to visualise the process of IMFs and that the general presentation and quality of the video was good. Changes were made to the resource following reflection on the student feedback given in the questionnaire. Reducing the amount of text, adding the signpost and providing a clearer audio were the changes that were made to the VoIF (see Table 6.4).

Table 6. 4 Summary of Students' comments of VoIF of the second section of the questionnaire (N=10).

Comments/Suggestions	
The most useful part of the video	Diagrams and images presented in the video (5 students)
	The first few slides with all the diagrams (2 students)
	The information and explanation on the video (3 students)
Less useful	A large amount of text presented in the video (7 students)
	The tables in the last few slides (the summary) (1 student)
	The flowchart of types of IMFs (1 student)
	None (1 student)
Changes	The text section presented in the video were too long (3 students)
	Add some animated video (1 student)
	Clearer audio (1 student)
	The audio is too fast, it is better to slow it down a little bit (4 students)
	None (1 student)
Notes (General comments)	The overall video was a useful resource and the figures were helpful as it helped me to visualise what happen to the molecules when having the intermolecular forces (3 students)
	Good video, was useful, the data tables and summary were a good touch (3 students)
	Well presented, clearer audio would help with further understanding (2 students)
	The information was clearly presented (1 student)
	None (1 student)

6.3.3 Reflections on the pilot study

The student feedback collected during the pilot study informed a number of changes that were made to the VoIF. The amount of text presented in the video was reduced in response to student feedback in order to help students grasp the concepts ("*there was too much text on the few last slides. I could not keep up with the last few slides of the video*"). As recommended by Vavra *et al.,* (2011) that visual aids should be combined with verbal or textual information for conceptual understanding and using the visual aids as a supplement to text, not a replacement of for text. The second main change was the addition of visual signposts in the video by adding arrows and emphasising key text through the use of colour (see table 6.5) (as students suggested "*maybe add some animated signage like an arrow to point out the specific explanation"*). The intention of these changes was to emphasise the connections between different areas of content by defining the logical order that ideas fit together. Highlighting key words and statements can help students to recognise important concepts in the VoIF. Vekiri (2002) suggested that an explicit explanation or guidance about the most relevant features and application of the display images should be provided. Confusion or informational overload can be avoided by matching the visualisation object and the key components of the corresponding linguistic instruction. No additional animations were included due to the limited time available to conduct this part of the study.

As a number of participants' feedback concerns about the quality and clarity of the audio narration thus the narration of the relevant sections was re-recorded (slides 11, 13 and 14). The final change involved slowing down the audio playback speed which was a particular problem in slides 15-17 and adapting the content by editing the slides. All changes were processed using the Movavi Video Editor 12 software package. The aim of reducing the pace of the audio was to give students more time to reflect on the meaning of the key points presented in the video. A summary of the changes made can be seen in Table 6.5.

Based on the analysis of the first section of the questionnaire, it was evident that most participants were given very positive response about the resource. The majority of respondents (8 out 10) provided free text comments indicating that the diagrams and images in the video helped develop their understanding of the topic. The respondents also praised other aspects of the resource (e.g. "*the information was clearly presented*" and "*overall the video was a useful resource*").

Table 6. 5 Summaries of changes made based on findings on a pilot study (N=10)

No	Findings	Changes	Rationale
1	The amount of text used in the video was too high	The length of the sections of text presented in the video were reduced	To improve students' interest in watching the video
2	Add some animated video or signage like an arrow to emphasise the explanation	Signage was added (arrow and put a different color to the text that relates to the explanation) to the video	To emphasises the relation between the images presented in the slide with the explanation
3	The audio needed to be clearer	The narration was re-recorded for the sections highlighted in student feedback	To make the video easy to understand
4	The audio in the video was too fast	Reducing the speed of the audio	To help students grasping the concepts

6.4 Evaluating the VoIF

The evaluation of the VoIF was conducted in the Chemistry Education Study Programme at the Department of Mathematics and Science Education, Faculty of Teacher Training and Education of Tanjungpura University, Indonesia. The VoIF was implemented as part of General Chemistry 1 course during the first semester as explained in Chapter 2.

Due to time constraints the evaluation of this TLR was limited to the questionnaire data and analysis of student performance in the pre- and post-tests. Quantitative analysis was conducted on both the questionnaire data and student performance in the pre- and pots-tests. The quantitative analysis of students' score to measure the impact on performance after watching the VoIF. If further time was available, the author would recommend further qualitative research on this resource by analysing students' answer on pre- and post-test, conducting interviews with students and evaluate the VoIF in second cycle. The rigorous methods used in this study were very time consuming (especially in developing and evaluating the resources).

6.4.1 The context of the evaluation

The evaluation took place during November 2016 and involved 82 first-year students from three different Chemistry Education Study Programme classes. The three classes were designated Chemistry Education A1, A2, and A3 and consisted of 31, 30 and 21 students respectively. All students were taught by the same lecturer under the same curriculum. At the time of the study students were studying General Chemistry 1 but had not studied the specific topics covered in this TLR.

6.4.2 Procedures of the Implementation of The VOiF

Prior to implementation the TLR had to be translated into the Indonesian Language (Bahasa). The lecturers at Tanjungpura University were also briefed on the use of the VoIF resource in advance of its implementation in class. The implementation was designed to take 45 minutes of class time which included the time needed for the pre-test and questionnaire.

The implementation procedure of the VoIF is summarised in Figure 6.6. Before students were given access to the video, they were asked to complete a pre-test on the relevant topics. The pre-test took 15 minutes to complete. Following completion of the pre-test, all students watched the video (13 minutes duration). Students were encouraged to make notes while watching the video. After watching the video, students were asked to discuss the topic with the students who sat around them in a small group (consists of 3 or 4). This discussion was facilitated by the course lecturer who answered any questions students had on the topic. The 15-20 minutes long peer discussion activity was integrated into the intervention to support the learning. For the last 10-15 minutes of the session, students were asked to fill in a questionnaire designed to measure student reaction to the resource. A post-test was scheduled as an integral part of the mid semester exam. This took place 5-6 weeks after the implementation. The post test was deferred to this point based on the recommendations of Brown, Irving and Keegan (2008) as explained in Chapter 4 This was suggested to measure the long-term impact of the learning experience.

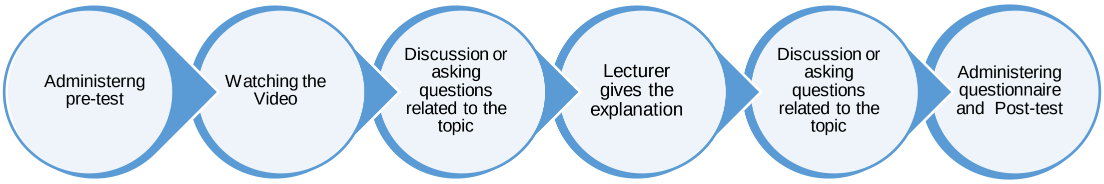


Figure 6. 6. The procedures of the implementation of VoIF

6.4.3 Findings of the evaluation: Students' Conceptual Understanding

Both pre-test and post-test scores were marked and tabulated to analyse students' understanding of IMFs. Students' scores of both tests were analysed using Excel and SPSS. The maximum score for both tests is 100. The scores of the individual pre-test and post-test score presented in figure 6.7. The performance of all students improved between the pre-test and the post-test. Two students scored 100 out of 100 for post-test.

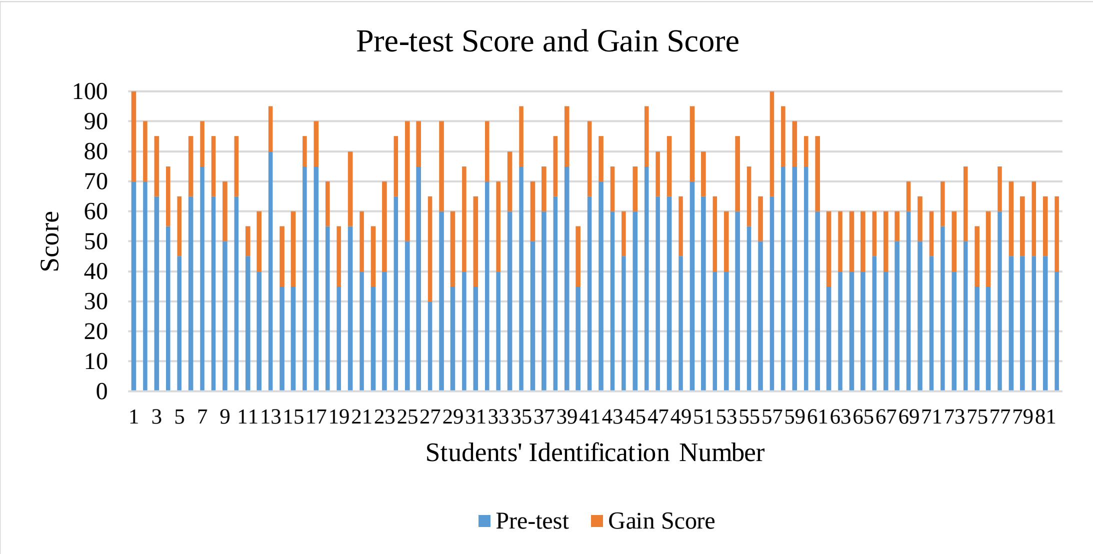


Figure 6. 7. Students pre-test and gain score (N=82).

The figure presented data of students' pre-test score and the gain score (the difference score between post-test and pre-test). The graph shows that all students experienced an increasing score in post-test.

Students' pre-test and post-test scores were classified into six different categories as presented in Table 6.6. 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. A further research would be needed to confirm this. Around 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 (Mayer & Anderson, 1991). They found that, the combination of visualisation (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 tyre 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. 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 visualise the process of IMFs (see Table 6.8) (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 visualise the process of IMFs). A similar finding was reported by Ardac and Akaygun (2004) who stated that learning resources based on multimedia representations can be very effective in helping students visualise the chemical process at the molecular level and recalling memories of facts, concepts and principles. Bergsma (2002) stated that visual message of multimedia are 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. Noble (1983) 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.

Table 6. 6 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

The table describes the percentage of students' range score of pre- and post-test.

The pre-test and post-test data were then analysed 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 (Table 6.7). 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 VoIF as a learning resource.

Table 6. 7 The result of Paired-sample t-test

Tests	**Mean**	***N***	**SD**	***Correlation***	***t Value***	***Gain***	***p Value***
Pre-test	53.78	82	13.912	.905	-31.111	20.488	.000
Post-test	74.27	82	13.220				

The table presents the outcomes of students' pre- and post-test score analysed by SPSS paired-sample t-test.

The above findings are consistent with those reported by Muchson (2013) who developed the interactive multimedia resource in CD (compact disc) format for teaching Intermolecular Forces topic. The software was designed by combining the text, animation, images, audio and video to emphasise the three levels of representations, especially the sub-microscopic level to visualise the abstract concepts in Intermolecular Forces. 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.*, (2015) 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 its 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 8 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 intermolecular forces and 88% of students agreed that the software can improve student performance. Barbosa, *et al.*, (2015) 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 Intermolecular Forces topic. Eliyawati *et al.* (2018) 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. 70 grade 10 students (35 students in control group and 35 students in experimental group) participated in this study. A similar 18 questions (initial test and final test) was 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 submicroscopic) in the software, as reported by Wu, Krajcik & Soloway, (2001) in their study that the use of a computer-based visualising 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 visualisation 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 computerised models can serve as a vehicle for students to generate mental images and improved students' understanding.

Students' Views and Responses of VoIF

The results presented in this section were based on the analysis of both sections of the post—implementation the questionnaire. Students' views and responses are presented graphically (Figure 6.7) and in the form of a table (Table 6.4). The graph (Figure 6.3) describes the findings of the first section of the questionnaire, while Table 6.5 summarises students' comments and suggestions on the second section of the questionnaire.

Figure 6.8 shows that student responses to three of the statements (see Table 6.3) are of particular interest. 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 intermolecular forces is good). Statement number 5 (This video did not help me in understanding the concepts of intermolecular forces) 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 intermolecular forces) 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.

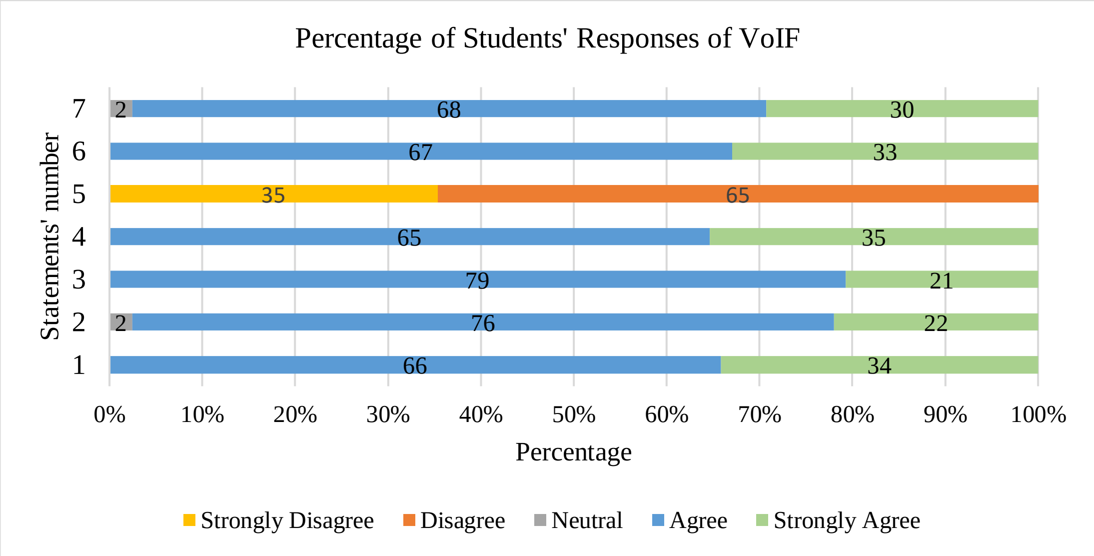


Figure 6. 8. Percentage of students' responses of VoIF on the evaluation (N=82).

The second section of the questionnaire consisted of four open-ended questions. A summary of student responses to these questions is shown in Table 6.8. 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 (*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 polarisation process, presented in the video help me understand the concepts)*. Based on students' general comments, the video was noted to useful.

Table 6. 8 Summary of students' comments and suggestions related to the VoIF

Comments/Suggestions	
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 visualise the process of IMFs (26 students)
	The video was helped to understand the concept along with the diagram (17 students)

When asked to provide general comments on the resource, students noted that the video is "well presented" (20 students) and that "the content was easy to read" (12 students). Apart from some comments asking for the pace of the video to be reduced, students gave positive comments suggested that the VoIF supported their understanding of key concepts related to IMFs.

6.4.4 Reflection on the evaluation

The feasibility of using the VoIF as a TLR to support student learning of key concepts in the area of IMFs has been evaluated through questionnaire and students pre- and post-test score. The questionnaire was given after viewing the TLR to collect students' responses. Students' pre- and post-test score were analysis to measure student performance before and after learning with the TLR. Both outcomes of the analysis suggest that the video has had a positive impact on student learning and that students found the content of the T accessible and useful. These outcomes support the potential effectiveness of this TLR in the teaching of IMFs as part of a General Chemistry course. The VoIF resource will made freely available as an open educational resource allowing students and educators to make use of it in a way that suits their context.

6.5 Summary

The aim of this study was to design, develop and evaluate the VoIF for teaching the Intermolecular Forces (IMFs) topic using an action research methodology. The specific research questions were developed based on the research questions of this thesis (Chapter 1, section 1.3). The connection between the specific research questions and the sources of data is described in Table 4.28. The four stages of AR in the cyclic form used in this study were successful in developing and evaluating the VoIF to challenge students' alternative conceptions of shapes of molecules concepts. The four modified stages of AR used in this study provided the opportunity for the researcher to design, develop, evaluate and reflect (the whole process) on the VoIF. Although, the VoIF was evaluated in one cycle and only based on quantitative analysis (pre- and post-test scores and questionnaire), the resource was shown to be successful. Based on the findings, the aim and the objective of the study have been achieved. The increase in scores from pre- to post-test are evidence of this conclusion. The AR approach was a successful approach for developing the VoIF. Students' positive responses confirmed that the VoIF was a TLR which improved students' engagement in learning the topic.

The AR approach used in this study has been successful in addressing students' alternative conceptions of Intermolecular Forces topics, as this approach allowed the researcher to design and develop the TLRs focused on students' problems. In addition to that, the literature review process also enabled identification of the main reasons for these problems. Therefore, the researcher had the chance to address the problems by designing and developing suitable TLRs.

Data collected through pre- and post-tests and interviews assessed the impact of VoIF on student learning. The increased scores between pre- and post-tests provided evidence that VoIF had improved students' understanding of the shapes of molecules topic. Also, analysis of students' answers (pre- and post-test) in both cycles has shown that students had an improved understanding after learning with VoIF. It is indicated that VoIF had a positive impact in supporting students' understanding of this topic.

Meanwhile, the findings from questionnaire, were used to answer the third research question. The questionnaires and interviews showed that students found the VoIF a good way to learn. Positive responses towards the VoIF confirmed that the resources were effective at providing an engaging learning experience.

Table 6.9 The Connection between the specific Research Questions and Data Sources

Research Questions	Data Sources		
	Researcher Notes	Pre- and Post-test	Questionnaire
How should educators develop the VoIF in order to challenge students' alternative conceptions of Shape of Molecule based on VSEPR theory?	√	√	√
What is the impact of the VoIF on student learning?		√	
How effective are these VoIF at providing engaging learning experience?			√

Researcher notes were derived from the review of the literatures

Chapter 7
Discussion and Conclusions

Chapter outline

The chapter consists of three sections: conclusions, limitations and implication. The main findings with regard to the research questions are summarised and general conclusions, based on the findings of the study presented in this thesis, are discussed. In the first section, conclusions are made based on the three research questions explained in Chapter 1. The conclusions consist of three sub-sections to answer each of the research questions. The first sub-section initially describes the development process of all Teaching and Learning Resources (TLRs) using action research. In the second sub-section, findings based on students' scores before and after learning with the targeted TLRs are presented to describe the improvement in students' understanding. The findings based on student interviews are also presented. The third sub-section discusses the findings of students' responses and feedback about the TLRs. The second section discusses the limitations of the study. The limitations are focused on the generalisability of the findings, the topics of the targeted TLRs, the researcher interpretation and analysis and the evaluation of the VoIF (the last TLR developed in this study) which only had one cycle due to the time constraints. The implications of the study are described in the third section, which is divided into 2 sub-sections. The first sub-section discusses the implications of the study to instructional process. This section also discusses the contribution of this study theoretically and practically (theoretical and practical implications). The second sub-section describes the implications for future research derived from this study.

7.1 General Conclusions

Misconceptions or alternative conceptions have been the main issue in learning chemistry. A number of researchers reported that students experienced misconceptions in various topics of chemistry (Gilbert & Watts, 1983; Ayas & Demirbas, 1997; Papageorgiou & Sakka, 2000; Abraham *et al*., 1992; De Vos & Verdonk, 1996; Nakhleh & Samarapungavan, 1999; Özmen *et al*., 2002; Valanides, 2000; Harrison & Treagust, 1996; Stavy, 1995; Taylor & Coll, 1997; Abraham *et al.*, 1992; Özmen & Ayas, 2003, Garnett & Treagust, 1992; Sanger & Greenbowe, 1997; Zoller, 1990; Abraham *et al*., 1992; Nicoll, 2001; Sumarni, 2009, Winarni, 2006, 2016; Goh, *et al.*, 1993; Peterson *et al*., 1989, 1993; Taber, 1995, 1998; Peterson & Treagust, 1989; Birk

& Kurtz (1999); Griffith & Preston, 1992; Coll & Taylor, 2001; Schmidt, 1996; and Henderleiter *et al*., 2001). The abstract nature of chemistry and the inability of students to make a connection between the three levels of representations (macroscopic, symbolic, and sub-microscopic) are believed as the primary cause of this problem. To overcome this problem, some researchers (Gabel, 1999; Nicoll, 2001; Rogers, Huddle & White, 2000) suggested to integrate these three level of representations in teaching and learning chemistry.

Thus, this thesis has concentrated on effective methods to develop and evaluate TLRs. The focus of this investigation is to address the main problem in teaching and learning chemistry: challenge students' alternative conceptions by embedding the three levels of representations. The findings presented Chapter 4, 5 and 6 implied the effectivity of the TLRs to promote students' conceptual understanding and to engage students to learning chemistry.

7.1.1 Research Question 1: How should educators develop targeted TLRs in order to challenge students' alternative conceptions of core ideas in General Chemistry?

Looking back to the development process of all TLRs in this study, the four stages of Action Research (AR) has given a successful approach to the process of the development and evaluation. One of the outcomes of this study is the modified four-stages of Action Research (AR) to develop and evaluate the Teaching and Learning Resources (TLRs) to challenge students' alternative conceptions in core ideas of General Chemistry course by embedding the three levels of representation. The modified four-stages are design (planning), develop (action), evaluate (observation), and reflection. These four stages framed in a cyclic form (see Figure 7.1).

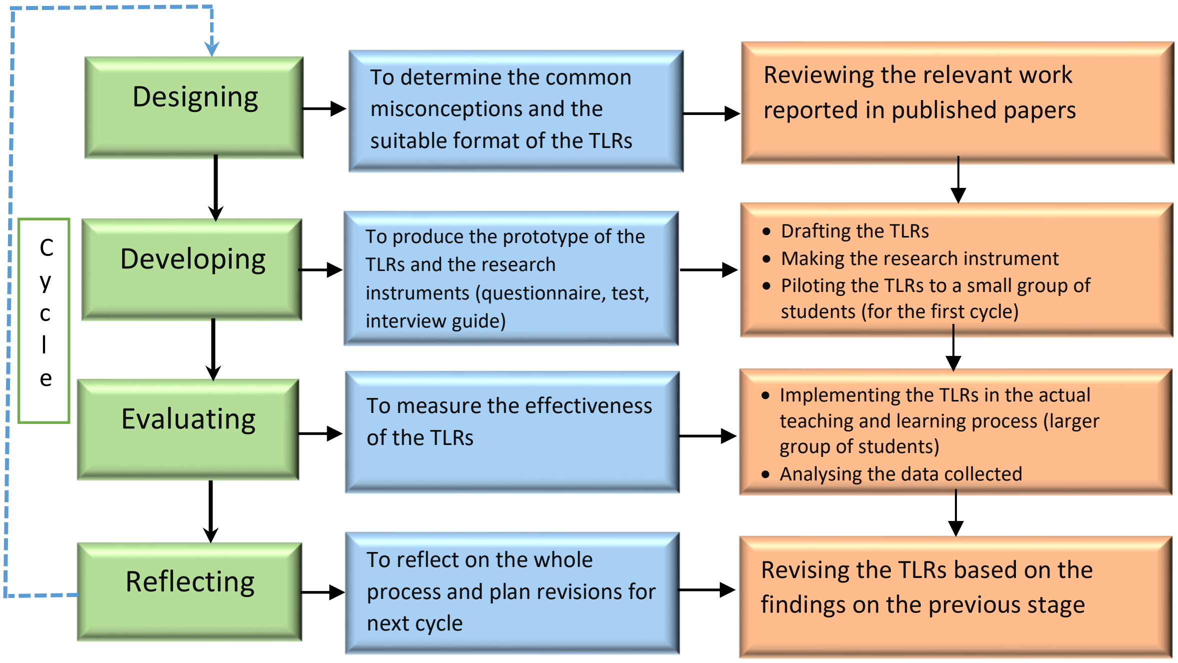


Figure 7. 1 Diagram of the 4 stages of 1 cycle Action Research (AR) in this study

The diagram shows the explanation of each stages in the AR used to formulate the development process of the TLRs. The terms used in each stage are modified from the original terms used in AR to suit the need of the research, except for the last stage, reflection. Designing=Planning; Developing= Action; Evaluating=Observation.

The stages of modified Action Research (AR)

The aims of each stage

Details of activity for each stage

The review started by identifying relevant studies reporting on students' common misconceptions in core chemical concepts, finding the relevant papers through literature searching tools. Meanwhile, the sources for printed papers were found in the library of University of Leicester. The key findings from this literature were then summarised and used to inform the choice of chemical concepts covered in the TLRs and the suitable formats.

Once the topics and the formats were chosen, the next step was to produce prototypes of the TLRs along with the research instruments (e.g. questionnaires, tests, and interview guides). The summary of the topics, formats and rationales of each TLR presented in Table 7.1. Prior to the evaluation stage of each TLR, a pilot study was conducted to obtain an initial insight into the effectiveness of each TLR, identify any issues with the TLR that needed to be addressed and to verify the validity of the research instruments. The findings from the pilot study were then used to revise the TLRs ahead of the evaluation stage.

In the evaluation stage, TLRs were implemented in the actual teaching and learning process (larger group of students). In this study, the implementation of the TLRs was embedded in a General Chemistry course when the topics were taught. All data collected were analysed to inform the revision process of the TLRs.

Reflection as the final stage of the AR, is more likely to reflect the whole process of the development. In this stage, revision of the TLRs was made based the findings in the evaluation stage. The revised version of the TLRs were then evaluated in the second cycle.

Table 7. 1 The types and purposes of the TLRs developed in this study.

Name of the TLRs	Topic and Format of the TLRs	Purposes and Rationale of each TLR
SoMCards and MMB	Topic: Shape of molecule Format: Cards and Molecular Model	• To show the process of predicting the shape of the molecule by choosing the correct answer to the questions given the cards and writing the steps of predicting the shape on the worksheet • To show the effect of the lone pair/s electron/s to the shape of the molecule by assembling the molecular model based on their answer on the cards
LoEN	Topic: Electronegativity, bond type and polarity Format: Leaflet	To explain the relationship between electronegativity, bond type and polarity by presenting the table, diagram and figures in the leaflet
VoIF	Topic: Intermolecular Forces Format: Video	To show the process of Intermolecular Forces by presenting the images of the atoms and molecules

The table presented the topic, format and the rationale of developing the TLRs. This table also shows the strength of each TLR in order to challenge students' common alternative conceptions.

All TLRs developed in this study emphasise embedding the three levels of representations to promote students' conceptual understanding. The three levels of representations presented in the form of molecular model using polystyrene balls and cocktail sticks (SoMCards and MMB) and inserting the images and diagram of atom and molecules (LoEN and VoIF) to the TLRs. The main purpose is to visualise the particulate level to explain the process of predicting the shape of a molecule, the relationship between EN, bond type and polarity, and the process of intermolecular forces. As suggested by Gabel (1999) and Herron (1996), that most topics in chemistry involve the representations of microscopic phenomena that are abstract and cannot be explained without the use of analogy or models. Wu and Foos (2010) claimed that analogies such as diagrams or molecular models can be used to explain and visualise those abstract concepts.

The rigorous action research method used in this study has proven to be an effective way to develop and evaluate the TLRs. However, the method is time-consuming particularly regarding qualitative data analysis (transcribing and translating the interview sessions). Despite the time-consuming nature, AR is a highly recommended methodology for those who want to do a similar study, indeed it could be used for similar development work across a wide range of STEM disciplines.

7.1.2 Research Question 2: What is the impact of the targeted TLRs on student learning?

The impact of the targeted TLRs on students' learning were assessed through the tests (pre- and post-test) and interviews. Students' prior and post understanding of each topic was measured using conceptual tests. Meanwhile, students reasoning about the concepts were collected through interviews. The key findings of quantitative analysis based on *paired sample t-test* to students' pre- and post-test scores (Chapter 4, 5 and 6), showed a similar trend. The result of the analysis for all the TLRs in cycle 1 and 2 demonstrates that there is a statistically significant difference (*p-value* <0.001) in performance in pre-test and post-test. A better performance on the post-tests after exposure to the TLRs indicates that the three resources have contributed to student understanding of these topics.

A few themes emerged from the qualitative analysis of students' interview about how the TLRs contribute to students understanding. A summary of the themes is presented in table 7.2.

Table 7. 2 The summary of students' responses about the way the TLRs (the SoMCards, MMB and the LoEN) had helped them understand the topic.

Question: In what ways did the TLRs (SoMCards, MMB and LoEN) help you understand the concept?		
Type of TLRs	**First Cycle**	**Second Cycle**
SoMCards and MMB	• Answering the questions in the cards • Assembling the molecular model • Combining the SoMCards with the molecular model building • I can see the shape of the molecule after assembling the molecular model	• Doing the whole activity from start to finish helped students to understand how to predict the shape of the molecule • Assembling the molecular model is the best part of the activity, as I (student) can see the 'real' shape of the molecule. • Assembling the molecular model help me understand the effect of lone pair electron/s around the central atom to the shape of the molecule
LoEN	• The language used in the leaflet is simple, so it is easy to understand • The language use in the leaflet was easy to follow and understand • By explaining the connection between the electronegativity, bond type, and polarity • The figures, table and diagram presented in the leaflet were helped in delivering the concept	• Presenting the table, image and diagram to show the connection between EN, bond type and polarity • The diagram in the summary section • The list of questions in the worksheet helped me to understand the topic • The language use to explain the concepts was easy to understand

The table presents the students' responses of how the TLRs developed in this study were helped them understand the topic in the first and second cycle.

For the SoMCards and MMB, in both cycles, students emphasised that the activity of assembling the molecular model was very helpful as they can see the 'real' shape of the molecule. In addition to that, students also stated that the assembly activity contributed to their understanding about the influence of the lone pair/s electrons to the shapes of molecules. As suggested by Huddle, White and Rogers, (2000), models provide representations of scientific concepts that can make the ideas more understandable to learners. Modelling requires the user to make links between the model and the reality that is being modelled (Chittleborough & Treagust, 2009). The use of concrete models to promote students' conceptual understanding at the microscopic level was also effective to correct students' misconceptions (Roger, Huddle, & White, 2002). Models are useful tools in learning science which can be used to improve explanations, generate discussion, make predictions, provide visual representations of abstract concepts and generate mental models (Treagust, Chittleborough, and Mamiala, 2003). Thus, it explained why the targeted TLRs had helped students understand the concepts.

For the LoEN, the simplicity of language, the use of images and diagrams, and the worksheet, consisting of lists of questions to guide the discussion activity, was identified by students as contributing to their better performance in the post-tests. As explained in chapter 2, visualisation is an effective tool of teaching to promote learning and understanding also to aid in analysis and problem solving. A combination of visual and text-based explanation can enable students to access the information so that students can construct a proper understanding (Vavra, *et al*., 2011).

Also, the three levels of representations embedded in the TLRs addressed one of the main causes of the difficulty of learning chemistry (Chapter 1), that is the abstract concepts at the basis of chemistry and the integration of the three levels of representations (macroscopic, symbolic and sub-microscopic).

7.1.3 Research Question 3: How effective are these targeted TLRs at providing engaging learning experience?

One of the objectives of the study was creating an engaging learning experience for students. The effectivity of the targeted TLRs were measured based on students' responses to the questionnaire, interview and researcher's observations during the activity. The key findings of students' responses shown in Chapter 4, 5 and 6.

The majority of students in both cycles commented on their enjoyment of doing the activity (such as answering the questions in the SoMCards, assembling the MMB, reading and discussing the topic in the LoEN, and watching the video). Students' also showed enthusiasm when carrying out the activity (based on the researcher's observations). They even suggested applying the TLRs to other topics and mentioned how fun the activity was in the interview. The primary reason why revealed in the interviews was that the activity allowed them to see the 'real' shape of the molecules (for SoMCards and MMB) while assembling the molecular model. All these findings indicated that the TLRs effectively raised students' engagement in learning General Chemistry.

Presenting the TLRs in three different topics (Shape of Molecule, Electronegativity, Bond Type and Polarity and Intermolecular Forces) and formats (Cards-game, Leaflet, and Video) also contributed to enhance students' understanding and in engaging students in learning chemistry. The different formats of the TLRs accommodated students with different learning styles (auditory, visual, verbal, and kinesthetic). As claimed by Csapo and Hayen (2006) students vary in the way they process and understand information. Thus, Sarasin (1999) argued that providing the suitable approaches to students' learning style is the key of effective teaching. Moreover, Dunn *et al*., (1995) found that students' average grade point increasing when teacher and student learning style more closely matched.

7.2 Limitations

The key limitations of this study are that the findings may not apply in other contexts. The sample size of the quantitative data was considered small, especially in cycle one (N=33). The sample size was limited by the availability of the subjects, time available for field trips to Indonesia to collect data and accessibility of students. Gathering data is dependent on voluntary participation of students which can limit engagement with the study.

The second limitation is that the methods used to develop TLRs in this study may not be directly transferable to other topics of science, but the findings on how students respond to different types of learning approaches may well be transferable. Also, the process of generating and evaluating the impact of TLRs described in this thesis can be applied in a much broader context making this approach accessible to educators in chemistry and other disciplines. Any conclusions that are made as a result of this research are valid for this particular study, situation and time. The extrapolation of the conclusions to other situations can be only hypothesised or proposed and are not necessarily validated by this study.

The third limitation is that the study is dependent primarily on the researcher interpretation and analysis of the research data that are presented, although the multiple data sources and crosschecking with both the supervisors against any major errors in the analysis process. The findings of the qualitative data sources are not always definitive but rather show trends and patterns. Therefore, the significance and importance of an observations or interview responses with individuals cannot always be statistically proven; however, these may still be important. “Triangulation” by combining quantitative and qualitative data also helped to validate the findings.

The last limitation is that the last TLR (the VoIF) was evaluated in one cycle only, while the other TLRs (SoMCard, MMB and the LoEN) were evaluated in two cycles. This was due to time constraints. This limitation resulted in the data collected being limited to a single measure of learning gain (pre and post-tests) and a measure of student attitudes towards the resource (the questionnaire). All of this data was analysed quantitatively (see Chapter 6).

7.3 Implications

The main value of this research lies in the three TLRs developed to challenge students’ alternative conceptions of the core ideas in General Chemistry Course. All of the TLRs can be used in the Chemistry teaching for undergraduate students as well as high school students (age 16-18), especially for those who have the inadequate internet connection to access the existing resources, such as Indonesia. All TLRs were developed with a minimal use of an advanced technology. The SoMCards and MMB, the LoEN and the VoIF offer a novel research-based approach for challenging students’ common misconceptions by successfully embedding the three levels of representations to emphasise the integration of those levels in core chemistry teaching.

7.3.1 Implications for Instructional Process

The use of Action Research (AR) for developing chemistry TLRs has not been reported previously. AR is usually used for developing new instructional methods, strategy, or approaches in the classroom in order to improve students' performance or understanding. Therefore, this study may trigger interest for more extensive research of the use of AR during the development of TLRs in Chemistry or other subjects. The model of AR proposed in this study, as describe in Figure 7.1 can be used to develop other teaching and learning resources for different topics and subjects.

Many studies have reported the use of chemical representations (microscopic, symbolic and sub-microscopic) to improve students' understanding (Williamson & Abraham, 1995; Kozma et al., 1996; Wu, Krajcik & Soloway, 2001; Kozma & Russell, 1997; Kozma et al., 2000). However, there is limited literature on the impact of embedding chemical representations in TLRs on challenging students' common alternative conceptions. The findings of this study suggested that targeted TLRs could be developed to improve students understanding of core chemical concepts by challenging common alternative conceptions at an early stage of their education.

The TLRs developed in this study have been presented at national and international conferences (STEM Higher Education Conference, 2016, 2017, 2018; International Conference on Chemistry Education (ICCE), 2017; Variety of Chemistry Education and Physics Higher Education Conference, 2018; ASERA Conference 2018). This has helped to raise the profile of the TLRs developed in this study (and the methodologies used to evaluate them) and has resulted in some requests for these to be made available to other educators. A publication based on the development and initial research into the SoMCards and MMB activities has been published in Journal of Chemical Education (published by the American Chemical Society) in 2018 (Erlina, Cane & Williams, 2018). This dissemination means the SoMCards and MMB are already available for educators to access along with detailed written and video instructions on how to use them. It is the author's intention that publications based on the other resources (the LoEN and VoIF) will be written for Journal of Chemical Education and Chemistry Education Research and Practice after completion of the thesis.

7.3.2 Implications for Future Research

The TLRs developed in this study were based on students' common alternative conceptions of core ideas in General Chemistry. The evaluation of the impact of the TLRs on student learning at General Chemistry course level was conducted. With minor modifications, the TLRs developed in this study may be transferable from the context of undergraduate students to high school or secondary school chemistry teaching or from a chemical context to one suitable for a different degree programme (e.g. Biochemistry, Organic Chemistry, etc) or be adapted for use in other countries (e.g. by alignment with the local curriculum and/or translation). The topic and activity of each TLR can be modified and expanded.

There is potential to identify students' alternative conceptions for other concepts in chemistry or other subjects and use this information as the basis for developing other resources. Further research focusing on combatting pre-existing student and perhaps even school-teacher misconceptions could lead to the development of new TLRs for chemistry or indeed in other STEM subjects, needs to be done to improve students' understanding.

The control-experiment classes, one class learning with the TLRs while the other class learning without learning with the TLRs should be designed to investigate the impact of the targeted TLRs based on multiple representations to improve students' conceptual understanding of core concepts and to challenge students' alternative conceptions in chemistry or other subjects.

Moreover, a comparative study related to the implementation of these TLRs between the UK and Indonesia or other international comparisons could be conducted to compare students' responses, perceptions, views and understanding when learning with the TLRs and to identify whether there is a cultural context to these potential misconceptions.

Furthermore, a study of the use of the AR approach as described earlier in this chapter, could be adopted by other researchers. The advantages of this approach are to focus on the educator-researchers' own practice, action and reflection as discussed in Chapter 3. Therefore, the AR approach could be beneficial for other researchers based on their own problems in teaching, particularly to design and develop other TLRs for other topics or subjects.

One particularly interesting area would be to investigate the self-awareness of students about their learning (e.g. recognising conceptual shifts, etc.). Understanding students' self-awareness could help teachers to design a suitable teaching and learning processes to enable students to focus their attention better in their studies

Finally, integrating the three levels of chemistry representations in the TLRs should be considered by other researchers when designing and developing TLRs for other topics, especially if the TLRs are aiming to address students' alternative conceptions since the three levels of representations are believed as one of the major contributors to students' difficulty in learning chemistry.

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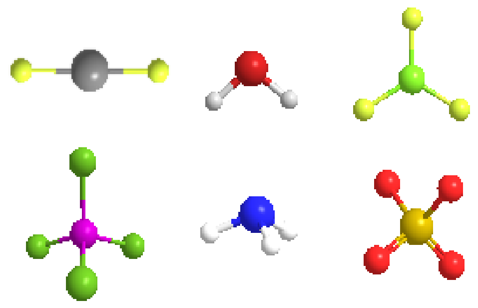
Appendix 1

Valence Shell Electron Pair Repulsion

Activities

How to predict the shape of molecules based on VSEPR Theory



Valence Shell Electron Pair Repulsion

How to play

In this activity you will be given a molecule and you have to predict its shape by answering some questions and following the instructions in the cards. Regarding to this, here are some procedures that you should follow:

1. You should work together as a group. Each group consists of four or five students.
2. At the end of the card you are given a choice as what to do next. Some of your decisions will lead to dead ends as you may have done something incorrectly, so you have to go back.
3. In the end of game, you should make the shape of the molecule that is given using polystyrene balls and cocktail sticks then write down the series of steps to predict the shape of molecules with your own word in the worksheet.

Good luck and have fun!

2

Valence Shell Electron Pair Repulsion

Introduction to VSEPR

The shape of molecules is one of important key concept in chemical bonding. Understanding the shape of molecules is an important step to discuss and predict the chemical properties. The shape of molecules influenced by some factors, namely electron configuration, number of lone or bond pair electrons and repulsion between electron pairs.

In Valence Shell Electron Pair Repulsion (VSEPR) theory, pairs of electrons that surround the central atom of a molecule or ion are arranged as far apart as possible to minimize electrons repulsion. This will influence the size of the bond angles and the shape of molecules.

4

Valence Shell Electron Pair Repulsion

Some definitions that you should consider:

1. ***Central atom*** is usually an atom that has the lowest electronegativity.
2. ***Electronegativity*** is a measure of tendency of an atom to attract a bonding pair of electron.
3. ***Electron configuration*** is the distribution of electrons in an atom.
4. ***Valence electron*** is electron that is located in the outer shell.
5. ***Outer atom/substituent*** is an atom or group of atoms that bonded to the central atom.
6. ***Electron pairs** repulsion* is the tendency of electron pairs around the central atom to orient themselves as far apart as possible.
7. ***Lewis structure*** is a diagram that shows the bonding between atoms in a molecule and the lone pair/s electron that may exist.
8. ***Molecule structure** or geometry* is a three-dimension shape of molecule.
9. ***TNVEP*** = Total Number of Valence Electron Pairs surrounding the central atom.

5

Valence Shell Electron Pair Repulsion

Learning objectives

By the end of this activity you will be able to:

1. Write the steps to predict the shape of molecules.
2. Apply the VSEPR to predict the shape of molecules.

3

Valence Shell Electron Pair Repulsion

1. How to decide which atom is the central atom?
   a. By choosing the most electronegative atom
   b. By choosing the atom that has the biggest valence electron
   c. By choosing the least electronegative atom
   d. By choosing the atom that has the smallest valence electron

2. What the central atom is in this example?
   a. B (if you choose this, go to p. 8)
   b. F (if you choose this, go to p. 9)

7

Valence Shell Electron Pair Repulsion

The questions in this game are all based on the following molecule:

BF_3
(Boron trifluoride)

6

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 8 and try again.

Hint:
Remember to count the core and valence electrons.

10

Valence Shell Electron Pair Repulsion

Correct!

3. What is the total number of electrons that B has?
    a. 3 (go to card 10)
    b. 5 (go to card 11)
    c. 7 (go to card 12)

8

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to *card 7* and try again.

Hint:
You have to consider that *central atom* usually is the atom that has the least electronegativity. To make a correct choice you have to compare the electronegativity between B and F using periodic table.

9

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 8 and try again.

Hint:
Remember to count the core and valence electrons.

12

Valence Shell Electron Pair Repulsion

Correct!

4. How many **valence** electrons does B have?
    a. 3 (go to card 13)
    b. 5 (go to card 14)
    c. 7 (go to card 15)

11

V Se Pr

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 11 and try again.

Hint:

Remember the valence electrons are those in the outer shell.

15

V Se Pr

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 11 and try again.

Hint:

Remember the valence electrons are those in the outer shell.

14

V Se Pr

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 13 and try again.

Hint:

Remember to count the core and valence electrons.

16

V Se Pr

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 13 and try again.

Hint:

Remember to count the core and valence electrons.

17

Valence Shell Electron Pair Repulsion

Correct!

You have decided that B is the central atom, so it means F is the outer atom or substituent.

5. What is the total number of electrons that F has?
   a. 5 (if you choose this, go to card 16)
   b. 7 (if you choose this, go to card 17)
   c. 9 (if you choose this, go to card 18)

13

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 18 and try again.

Hint:
Remember the valence electrons are those in the outer shell.

19

Valence Shell Electron Pair Repulsion

Correct!

6. How many **valence** electrons does F have?
   a. 5 (if you choose this, go to card 19)
   b. 7 (if you choose this, go to card 20)
   c. 9 (if you choose this, go to card 21)

18

Valence Shell Electron Pair Repulsion

Correct!

Now, you have to count the total number of valence electron pairs surrounding the central atom (TNVEP) by using the formula below:
TNVEP = ½ (valence electron of central atom + the number of electrons given by substituent/s – the charge (if the molecule is an ion).

8. What is the total number of valence electron pairs surrounding the central atom?
   a. 3 (go to card 25)
   b. 4 (go to card 26)
   c. 5 (go to card 27)

22

Valence Shell Electron Pair Repulsion

Correct!

7. How many electrons are used by each F atom to make bonds with central atom?
   a. 1 (go to card 22)
   b. 2 (go to card 23)
   c. 3 (go to card 24)

20

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 18 and try again.

Hint:
Remember the valence electrons are those in the outer shell.

21

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 20 and try again.

Hint:
Think about how many F atoms are bonded to the central atom.

23

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 20 and try again.

Hint:
Think about how many F atoms are bonded to the central atom.

24

V Se Pr

Valence Shell Electron Pair Repulsion

Sorry this is wrong. Please go back to card 22 and try again.

Hint:
You should put all substituents that involved.

27

V Se Pr

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 22 and try again.

Hint:
You should put all substituents that involved.

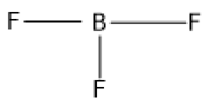
26

V Se Pr

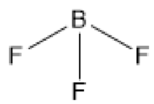
Valence Shell Electron Pair Repulsion

Correct!

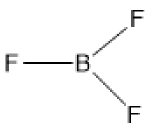
10. What is the Lewis structure of NF_3?

a. 

Go to p. 31

c. 

Go to p. 33

b. 

Go to p. 32

30

V Se Pr

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 25 and try again.

Hint:
Here are two important definitions:
Bond pairs are pairs of electrons around the central atom that are used to bond to substituent/s.
Lone pairs are pairs of electrons around the central atom that are not used to bond to substituent/s.

28

Valence Shell Electron Pair Repulsion

Correct!

9. How many bond pairs (BP) and lone pairs (LP) are there around the central atom?
   a. 3 BP and 2 LP (go to card 28)
   b. 2 BP and 3 LP (go to card 29)
   c. 3 BP, but no LP (go to card 30)

To answer this you may use the formula below:
BP = the number of substituents involved
LP = Valence electron of central atom – TNVEP

25

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 30 and try again.

Hint:
You have to consider that B does not have lone pair electron, so the Lewis structure will not like this.

31

Valence Shell Electron Pair Repulsion

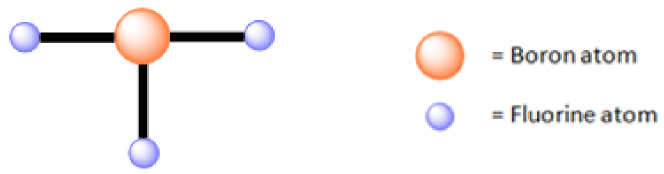
Sorry, this is wrong. Please go back to card 25 and try again.

Hint:
Here are two important definitions:
Bond pairs are pairs of electrons around the central atom that are used to bond to substituent/s.
Lone pairs are pairs of electrons around the central atom that are not used to bond to substituent/s.

29

Valence Shell Electron Pair Repulsion

Sorry, this is wrong shape.



Hint:
This shape only occurs if Boron as central atom has lone pair/s electron.

34

V Se Pr

Valence Shell Electron Pair Repulsion

Correct!

This is the right Lewis structure because there is no lone pair electron around the central atom.

11. Then, based on your Lewis structure, what is the shape of the molecule?
    a. T-shaped (go to card 34)
    b. Trigonal planar (go to card 35)
    c. Trigonal pyramidal (go to card 36)

32

V Se Pr

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 30 and try again.

Hint:

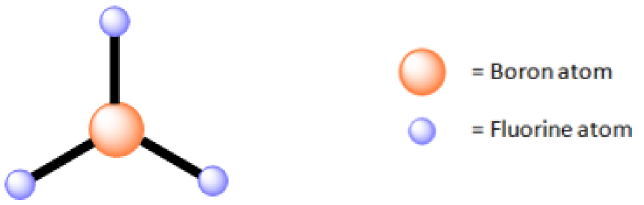
You have to consider that B does not have lone pair/s electron, so the Lewis structure will not like this.

33

V Se Pr

Valence Shell Electron Pair Repulsion

Congratulation! This is the correct shape!



Well done! This is the correct shape because there is no lone pair electrons around the central atom, so the substituents will be in this positions with the same angle to get a stable position and to reduce the repulsion between electrons.

35

V Se Pr

Valence Shell Electron Pair Repulsion

Sorry this is the wrong shape.

Hint:

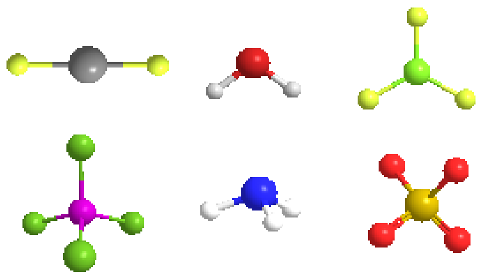
This shape only occurs if Boron as central atom has lone pair/s electron.

36

Valence Shell Electron Pair Repulsion

Activities

How to predict the shape of molecules based on VSEPR Theory



Valence Shell Electron Pair Repulsion

How to play

In this activity you will be given a molecule and you have to predict its shape by answering some questions and following the instructions in the cards. Regarding to this, here are some procedures that you should follow:

1. You should work together in pairs.
2. At the end of the card you are given a choice as what to do next. Some of your decisions will lead to dead ends as you may have done something incorrectly, so you have to go back.
3. In the end of game, you should make the shape of the molecule that is given using polystyrene balls and cocktail sticks then write down the series of steps to predict the shape of molecules with your own word in the worksheet.

Good luck and have fun!

2

Valence Shell Electron Pair Repulsion

Introduction to VSEPR

The shape of molecules is one of important key concept in chemical bonding. Understanding the shape of molecules is an important step to discuss and predict the chemical properties. The shape of molecules influenced by some factors, namely electron configuration, number of lone or bond pair electrons and repulsion between electron pairs.

In Valence Shell Electron Pair Repulsion (VSEPR) theory, pairs of electrons that surround the central atom of a molecule or ion are arranged as far apart as possible to minimize electrons repulsion. This will affect the size of the bond angles and the shape of molecules.

4

Valence Shell Electron Pair Repulsion

Some definitions that you should consider:

1. ***Central atom*** is usually an atom that has the lowest electronegativity.
2. ***Electronegativity*** is a measure of tendency of an atom to attract a bonding pair of electron.
3. ***Electron configuration*** is the distribution of electrons in an atom.
4. ***Valence electron*** is electron that is located in the outer shell.
5. ***Outer atom/substituent*** is an atom or group of atoms that bonded to the central atom.
6. ***Electron pairs** repulsion* is the tendency of electron pairs around the central atom to orient themselves as far apart as possible.
7. ***Lewis structure*** is a diagram that shows the bonding between atoms in a molecule and the lone pair/s electron that may exist.
8. ***Molecule structure** or geometry* is a three-dimension shape of molecule.
9. ***TNVEP*** = Total Number of Valence Electron Pairs surrounding the central atom.

5

Valence Shell Electron Pair Repulsion

Learning objectives

By the end of this activity you will be able to:

1. Write the steps to predict the shape of molecules.
2. Apply the VSEPR to predict the shape of molecules.

3

Valence Shell Electron Pair Repulsion

1. How to decide which atom is the central atom?
   a. By choosing the most electronegative atom
   b. By choosing the atom that has the biggest valence electron
   c. By choosing the least electronegative atom
   d. By choosing the atom that has the smallest valence electron

2. What the central atom is in this example?
   a. N (if you choose this, go to p. 8)
   b. F (if you choose this, go to p. 9)

7

Valence Shell Electron Pair Repulsion

The questions in this game are all based on the following molecule:

NF_3

(Nitrogen trifluoride)

6

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 8 and try again.

Hint:
Remember to count the core and valence electrons.

10

Valence Shell Electron Pair Repulsion

Correct!

3. What is the total number of electrons that N has?
    a. 5 (go to card 10)
    b. 7 (go to card 11)
    c. 11 (go to card 12)

8

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to *card 7* and try again.

Hint:
You have to consider that *central atom* usually is the atom that has the least electronegativity. To make a correct choice you have to compare the electronegativity between N and F using periodic table.

9

Valence Shell Electron Pair Repulsion

Correct!

4. How many **valence** electrons does N have?
    a. 3 (go to card 13)
    b. 5 (go to card 14)
    c. 7 (go to card 15)

11

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 8 and try again.

Hint:
Remember to count the core and valence electrons.

12

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 11 and try again.

Hint:
Remember the valence electrons are those in the outer shell.

13

Valence Shell Electron Pair Repulsion

Correct!

You have decided that N is the central atom, so it means F is the outer atom or substituent.

5. What is the total number of electrons that F has?
   a. 5 (if you choose this, go to card 16)
   b. 7 (if you choose this, go to card 17)
   c. 9 (if you choose this, go to card 18)

14

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 14 and try again.

Hint:
Remember to count the core and valence electrons.

16

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 14 and try again.

Hint:
Remember to count the core and valence electrons.

17

V Se Pr

Valence Shell Electron Pair Repulsion

Sorry, this is wrong, Please go back to card 11 and try again.

Hint:

Remember the valence electrons are those in the outer shell.

15

V Se Pr

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 18 and try again.

Hint:

Remember the valence electrons are those in the outer shell.

19

V Se Pr

Valence Shell Electron Pair Repulsion

Correct!

6. How many **valence** electrons does F have?
   a. 5 (if you choose this, go to card 19)
   b. 7 (if you choose this, go to card 20)
   c. 9 (if you choose this, go to card 21)

18

V Se Pr

Valence Shell Electron Pair Repulsion

Correct!

Now, you have to count the total number of valence electron pairs surrounding the central atom (TNVEP) by using the formula below:
TNVEP = ½ (valence electron of central atom + the number of electrons given by substituent/s – the charge (if the molecule is an ion))

8. What is the total number of valence electron pairs surrounding the central atom?
   a. 3 (go to card 25)
   b. 4 (go to card 26)
   c. 6 (go to card 27)

22

Valence Shell Electron Pair Repulsion

Correct!

7. How many electrons are used by each F atom to make bonds with central atom?
   a. 1 (go to card 22)
   b. 2 (go to card 23)
   c. 3 (go to card 24)

20

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 18 and try again.

Hint:
Remember the valence electrons are those in the outer shell.

21

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 20 and try again.

Hint:
Think about how many F atoms are bonded to the central atom.

23

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 20 and try again.

Hint:
Think about how many F atoms are bonded to the central atom.

24

Valence Shell Electron Pair Repulsion

Sorry this is wrong. Please go back to card 22 and try again.

Hint:
You should put all substituents that involved.

25

Valence Shell Electron Pair Repulsion

Correct!

9. How many bond pairs (BP) and lone pairs (LP) are there around the central atom?
   a. 3 BP and 1 LP (go to card 28)
   b. 1 BP and 3 LP (go to card 29)
   c. 3 BP, but no LP (go to card 30)

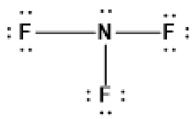
To answer this you may use the formula below:
BP = the number of substituents involved
LP = Valence electron of central atom – TNVEP

26

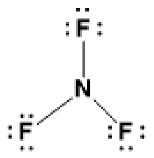
Valence Shell Electron Pair Repulsion

Correct!

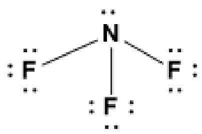
10. What is the Lewis structure of NF_3?

a.


Go to p. 31

b.


Go to p. 32

c.


Go to p. 33

28

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 26 and try again.

Hint:
Here are two important definitions:
Bond pairs are pairs of electrons around the central atom that are used to bond to substituent/s.
Lone pairs are pairs of electrons around the central atom that are not used to bond to substituent/s.

29

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 22 and try again.

Hint:
You should put all substituents that involved.

27

Valence Shell Electron Pair Repulsion

Correct!

This is the right Lewis structure because you have already drawn lone pair/s electron around the central atom.

11. Then, based on your Lewis structure, what is the shape of the molecule?
    a. Trigonal planar (go to card 34)
    b. T-shaped (go to card 35)
    c. Trigonal pyramidal (go to card 36)

31

Valence Shell Electron Pair Repulsion

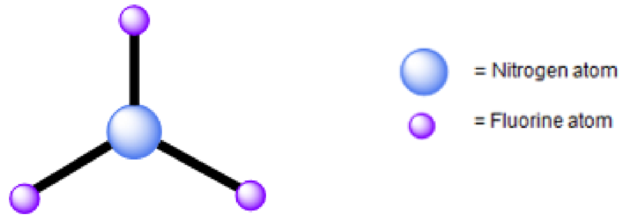
Sorry, this is wrong. Please go back to card 26 and try again.

Hint:
Here are two important definitions:
Bond pairs are pairs of electrons around the central atom that are used to bond to substituent/s.
Lone pairs are pairs of electrons around the central atom that are not used to bond to substituent/s.

30

Valence Shell Electron Pair Repulsion

Sorry, this is wrong shape. Please go back to card 31 or 33 and try again



Hint:
You have to consider about lone pair electrons around the central atom

34

V Se Pr

Valence Shell Electron Pair Repulsion

Sorry, this is wrong. Please go back to card 28 and try again.

Hint:

You have to consider that N has one lone pair electron, so the Lewis structure will not like this. This structure only happened when NF_3 molecule is an ion.

32

V Se Pr

Valence Shell Electron Pair Repulsion

Correct!

This is the right Lewis structure because you have already drawn about the lone pair electrons around the central atom.

11. Then, based on your Lewis structure, what is the shape of the molecule?
    a. Trigonal planar (go to card 34)
    b. T-shaped (go to card 35)
    c. Trigonal pyramidal (go to card 36)

33

V Se Pr

Valence Shell Electron Pair Repulsion

Sorry this is the wrong shape. Please go back to card 31 or 33 and try again

Hint:

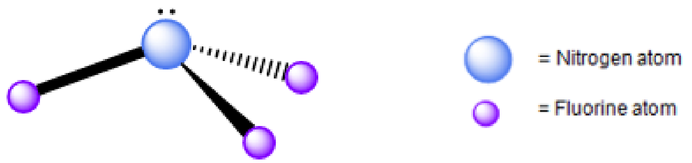
Although you have already thought the lone pair electron around the central atom, but you have to consider that the lone pair need more space so they will push the bond pairs electron between N-F as far as possible to get a stable position.

35

V Se Pr

Valence Shell Electron Pair Repulsion

Congratulation! This is the correct shape!



Well done! This is the correct shape. The lone pair electron around the central atom need more space, so they will push the bond between N-F as far as possible to get a stable position to reduce the repulsion between electrons.

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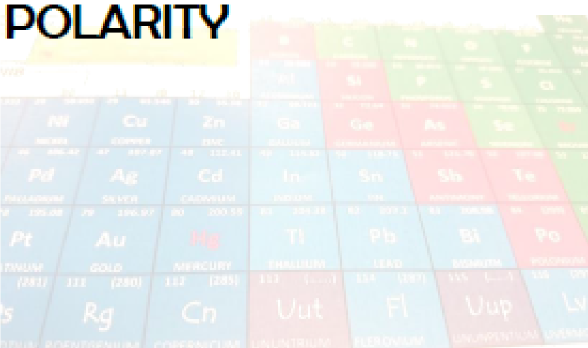
Appendix 2

Basic concept of Chemical Bonding

ELECTRONEGATIVITY, BOND TYPES AND POLARITY



UNIVERSITAS TANJUNGPURA UNIVERSITY OF LEICESTER

Electronegativity

One of the most important concepts in chemical bonding is electronegativity (EN). Electronegativity is the ability of an atom in a molecule to attract shared electrons to it-self. The greater an atom's electronegativity, the greater its ability to attract electrons to it-self. The trend of electronegativity in the periodic table can be seen in the figure 1.

Electronegativity is one of periodic table trends. The most common way to measure electronegativity is by using the Pauling scale. Linus Pauling was an American scientist who won the Nobel Prizes for both chemistry and peace. The Pauling scale of electronegativity can be seen on figure 1 as well.

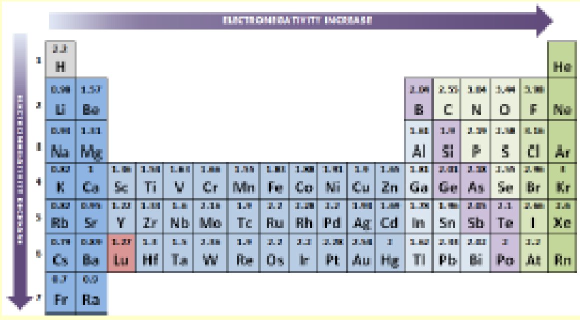


Figure 1 The Pauling's Electronegativity Scale

In general, electronegativity increases across a period and decreases down a group. Note that the most electronegative element is fluorine (4.0), while francium has the least (0.7).

Bond Character and Bond Types

A chemical bond between atoms of different elements is never completely ionic or covalent. The degree of ionic or covalent character of a bond depends on how strongly each of the bonded atoms attracts electrons. As shown in Table 1, the character and type of a chemical bond can be predicted using the electronegativity differences of the elements that bond.

Table 1 EN difference and Bond character

ΔEN and Bond Character	
Electronegativity Difference	**Bond Character**
> 1.7	mostly ionic
0.4 - 1.7	polar covalent
< 0.4	mostly covalent
0	nonpolar covalent

Electrons in bonds between identical atoms have an electronegativity difference of zero—meaning that the electrons are equally shared between the two atoms. This type of bond is considered nonpolar covalent, or a pure covalent bond. On the other hand, because different elements have different electronegativity, the electron pairs in a covalent bond between different atoms are not shared equally.

Unequal sharing results in a polar covalent bond. When there is a large difference in the electronegativity between bonded atoms, an electron is transferred from one atom to the other, which results in bonding that is primarily ionic.

Bonding is not often clearly ionic or covalent. An electronegativity difference of 1.70 is considered 50 percent covalent and 50 percent ionic.

As the difference in electronegativity increases, the bond becomes more ionic in character. Generally, ionic bonds form when the electronegativity difference is greater than 1.70.

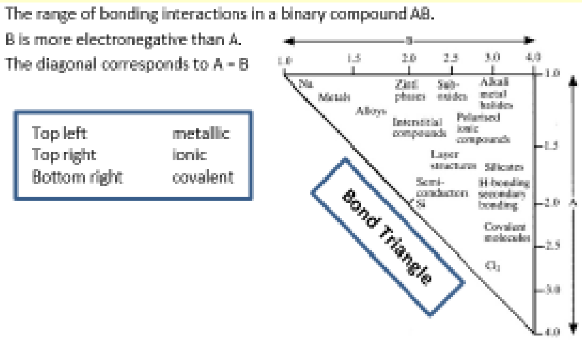
Bond types

How to identify the bond types? There are 2 ways to identify the bond types. The first approach is to use our understanding of the periodic table. This is the most common and easiest way to identify the bond types.

Here are the rules to predict the bond type:

1. **Ionic bonding** usually happens between metallic elements and non-metallic elements, such as NaCl, $MgCl_2$, MgO etc.
2. **Covalent bonding** usually happens between non-metallic elements. For instance, O_2, Cl_2, H_2O, etc.
3. **Metallic bonding** happens between metallic elements. Examples; Al, Cu, Fe, etc.

Another way to predict the bond types is using the difference in the electronegativity (ΔEN) of the bonded atom. We can use the Bond Triangle to provide an overview of bonding types.



Polarity

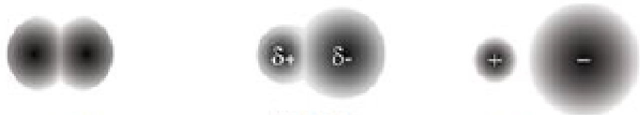
The relationship between electronegativity and bond character (table 1) can also be used to identify whether a molecule is polar or non-polar covalent.

By understanding the concept of electronegativity we can explain not only the types of chemical bond but polarity as well.

Bond polarity is a measure of how equally or unequally the electrons in any covalent bond are shared. A nonpolar covalent bond is one in which the electron are shared equally, as in Cl_2 and H_2. In a polar covalent bond, one of the atoms exerts a greater attraction for the bonding electrons than the other. If the difference in relative ability to attract electrons is large enough, an ionic bond is formed.

We can use the difference in electronegativity between two atoms to gauge the polarity of the bond the atoms form. Consider these three chlorine-containing compounds:

Molecules	Cl_2	HCl	NaCl
Electronegativity difference	3.0 – 3.0 = 0	3.0 – 2.1 =0.9	3.0 – 0.9 = 2.1
Type of bond	Non-polar covalent	Polar covalent	Ionic
Criteria	ΔEN < 0.4	ΔEN 0.4 - 1.7	ΔEN > 1.7



In Cl_2 the electrons are shared equally between the chlorine atoms and, thus, the covalent bond is nonpolar. A nonpolar covalent bond results when the electronegativities of the bonded atoms are equal.

In HCl the chlorine atom has a greater electronegativity than the hydrogen atom, with the result that the electrons are shared unequally, thus the bond is polar covalent.

In general, a polar covalent bond result when the atoms differ in electronegativity and tend to occur between atoms of moderately different electronegativities (0.4 - 1.7).

Polarity plays an important role in chemistry because of two reasons. First, polar and nonpolar molecules do not mix to form a solution. Second, polarity influences several physical properties of matter, such as solubility, surface tension and melting point. Polar molecules and ionic compounds usually soluble in polar substances, but non polar molecules dissolve only in non-polar substances.

In HCl the more electronegative chlorine atom attracts electron density away from the less electronegative hydrogen atom, leaving a partial positive charge on the hydrogen atom and a partial negative charge on the chlorine atom. We can represent this charge distribution as

$$\overset{\delta+}{H} - \overset{\delta-}{Cl}$$

The δ+ and δ- (read delta plus and delta minus) symbolize the partial positive and negative charges, respectively. In a polar bond, these numbers are less than the full charges of the ions.

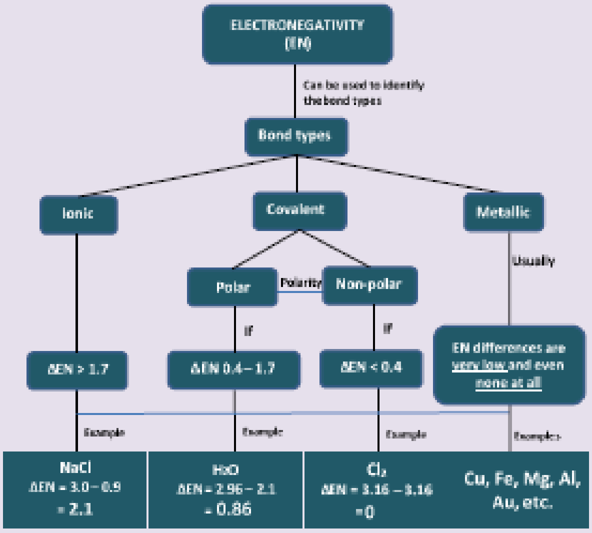
In NaCl the electronegativity difference is very large. It effectively means that one Na's valence electrons is transferred to Cl to produce a pair of ions. The resultant bond is therefore most accurately described as ionic. Thus, if we considered the bond in NaCl to be fully ionic, we could say δ+ for Na is +1 and δ- for Cl is 1-. Electronegativity also give us a simple way of predicting which atom in a polar covalent has the partial negative charge and which has the partial positive charge. *In a polar covalent bond, the atom with the higher electronegativity has the partial negative charge, and the atom with the lower electronegativity has the partial positive charge.*

For example, the electronegativity of fluorine (4.0) is higher than for hydrogen (2.1). In an H-F bond, we predict that the fluorine atom attracts more strongly than the hydrogen atom and gets a partial negative charge.

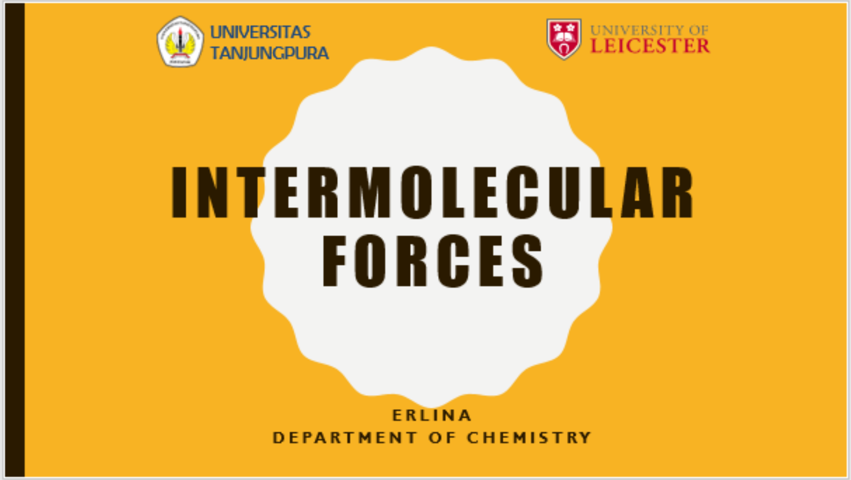
Due to its lower electronegativity, the hydrogen atom has a partial positive charge.

Summary

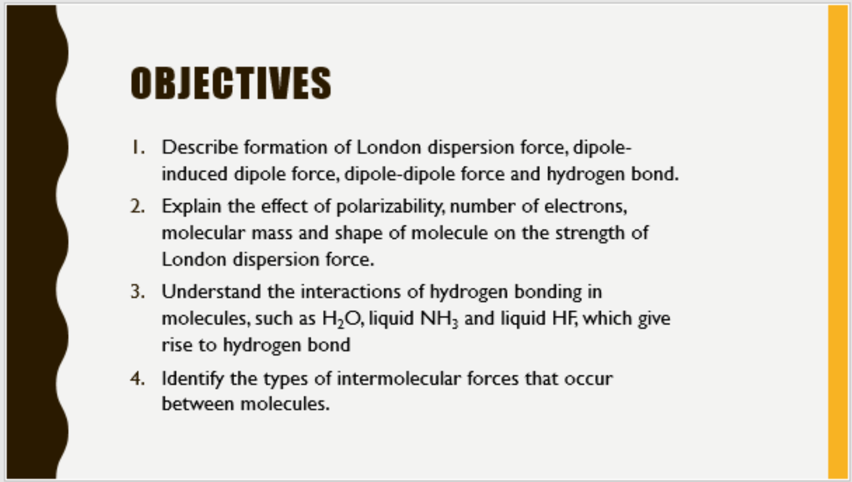
In conclusion, here is the diagram to depict the relationship between electronegativity (EN), ΔEN, bond types and polarity and how to predict the bond types using ΔEN.



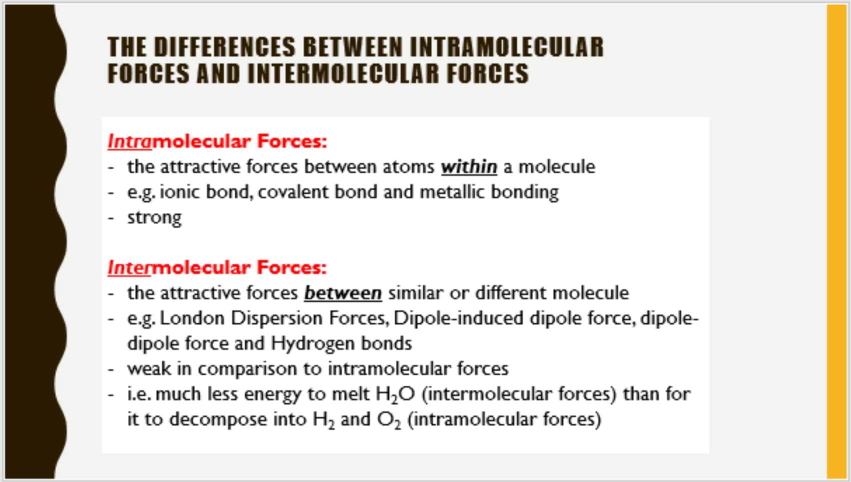
Appendix 3



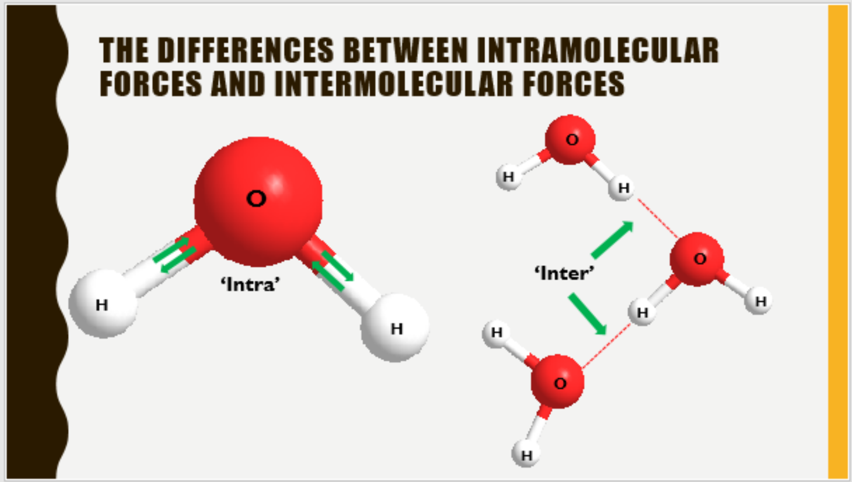
1



2

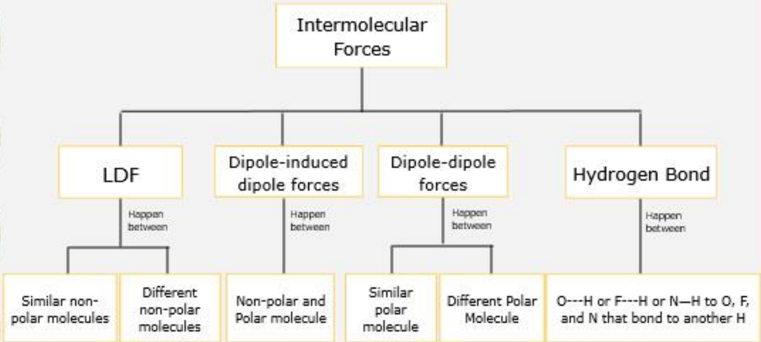


3



4

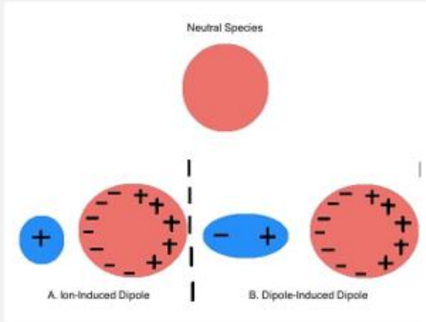
TYPES OF INTERMOLECULAR FORCES



5

LONDON DISPERSION FORCES (LDFS)

POLARIZABILITY



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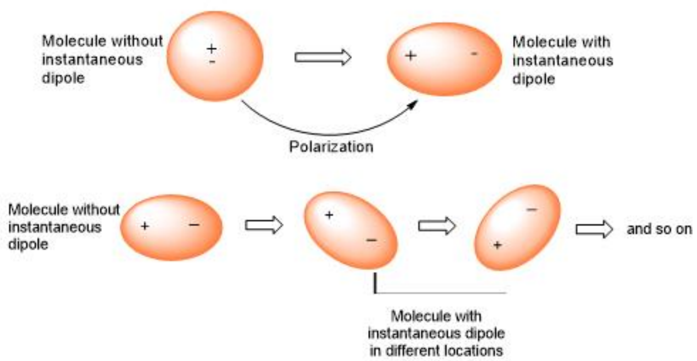
LONDON DISPERSION FORCES (LDF)



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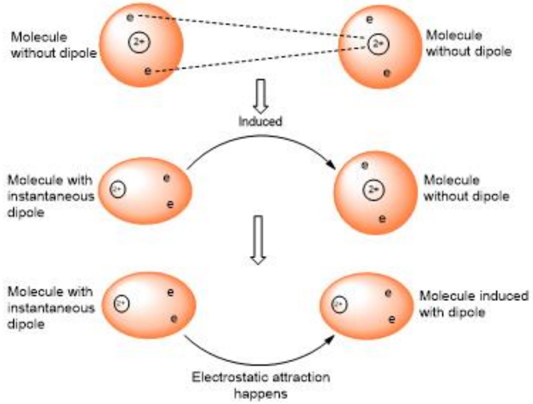
LONDON DISPERSION FORCE



8

LONDON DISPERSION FORCES (LDF)

POLARIZABILITY

Table 1. Boiling point of noble gases and halogens

Noble gases	Number of Electron	Boiling point (°C)
He	2	-268.6
Ne	10	-245.9
Ar	18	-185.7
Kr	36	-152.3
Xe	54	-107.1
Rn	86	-61.8

INCREASES

Halogens	Number of Electron	Boiling point (°C)
F_2	18	-188.1
Cl_2	34	-34.6
Br_2	70	58.8
I_2	106	184.4

9

LONDON DISPERSION FORCES (LDF)

NUMBER OF ATOM IN A MOLECULE

Table 2. Boiling points of some hydrocarbon

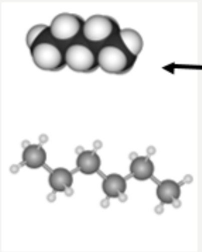
Hydrocarbon	Name	Boiling point at 1 atm (°C)
CH_4	methane	-161.5
C_2H_6	ethane	-88.6
C_3H_8	propane	-42.1
C_4H_{10}	*n*-butane	-0.5
C_5H_{12}	*n*-pentane	36.1
C_6H_{14}	*n*-hexane	68.7
C_7H_{16}	*n*-heptane	98.42
C_8H_{18}	*n*-octane	125-126
C_9H_{20}	*n*-nonane	150.80
$C_{10}H_{22}$	*n*-decane	174.1

INCREASES

10

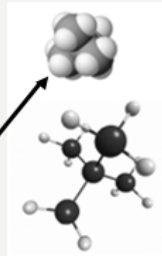
LONDON DISPERSION FORCES (LDF)

THE SHAPE OF MOLECULE



Larger surface area enhances intermolecular contact and increases dispersion force

Smaller surface area diminishes intermolecular contact and decreases dispersion force

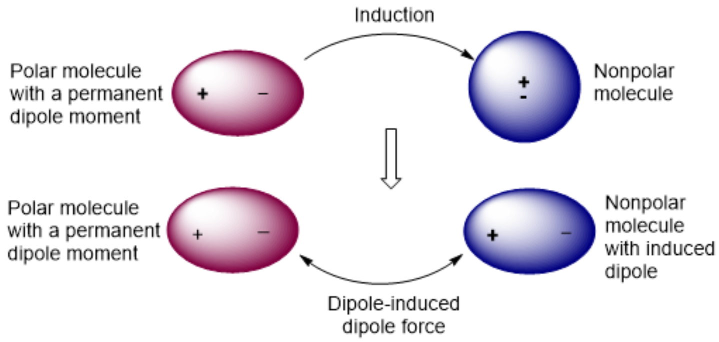


Linear Molecule
n-Pentane (C_5H_{12})

Spherical Molecule
Neopentane (C_5H_{12})

11

DIPOLE-INDUCED DIPOLE FORCES



12

LONDON DISPERSION FORCES (LDF)

POLARIZABILITY

Table 1. Boiling point of noble gases and halogens

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He	2	-268.6
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INCREASES

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I_2	106	184.4

9

LONDON DISPERSION FORCES (LDF)

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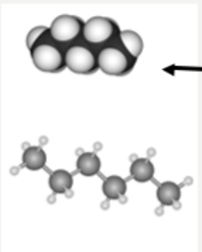
C_5H_{12}	*n*-pentane	36.1
C_6H_{14}	*n*-hexane	68.7
C_7H_{16}	*n*-heptane	98.42
C_8H_{18}	*n*-octane	125-126
C_9H_{20}	*n*-nonane	150.80
$C_{10}H_{22}$	*n*-decane	174.1

INCREASES

10

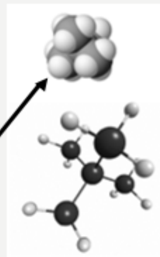
LONDON DISPERSION FORCES (LDF)

THE SHAPE OF MOLECULE



Larger surface area enhances intermolecular contact and increases dispersion force

Smaller surface area diminishes intermolecular contact and decreases dispersion force

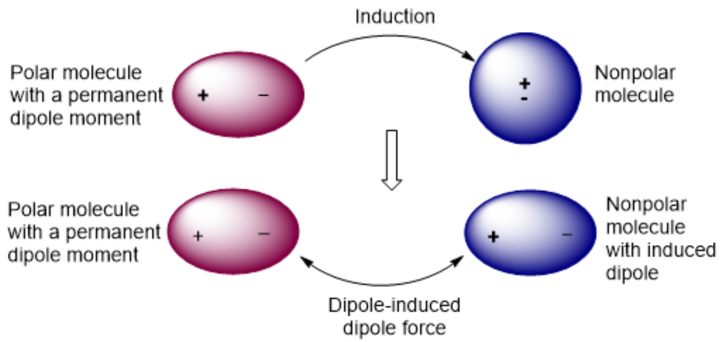


Linear Molecule
n-Pentane (C_5H_{12})

Spherical Molecule
Neopentane (C_5H_{12})

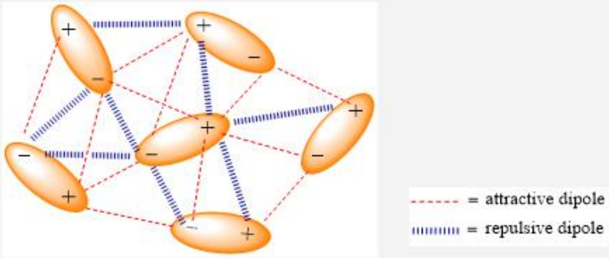
11

DIPOLE-INDUCED DIPOLE FORCES



12

DIPOLE-DIPOLE FORCES

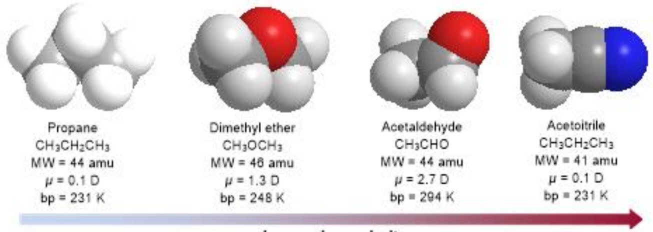


Dipole-dipole forces between polar molecules in liquid state

13

DIPOLE-DIPOLE FORCE

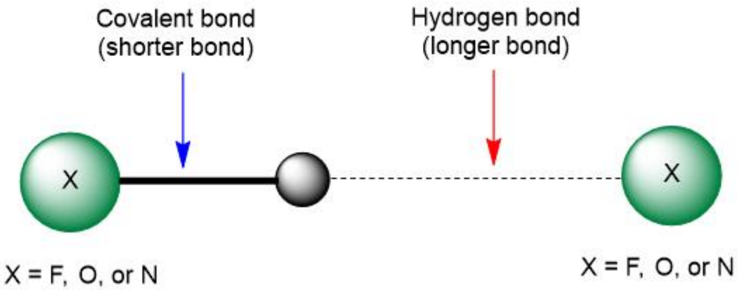
Dipole-dipole interactions



The more polar the molecule, the higher its boiling point.

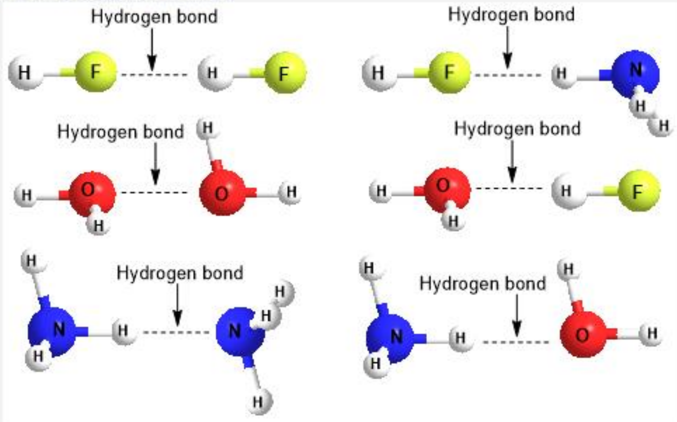
14

HYDROGEN BOND



15

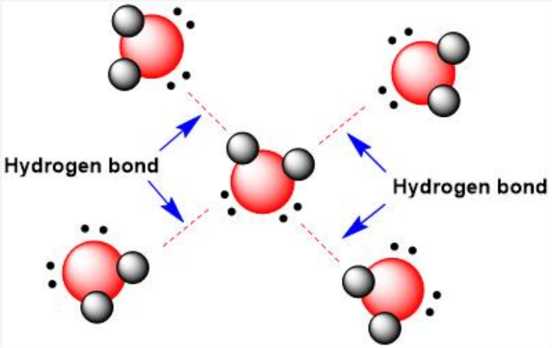
HYDROGEN BOND



16

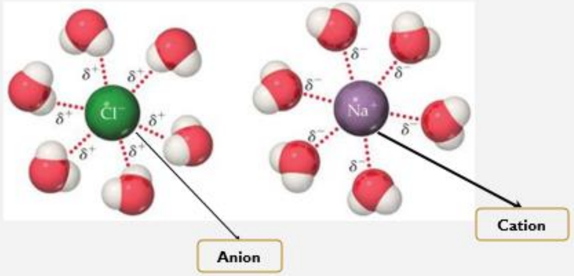
HYDROGEN BOND

HYDROGEN BOND IN WATER



17

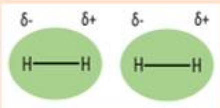
ION-DIPOLE FORCE



18

SUMMARY

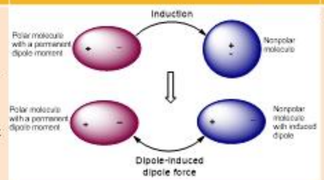
LONDON DISPERSION FORCE

Definition	Diagram	Relative strength	Other information
- Attraction between 2 instantaneous dipoles - Asymmetrical electron distribution - All atoms and molecules		Weakest among other intermolecular forces	Increase in strength as molar mass increases (more electrons)

19

SUMMARY

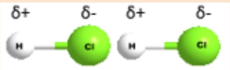
DIPOLE-INDUCED DIPOLE FORCE

Definition	Diagram	Relative strength	Other information
- Attraction between polar and nonpolar molecules by disturbing the arrangement of electrons in the nonpolar species - Occur between the polar molecules having permanent dipole and the molecules lacking permanent dipole		Weak	Induced dipole moment depends upon the dipole moment present in the permanent dipole and the polarizability of the electrically neutral molecule

20

SUMMARY

DIPOLE-DIPOLE FORCE

Definition	Diagram	Relative strength	Other information
- Attraction between 2 permanent dipoles - Polar molecules		Medium strength	Stronger when molecules are closer

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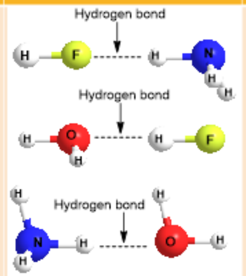
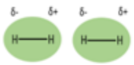
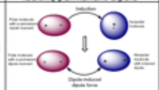
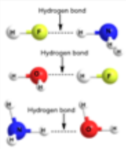
SUMMARY

HYDROGEN BOND

Definition	Diagram	Relative strength	Other information
- Attraction between molecules with N--H, O--H, & H--F bonds - Extremely polar bonds with very strong dipole-dipole force		Strongest among other intermolecular forces	Not chemical bonding

22

SUMMARY

	LONDON DISPERSION FORCE	DIPOLE-INDUCED DIPOLE FORCE	DIPOLE-DIPOLE FORCE	HYDROGEN BOND
Definition	• Attraction between 2 instantaneous dipoles • Asymmetrical electron distribution • All atoms & molecules	• Attraction between polar and nonpolar molecules by disturbing the arrangement of electrons in the nonpolar species • Occur between the polar molecules having permanent dipole and the molecules lacking permanent dipole	• Attraction between 2 permanent dipoles • Polar molecules	• Attraction between molecules with N-H, O-H & F-H bonds • Extremely polar bonds with very strong dipole-dipole force
Diagram				
Relative Strength	Weakest	Weak	Medium strength	Strongest
Other Information	Increase in strength as molar mass increases (more electrons)	Induced dipole moment depends upon the dipole moment present in the permanent dipole and the polarisability of the electrically neutral molecule	Stronger when molecules are closer	Not chemical bonding

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Appendix 4

Link of the video

Link of how to play the SoMCards and MMB activity

https://youtu.be/872N7GUSswU

Link of the VoIF

https://youtu.be/wi2smJ4tc_s

Appendix 5

Feedback Questionnaire of SoMCards and MMB

Instructions:

1. Tick (√) the most appropriate column in section 1.
2. Please write down your comments in section 2

Section 1

No	Statements	Options				
		Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
1	The card-game instructions are clear and understandable					
2	Answering the questions in the card-game helped me understand the topic					
3	I know how to predict the shape of molecule based on VSEPR theory					
4	The questions in the card-game are challenging					
5	I enjoyed playing the card-game					
6	The presentation of the card-game is good					
7	Making the molecular model using polystyrene balls and cocktail sticks are engaging					
8	Making the molecular model help me understand the influence of lone pair electrons on shape of molecules					

Section 2

Comments or suggestions

1. Which parts of the card game was most useful?

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2. Which parts of the card game was less useful?

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3. What changes would you like us to make to the card game?

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Feedback Questionnaire of the LoEN

Instructions:

3. Tick (√) the most appropriate column in section 1.
4. Please write down your comments in section 2

Section 1

No	Statements	Options				
		Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
1	Contents of the leaflet are clear and understandable					
2	Learning with leaflet help me understand the topic					
3	I know how to predict the bond types and polarity through concept presented in leaflet					
4	Concepts presented in leaflet are complete					
5	I enjoyed learning with the leaflet					
6	The presentation of the leaflet is interesting					
7	Learning with the leaflet is effective					
8	Leaflet is easy to use and practical					

Section 2

Comments or suggestions

4. Which parts of the leaflet was most useful?

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5. Which parts of the leaflet was less useful?

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6. What changes would you like us to make to the leaflet?

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Feedback Questionnaire of VoIF

Instructions:

5. Tick (√) the most appropriate column in section 1 and 2
6. Please write down your comments in section 3

Section 1. Video presentation

No	Statements	Options				
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	I enjoyed watching the intermolecular forces video					
2	All pictures and figures were clear					
3	The explanations helped me to understand the concepts					
4	The video helped me to visualise intermolecular forces					
5	This video did not help me in understanding the concepts of intermolecular forces					
6	The presentation of the intermolecular forces video is good					
7	The pictures presented in the video are useful					

Section 2. Comments or suggestions

7. Which parts of the video was most useful in assisting you to understand the concepts of intermolecular forces?

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8. Which parts of the video was less useful in assisting you to understand the concepts of intermolecular forces?

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9. What changes would you like us to make to the video?

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Any general comments:

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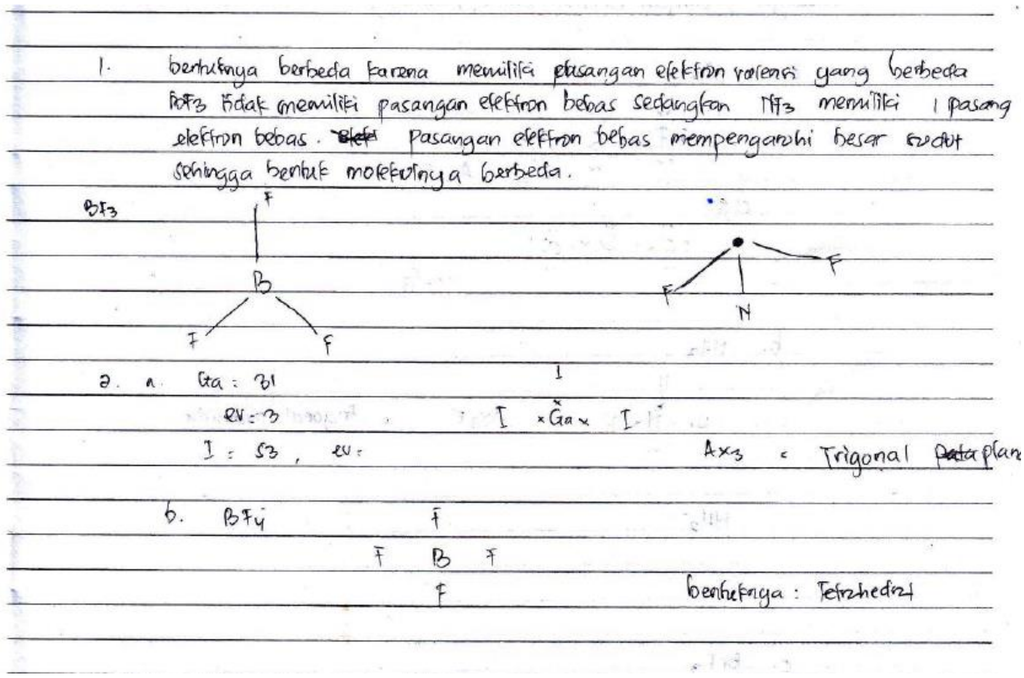
Appendix 6

Samples of Students' Answer (Pre-test and Post-test of Shape of Molecule)

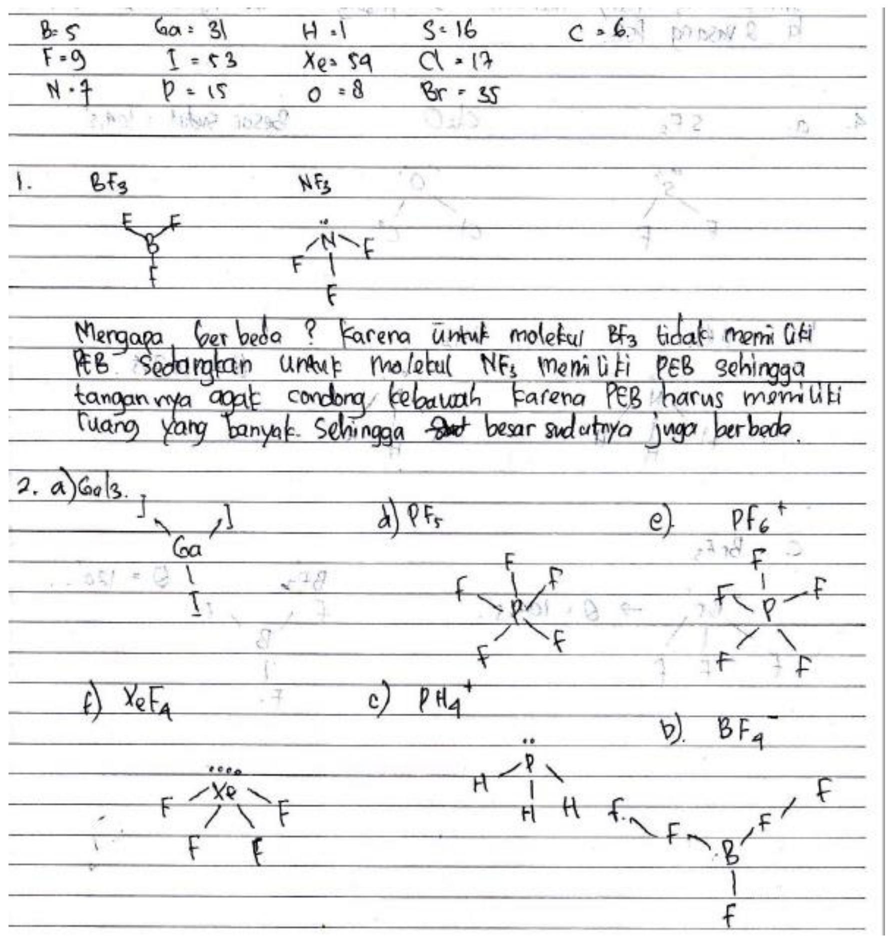


1. bentuknya berbeda karena memiliki ~~pasangan~~ pasangan elektron valensi yang berbeda BF_3 tidak memiliki pasangan elektron bebas sedangkan NF_3 memiliki 1 pasang elektron bebas. ~~elek~~ Pasangan elektron bebas mempengaruhi besar sudut sehingga bentuk molekulnya berbeda.

BF_3

2. a. Ga : 31
ev = 3
I : 53 , ev =
AX_3 = Trigonal ~~datar~~ planar

b. BF_4
bentuknya : Tetrahedral



B = 5	Ga = 31	H = 1	S = 16	C = 6
F = 9	I = 53	Xe = 54	Cl = 17	
N = 7	P = 15	O = 8	Br = 35	

1. BF_3 NF_3

Mengapa berbeda ? Karena untuk molekul BF_3 tidak memiliki PEB sedangkan untuk molekul NF_3 memiliki PEB sehingga tangannya agak condong kebawah karena PEB harus memiliki ruang yang banyak. Sehingga ~~sud~~ besar sudutnya juga berbeda.

2. a) GaI_3. d) PF_5 e) PF_6^+

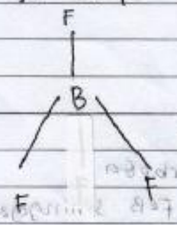
f) XeF_4 c) PH_4^+ b) BF_4^-

NO URUT PRESENTASI :
PROGRAM STUDI BKK : Pendidikan kimia
HARI/TANGGAL : Senin, 25 Juli 2016
MATA KULIAH :
TANDA TANGAN :

1. * BF_3

$_5B = 2,3$

$_9F = 2,7$

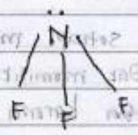


Trigonal Planar

* NF_3 *

$_7N = 2,5$

$_9F = 2,7$



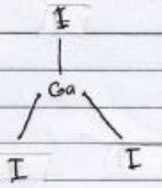
trigonal planar

BF_3 dan NF_3 merupakan molekul yang memiliki rumus trigonal plar tetapi bentuknya berbeda karena dipengaruhi oleh PEI (Pasangan elektron Ikatan) dan PEB (pasangan elektron bebas) Pada BF_3 hanya memiliki PEB 3 sedangkan Pada NF_3 memiliki 3 PEI dan 1 PEB.

2. a. GaI_3

$_{31}Ga = 2,8,18,3$

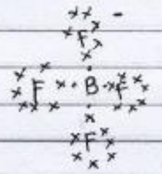
$_{53}I = 2,8,18,18,7$



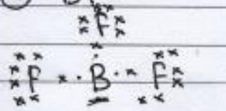
b. BF_4^-

$_5B = 2,3$

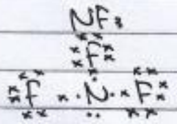
$_9F = 2,7$



(1) BF_3

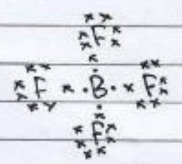


NF_3

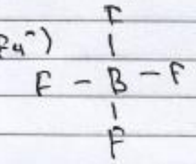


Bentuk yang berbeda karena nilai elektron bebas pada masing-masing molekul, pada molekul NF_3 terdapat PEB sedangkan pada molekul BF_3 tidak ada

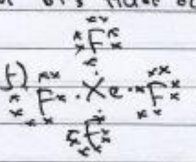
(2) b.)



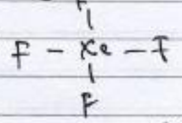
(BF_4^-)



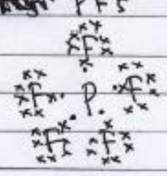
f.)

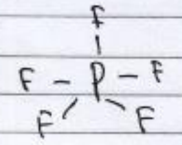


(XeF_4)

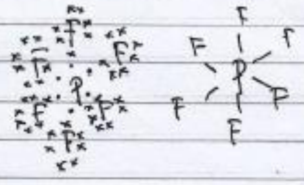


d.) PF_5

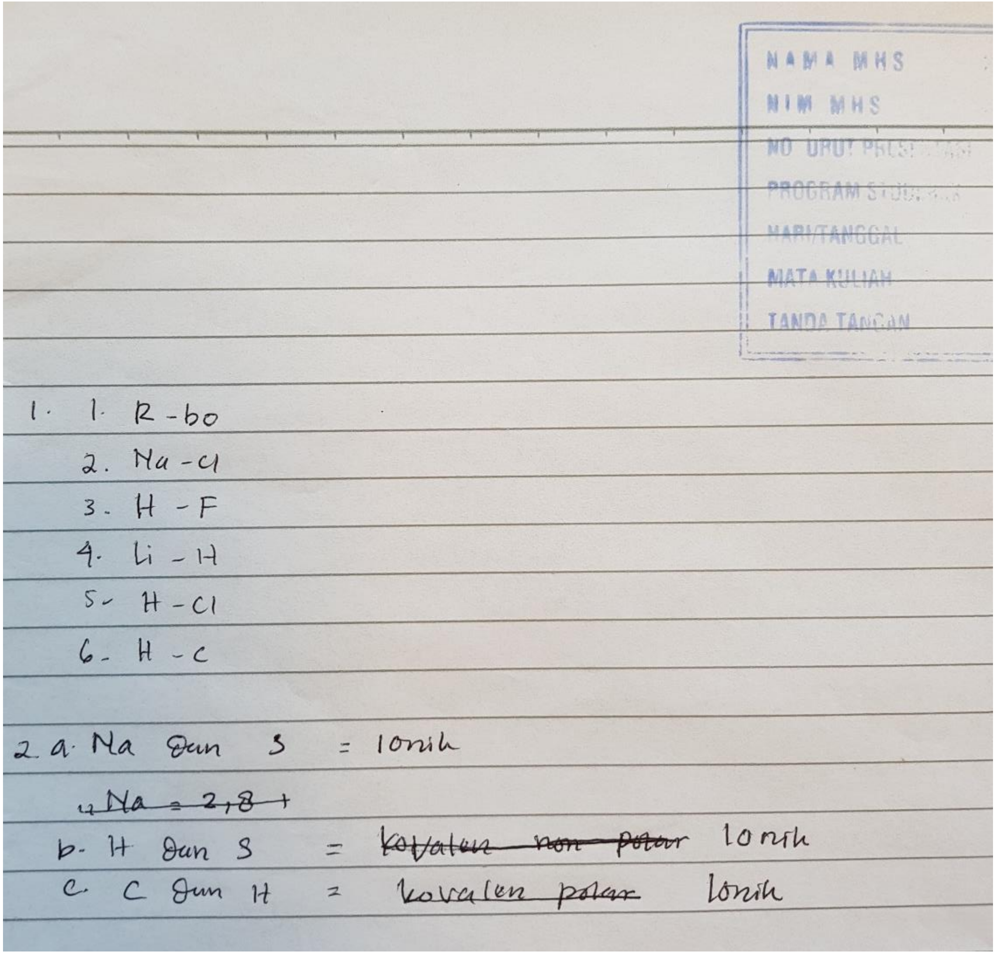




e.) PF_6^+



Samples of Students' Answer (Pre-test and Post-test of Electronegativity, Bond Type, Polarity)



NAMA MHS
NIM MHS
NO URUT
PROGRAM STUDI
HARI/TANGGAL
MATA KULIAH
TANDA TANGAN

1\. 1. R - bo
2\. Na - Cl
3\. H - F
4\. Li - H
5\. H - Cl
6\. H - C

2\. a. Na dan S = Ionik
~~₁₁Na = 2,8,1~~
b. H dan S = ~~kovalen non polar~~ Ionik
c. C dan H = kovalen ~~polar~~ Ionik

1. a. Na – Cl = 2,1   d. H–F = 1,9
b. Li – H = 1,1   e. Rb–O = 2,7
c. H – C = 0,4   f. H–Cl = 0,9
Urutan : c, f, – b – 1,9 – 2,1 – 2,7

2. a. Na dan S → ikatan ionik (logam & non logam)
b. H dan S → ikatan kovalen
c. C dan H → kovalen ~~non~~ polar.

3. H_2S memiliki sifat polar

① Keelektronegatifan adalah kecenderungan suatu atom untuk menangkap elektron sehingga bermuatan lebih negatif.

② * Semakin jauh perbedaan nilai keelektronegatifannya, maka semakin besar polaritasnya.

a. Na – Cl → 3,0 – 0,9 = 2,1   5
b. Li – H → 2,1 – 1,1 = 1,1   3
c. H – C → 2,5 – 2,1 = 0,4   1
d. H – F → 4 – 2,1 = 1,9   4
e. Rb – O → 3,5 – 0,8 = 2,7   6
f. H – Cl → 3 – 2,1 = 0,9   2

Sehingga ~~berd~~ urutannya berdasarkan peningkatan polaritas ~~ad~~ (dari rendah ke tinggi) adalah.
H-C < H-Cl < Li-H < H-F < Na-Cl < Rb-O atau
c < f < b < d < a < e

NO URUT PRES...
PROGRAM STUDI...
HARI/TANGGAL
MATA KULIAH
TANDA TANGAN

1.) a. Na – Cl

ΔEN = 3,0 – 0,9
= 2,1 (2)

b. Li – H

ΔEN = 2,1 – 1,0
= 1,1 (4)

c. H – C

ΔEN = 2,5 – 2,1
= 0,4 (6)

d. H – F

ΔEN = 4,0 – 2,1
= 1,9 (3)

e. Rb – O

ΔEN = 3,5 – 0,8
= 2,7 (1)

f = H – Cl

ΔEN = 3,0 – 2,1
= 0,9. (5)

Urutan dari paling polar sampai paling tidak polar

- 1 = Rb – O
- 2 = Na – Cl
- 3 = H – F
- 4 = Li – H
- 5 = H – Cl
- 6 = H – C

2.) a. Na dan S → Ikatan ionik
b. H dan S → Ikatan kovalen ~~non~~ polar
c. C dan H → Ikatan kovalen non polar

Keelektronegatifan

1. a. Na–F → 3,9 – 0,93 = 2,97 (ionik)
b. Li–H → 2,19 – 0,98 = 1,21 ~~(ionik)~~ (kovalen polar)
c. H–S → ~~2,58~~ 2,58 – 2,19 = 0,39 ~~(ionik)~~ (kovalen)
d. Rb–O → 3,44 – 0,82 = 2,62 (ionik)
e. H–Cl → 3,16 – 2,19 = 0,97 (kovalen polar)
F. H–O → 3,44 – 2,19 = 1,25 (kovalen polar)

Urutan dari paling polar ke paling tidak polar
~~F, e, C,~~ F, b, e, c, d, a

2 a. Mg dan O → 3,44 – 1,31
= 2,13 (ionik)

b. H dan F → 3,98 – 2,19
= 1,79
(ionik) kovalen polar

c. C dan Cl → 3,16 – 2,55
= 0,61 (~~kop~~ kovalen polar)

Appendix 7

Example of Interviews' Transcription on LoEN

Cycle 1

Students' ID	Have you learned about the EN and its use to identify the bond type?	In what ways the leaflet helped you understand the concept of EN, bond type and polarity?	What kind of TLR (Teaching and Learning Resources) that your teacher used to teach chemistry?
A1	I have never learned the relationship between EN with bond type and polarity in high school. I know the EN and read about it in my chemistry textbook. I don't know about the bond character either. I never thought that all covalent molecules would share the electron equally.	I know this concept (identify the bond type using the EN difference and the idea of bond character) when I read the Leaflet. In my opinion, the Leaflet is engaging, easy and practical. The language used are quite easy to understand.	My teacher never used the TLR. The only resource that she used is chemistry textbook.
A2	I know about the definition of the EN, and I know about the bond types, but I don't know that the bond types could be predicted using the difference of EN. I've learned about the polarity in high school, but I couldn't relate it to the concept of EN and bond character. For all this time I thought that	I know more about the EN by reading this leaflet. I've heard the term of bond character for the first time. This leaflet also gave me some insight about the polarity.	My teacher usually uses PowerPoint to teach chemistry. She also used a chemistry textbook.
A3	My chemistry teacher never taught me about identifying the bond type using the difference of EN. I couldn't find this on my chemistry textbook. This is the first time I heard about the bond character.	This is the first time I heard about the bond character after I read the Leaflet. For all this time I only thought that covalent molecule is pure covalent so as the ionic molecule.	Sometimes she uses PowerPoint but it only a couple times. Usually, she uses LKS (the simplified version of a chemistry textbook).
A4	I've only learned about the definition of EN and EN as one of the periodic table trends such as affinity electron, ionisation energy, and atomic radii. I've never known about the bond character before this. I only thought	The term bond character is new for me. I never heard about this before. After reading the leaflet I know about the term, the table also illustrated the bond character. The topic presented in the	Textbook and mostly LKS as not all of us have a textbook hence my teacher uses LKS which is cheaper than textbook.

	that the covalent molecules must be shared electron equally. I never realised the relationship between EN, bond type and polarity.	leaflet is the topic that I never read in any chemistry textbook.	
A5	When I was in high school, I never learn about the concept of bond character at all. Actually, this is the first time I heard about the bond character. I also never knew about the use of EN to identify the bond type. I know about the EN, the definition and the trend of EN in the periodic table.	By reading the leaflet I understand that the EN difference can be used to identify the bond type and polarity. I also understand the relation between EN, bond type and bond character. I never read this topic in my chemistry textbook.	Once my teacher used the PowerPoint, but after that, she never used it anymore, and she uses the textbook instead. We have a lab work a few times for the concepts like electrochemistry, acid-base and colloid.
A6	I know the definition of EN, and I know about the bond type, but I don't know that the difference of EN could be used to identify the bond type. I also never realised about bond character as I cannot find the explanation about this on the chemistry textbook.	I know the term bond character from reading the leaflet. For all this time all I know is that covalent molecule will be pure covalent or ionic molecule will be pure ionic. I know about the polarity, but I can relate it with the concept of a bond character.	PowerPoint and chemistry textbook. My teacher sometimes uses a different approach, like Think-Pair-Share (one of the cooperative learning strategies). We have a laboratory work for the topic electrochemistry, acid-base, colloid.
A7	I had not learned this topic especially when I was in high school. Identifying the bond type using the electron difference also new for me. For all this time to recognize the bond type I only use the types of the element in the periodic table. I cannot find an explanation about this topic in the chemistry textbook.	The topic presented in the leaflet had helped me understand the EN and its relationship to bond type and polarity. Also, I know the term bond character which I never heard before. The figure and table presented also helped me understand the topic.	My teacher uses chemistry textbook and LKS as the primary source. We have a laboratory work twice for the topic electrochemistry and acid-base.
A8	I know how to identify the bond type by using the forms of the element in the table periodic, but I don't know how to determine the bond type using the EN difference. Honestly, I never learn about the bond	The leaflet presents the topic which I've never read in my chemistry textbook. The concept describes the topic in a quite interesting way as the leaflet is	PowerPoint, textbook, and LKS. We used to have laboratory work for some topics.

	character. I cannot find an explanation about this topic in the chemistry textbook.	full colour and consist of picture, table, and diagram not only the text. Especially for the concept of bond character which differs from what I thought for all this time.	
A9	I only know to identify the bond type using the types of the element (atom) in the periodic table, like when metallic element bond to non- metallic molecule = ionic bonding. I never heard about the bond character before. Also, this topic never be explained in the chemistry textbook. In addition to that, my teacher never explained this when I was in High school.	I never heard about the bond character before I read the leaflet. All I understand is	LKS and textbook. The internet connection in our town is poor so it is hard to access the internet. Thus my teacher only relies on the textbook and LKS.
A10	I know the definition of EN, but I never knew that the EN difference could be used to identify the bond type. I also never heard about the bond character.	I did not know about the bond character before I read the leaflet. The table of bond character in the leaflet had helped me understand the topic of bond character.	PowerPoint, textbook, and LKS. My teacher uses ppt for a few times. We do have laboratory work.
A11	My chemistry teacher only explains the electronegativity as one of the periodic table trends and never related to the bond type. I also cannot find an explanation on my chemistry textbook.	I can read the leaflet anytime anywhere I want. The concepts presented in the leaflet is easy to read and understand. In addition to that, I knew the concept bond character after reading it.	Chemistry textbook and LKS. Sometimes we have laboratory work for some topics.
A12	This topic was never taught when I was in high school. I also cannot find the topic in my chemistry textbook. I do understand about the EN, but I don't know about the relationship between the EN and the bond type. The term bond character also new for me.	The leaflet was presenting the concept that I never read before which is a bond character. The leaflet appearance is also quite interesting for me. It is very handy. I wish there is another topic presented in the leaflet like this.	PowerPoint, Textbook, LKS. We do have laboratory work for some topics. My teacher sometimes uses a different strategy in teaching like a group discussion.

A13	My chemistry teacher never taught me about the concept of a bond character. I know the concept when I read the Leaflet. I was never realised that the electronegativity can be used to identify the bond type. I also cannot find an explanation about this topic in my high school chemistry textbook.	Reading the leaflet had helped me to understand the relationship between the EN, bond type and polarity.	LKS and chemistry textbook. Sometimes my teacher using the demonstration to explain some topics such as electrochemistry, acid-base and colloid as we don't have a proper lab.

Note:

LKS is the concise version of the textbook with a brief explanation and emphasise more on questions for students to practice. It is made by the local publisher. It printed in poor quality of paper (like the paper on newspaper) and in black and white.

Cycle 2

Student's ID	Have you learned about the EN and its use to identify the bond type?	In what ways the leaflet helped you understand the concept of EN, bond type and polarity?	What kind of TLR (Teaching and Learning Resources) that your teacher used to teach chemistry?
B1	When I was in high school, my teacher only taught me about the EN as one of the Periodic Table like affinity electron, ionisation energy, atomic radii. Thus, I never heard about the relationship between EN and bond type and polarity. I also never heard about the term bond character.	I think the leaflet has presented the topic in a good order. It explains the relationship between the EN, bond type, bond character and polarity. For all this time I never realised about the bond character and even have not heard the term before. I always thinking that covalent molecule will be pure covalent.	My teacher only uses chemistry textbook to teach. She usually starts to explain the topic by giving a lecture and writing in the blackboard. Sometimes we have a lab work for some topics as well.
B2	I know how to identify the bond type using the types of element, but I don't know that the EN difference can be used to identify the bond type. I haven't learned about this in high school and my teacher never explained about this. He only explained the EN as the one of the periodic table trends. I have not learned about bond character before I read the leaflet.	Since the LoEN presented the topic in a simple way but details I can easily understand the topic. Also, the colourful of the leaflet attracts me to read it. The most interesting about the LoEN is the bond character concept. Honestly, I've never thought that way. (the appearance the LoEN) (the simplicity of the language)	Sometimes PowerPoint, but the main TLR is the textbook and LKS.
B3	My chemistry teacher never taught this concept. I think its maybe because this topic was not explained in the textbook. Moreover, the term bond character. This is the first time I heard about the bond character.	I think because the leaflet explains the topic in simple, easy and attractive way. I like the colour though. Moreover, the topics presented in detail and easy to follow. The pictures help me grasp the concept. I was completely do not know about the concept of bond character for all this time and I think the LoEN succeed helped me understand the concept. (the appearance of figures, tables and diagram) (the appearance of the leaflet)	PowerPoint, textbook and LKS

		(getting new understanding)	
B4	I know this topic from my chemistry tutor (identify the bond type using the electronegativity difference and bond character). My chemistry teacher never taught me about this. But reading the explanation on the leaflet helped me understand the topic.	Because the LoEN presented the figures, table and diagram which help me to understand the concept. (the appearance of figures, tables and diagram)	Textbook and LKS
B5	No, I have not. My chemistry teacher never explained about the topic. I also cannot find the explanation about this topic in the chemistry textbook.	As the topic presented in the LoEN explain about the electronegativity, bond type and polarity in details thus I can see the relationship among them. In addition to that, the presentation of the LoEN very simple and quite attractive so I can read it many times inside or outside the class.	Textbook and LKS
B6	I don't think I have. Since my teacher never explained about how to identify the bond type using the EN difference. I only knew to identify the bond type by comparing the types of the element involved.	This is the first time I heard about the term bond character. For all this time I thought that covalent molecule will be pure covalent so as the ionic molecule. The concept presented in the leaflet has gave an insight related to it.	Sometimes PowerPoint, but the most common is the LKS and Textbook
B7	I have learned about the EN when I was in the high school. But, I did not know that the EN difference can be used to identify the bond type.	I learned something new from this leaflet. Since the leaflet discussed the EN and the difference of EN can be used to identify the bond type which I never know. Moreover, for all this time I never thought that the compound has bond character. The concept of bond character is something new for me.	Textbook and LKS
B8	No, I have not. This topic was never taught when I was in high school. I cannot find the explanation about this topic in the chemistry textbook.	The leaflet helped me understand the concept of electronegativity, bond character and polarity. I thought the compound which bonded by ionic or covalent will be pure	PowerPoint and textbook

		covalent or ionic. I never thought that the concept of bond character and the EN difference is something new for me. (insight to new concept)	
B9	No, I have not. My teacher never taught me about this topic. Even my teacher asked the students to read the topic of EN in the textbook.	Reading the leaflet gave me some insight related to EN, bond type, bond character and polarity which I never knew before. (insight to new concept)	LKS
B10	I've learned about the EN and how to identify using the types of element, but I have not learned about the use of EN difference to identify bond type as well as the bond character.	The language use in the leaflet was easy to follow and understand. The topic presented (Language use)	My teacher used PowerPoint, Textbook and LKS.
B11	No, I have not. My teacher never explained about this topic. He only mentioned about the EN as one of the periodic table trends. I knew how to identify the bond type by comparing the types of element in the periodic table.	The leaflet presented the topics concisely but quite detail. I love the way the leaflet presented with a bright colour. What I like the most from the leaflet is the diagram on the conclusion part. I do understand the role of EN difference to bond type and bond character by reading this leaflet. (the concise of the concept)	Textbook and LKS, but dominantly LKS.
B12	I never learned about this topic in high school as my teacher never taught this topic. I also never found the topic in the chemistry textbook.	I know about the bond character by reading this leaflet as well as how to identify the bond type using EN difference. By reading the leaflet I know the relationship between bond character, electronegativity, bond type and polarity.	Mainly LKS and textbook
B13	I haven't learned that the EN difference can be used to identify the bond type. I can't find it (the explanation about this topic) in my chemistry textbook.	The leaflet had helped me understand how to use the EN difference to identify the bond type. The leaflet gives a brief explanation but quite detail about the concept. The pictures and tables presented help me grasp the idea.	Textbook and LKS

B14	I've heard about the Pauling Scale, but I don't know that I've heard about the bond character from my chemistry tutor. My chemistry teacher never taught me about this and I also cannot find the topic in the textbook.	I think, reading the leaflet contributes an understanding for me. It also gave an insight related to the concept of bond character. I never thought about the compound that is bonded by covalent bond still has the ionic character.	PowerPoint, Textbook and LKS. Sometimes, I watch the video by myself to support my understanding.
B15	My teacher only explains about the EN as one of the periodic table trend. For all this time I only understand that the bond type can be identify using the types of the elements in the periodic table or using electron configuration (number of valence electron) and draws the Lewis structure. I also never heard about the term bond character.	I never thought about the compound that bonded either ionic or covalent still has covalent or ionic character on it. I thought if the compound is bonded covalently it means that the character of the compound will definitely has covalent character. I guess this is one advantage of this LoEN, which I cannot found in the textbook. (insight to new concept)	Textbook and LKS.

Appendix 8

SPSS Analysis

Pre-test and Post-test SoMCards and MMB Cycle 1

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Score Pre-test	49.1818	33	11.19837	1.94939
	Score Post-test	70.7273	33	12.06822	2.10081

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Score Pre-test & Score Post-test	33	.732	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Score Pre-test - Score Post-test	-21.54545	8.55530	1.48929	-24.57903	-18.51188	-14.467	32	.000

Pre-test and Post-test SoMCards and MMB Cycle 2

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Score Pre-test	51.77	82	15.993	1.766
	Score Post-test	73.65	82	14.396	1.590

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Score Pre-test & Score Post-test	82	.882	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Score Pre-test - Score Post-test	-21.878	7.555	.834	-23.538	-20.218	-26.224	81	.000

Pre-test and Post-test LoEN Cycle 1

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Score Pre-test	56.03	33	9.299	1.619
	Score Post-test	75.61	33	9.630	1.676

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Score Pre-test & Score Post-test	33	.814	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Score Pre-test - Score Post-test	-19.576	5.777	1.006	-21.624	-17.527	-19.465	32	.000

Pre-test and Post-test LoEN Cycle 2

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Score Pre-test	57.44	82	11.754	1.298
	Score Post-test	76.62	82	11.589	1.280

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Score Pre-test & Score Post-test	82	.835	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Score Pre-test - Score Post-test	-19.183	6.711	.741	-20.658	-17.708	-25.883	81	.000

Pre-test and Post-test VoIF

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Score Pretest	53.78	82	13.912	1.536
	Score Posttest	74.27	82	13.220	1.460

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Score Pretest & Score Posttest	82	.905	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Score Pretest - Score Posttest	-20.488	5.963	.659	-21.798	-19.178	-31.111	81	.000