UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF ORGANIC REACTION TEACHING MODEL FOR PRE-UNIVERSITY PROGRAMS IN MALAYSIA

SABITU ABDULMALIK

FPP 2022 45

DEVELOPMENT OF ORGANIC REACTION TEACHING MODEL FOR PRE-UNIVERSITY PROGRAMS IN MALAYSIA

By

SABITU ABDULMALIK

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

February 2022

DEDICATION

This work is dedicated to my mother, Malama Mariya Nuhu, May Allah continues to have mercy on her soul, my father, Alhaji Sabitu Sabiu, who inspired me to always do the right thing at the right time, my lovely wife, Fadila Bello Tunau for her kindness and good manners and finally, my children, Muhammad Jawwad and Muhammad Bello for their scarifies, love and prayers, I am much grateful.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF ORGANIC REACTION TEACHING MODEL FOR PRE-UNIVERSITY PROGRAMS IN MALAYSIA

By

SABITU ABDULMALIK

February 2022

Chairman : Othman bin Talib, PhD
Faculty : Educational Studies

Previous theories and research have shown that collaboration between scholars and practitioners has far-reaching consequences for students' learning. Therefore, bridging the lacuna between research and practice is necessary in the development and validation of an instructional model. The objective of this study is to develop and validate an organic reaction teaching model (ORTM) for pre-university programs in Malaysia based on the experts' collective opinion. Given that matriculation colleges serve as entry points into universities, developing instructional models is beneficial. The focus on the organic reaction concept is due to its significance and centrality in many science-related subjects as a set of steps that explain the chemical changes that occur in organic compounds. Moreover, many students perceive organic reaction mechanisms as difficult concepts that serve as barriers to their understanding of advanced organic chemistry. This perceived difficulty makes organic reactions less appealing to students, leading to misconceptions and errors of serious concern. Thus, the in-depth information about students' common errors and other challenges in organic chemistry instruction formed the basis of this study to develop a model for minimizing students' common errors and improving their academic performance in chemistry. Specifically, the research questions include: 1) To what extent is it necessary to develop ORTM to minimize common errors in organic reactions, based on the experts' collective opinion? 2) What are the opinions of experts on the instructional activities and constructs to be included in the development of the ORTM? and 3) How does the ORTM help lecturers to improve students' understanding of organic reaction mechanisms?

The design and development research approach was adopted using an embedded mixed-method as the overall design of the study, so that one set of data plays a supporting or secondary role to the other data type coherently in the three phases of the study. The need for developing the model was justified in phase 1 through three sub-studies, i.e., scoping review, experts' interviews, and analyses of students' manuscripts. During this phase, an exploratory design was used, and data was collected qualitatively and analyzed using ATLAS.ti (version 8) software. Data source triangulation, peer debriefing, member

checks, and audit trail were used to validate the findings. The second phase covered the design and development processes using exploratory mixed-method design. The main components of the model were identified qualitatively from literature and content analysis, pre-listed and presented to experts for scrutiny using the Delphi method. Quantitative data was obtained from 21 and 17 experts in two iterative Delphi rounds, respectively. Their views were analysed using the Inter Quartile Range (IQR), the Coefficient of Variance (CV), and the Kendall coefficient of concordance (W) at a consensus level of $\geq$75%. The ORT model was validated in phase three using an explanatory mixed design. The internal validity of the model was conducted to determine the suitability and usability of the model components using the fuzzy Delphi method (FDM). Qualitative data was collected using a fuzzy Delphi questionnaire from 14 experts purposively drawn from various related disciplines, and the external validity was conducted to determine the ORT model's practicability and potential in the actual classroom using the field-testing method (FTM) with five chemistry lecturers and 40 students from five matriculation colleges in Malaysia. Qualitative data was collected using an open-ended questionnaire, which was analysed using thematic analysis.

Findings in phase one showed the variables studied, reasons for the difficulty of ORM, and students' common errors from the past literature. Analysis of the expert interviews revealed five themes indicating the significance of ORM, challenges in ORM instruction, teaching strategies adopted by the teachers, students' errors, and ways for improving ORM instruction. Also, failure to conserve charges, backward arrow positioning, the formation of hypervalent atoms, and missing arrows were the common errors identified from the analysis of students' manuscripts. These findings stressed the need for developing an alternative model specifically for teaching organic reactions. The findings of phase two showed the developed model was comprised of 30 instructional activities, 5 instructional constructs including symbolisms, crosscutting, mechanisms, visualization, and refelection with mean ratings of (χ = 25.00, 22.35, 21.76, 18.47, & 14.41) respectively, and 3 instructional domains for avoidance, interference, and correction with a mean rating of (χ = 35.00, 33.53, & 31.47) at consensus level (W = 0.511, $p<0.001$) and a correlation in stability of rounds (rho = 0.41, $p< 0.01$). The mean ratings prioritized the domains and constructs for easy implementation of the model in the actual classrooms. Findings from phase three show that the model is valid as the fuzzy Delphi results indicated a consensual agreement on the suitability of the model components at a threshold value of 98.1% and defuzzification values of 13.20, 12.80, and 12.30 for the usability of instructional activities, instructional constructs, and domains, respectively. This indicates that the model components were consistently reliable for teaching to minimize students' errors in ORM. In addition, findings from the field-testing method revealed that the model could be used in other settings, as expressed by the views of chemistry lecturers after implementing the model across the 5 matriculation colleges. Model compatibility, model clarity, model efficiency, and model flexibility themes indicate the practicability of the model in the classroom. The result also shows the potentiality of the model in minimizing students' common errors in ORM and improving their academic performance at an overall average score of 84.4%.

The findings from the need analysis phase provided a myriad view of the experts and the lacunae in organic chemistry instruction, which necessitates the development of an organic reaction teaching model. The model was developed in phase two, and the components were conceptually agreed upon by the experts. Also, both internal and external validity of the model were ensured in phase 3 of the study. Thus, the product of the study therefore removed the lacuna between research and practice, since practitioners, as the end users of the model, were fully involved in all the stages of the study. Furthermore, this study provides an instructional model as a guideline that helps teachers plan step-by-step lessons to minimize errors in ORM, and the domains of the model can be adopted in avoiding, interfering with, and correcting students' errors. Also, the model components could simplify the planning and implementation of lessons in the classrooms and extend the comprehension of Johnstone's model in terms of explicit representation of organic reaction mechanisms from 3 to 5 levels. More importantly, ORTM integrated the principles of threshold concepts and repair learning theories into teaching to overcome students' common errors in organic reactions. Moreover, the use of experts' opinions in the design and development research approach adopted using Fuzzy Delphi and field-testing methods was crucial in curriculum and instruction. Finally, it is recommended for further studies to be conducted by stakeholders in the curriculum and instruction as well as the international science education community to plan, develop, validate, and implement alternative modules, e-learning tools, and measuring instruments based on ORTM components.

Keywords: Organic Reaction (OR), Students' Common Errors, Design and Development Research (DDR), Validation, Fuzzy Delphi, Field Testing.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN MODEL PENGAJARAN REAKSI ORGANIK UNTUK PROGRAM PRE-UNIVERSITI DI MALAYSIA

Oleh

SABITU ABDULMALIK

Februari 2022

Pengerusi : Othman bin Talib, PhD
Fakulti : Pengajian Pendidikan

Teori dan penyelidikan terdahulu telah menunjukkan bahawa kerjasama antara penyelidik dan pengamal mempunyai kesan yang besar untuk pembelajaran pelajar. Oleh itu, jurang antara penyelidikan dan amalan perlu dirapatkan dalam pembangunan dan pengesahan model pengajaran. Objektif kajian ini adalah untuk membangunkan dan mengesahkan model pengajaran tindak balas organik (ORTM) untuk program pra universiti di Malaysia berdasarkan pendapat kolektif pakar. Memandangkan kolej matrikulasi berfungsi sebagai jalan utama ke universiti, membangunkan model pengajaran adalah sangat berfaedah.

Fokus kajian ini terhadap konsep tindak balas organik adalah disebabkan oleh kepentingannya dalam banyak mata pelajaran berkaitan sains yang menerangkan perubahan kimia yang berlaku dalam sebatian organik. Selain itu, ramai pelajar menganggap mekanisme tindak balas organik sebagai konsep sukar yang menjadi penghalang kepada pemahaman mereka tentang kimia organik lanjutan. Kesukaran yang dirasakan ini menjadikan tindakbalas organik kurang menarik kepada pelajar, yang membawa kepada salah tanggapan dan kesilapan yang membimbangkan yang serius. Oleh itu, maklumat lanjut tentang kesilapan biasa pelajar dan cabaran lain dalam pengajaran kimia organik membentuk asas kajian ini untuk membangunkan model untuk meminimumkan kesilapan biasa pelajar dan meningkatkan prestasi akademik mereka dalam kimia. Secara khususnya, soalan kajian adalah. 1) Sejauh manakah keperluan membangunkan ORTM untuk meminimumkan kesilapan biasa dalam tindak balas organik, berdasarkan pendapat kolektif pakar? 2) Apakah pendapat pakar tentang aktiviti dan konstruk pengajaran yang perlu dimasukkan dalam pembangunan ORTM? dan 3) Bagaimanakah ORTM membantu pensyarah meningkatkan pemahaman pelajar tentang mekanisme tindak balas organik?

Pendekatan penyelidikan reka bentuk dan pembangunan telah diguna pakai menggunakan kaedah gabungan pelbagai cara sebagai reka bentuk keseluruhan kajian, supaya satu set data memainkan peranan sokongan atau sekunder kepada jenis data lain secara koheren dalam tiga fasa kajian. Keperluan untuk membangunkan model tersebut adalah diwajarkan dalam fasa 1 melalui tiga sub-kajian, iaitu, ulasan berskop, temu bual pakar, dan analisis manuskrip pelajar. Semasa fasa ini, reka bentuk penerokaan telah digunakan, dan data dikumpul secara kualitatif dan dianalisis menggunakan perisian ATLAS.ti (versi 8). Triangulasi sumber data, temubual rakan sebaya, semakan oleh peserta dan jejak audit digunakan untuk mengesahkan hasil penemuan. Fasa kedua meliputi proses pembangunan reka bentuk menggunakan reka bentuk penerokaan gabungan pelbagai cara. Komponen utama model telah dikenal pasti secara kualitatif daripada analisis literatur dan kandungan, disenaraikan dan dibentangkan kepada pakar untuk diteliti menggunakan kaedah Delphi. Data kuantitatif diperoleh daripada 21 orang pakar dan 17 orang pakar masing-masing, dalam dua pusingan Delphi berulang. Pandangan mereka dianalisis menggunakan Julat Antara Kuartil (IQR), Pekali Varians (CV), dan pekali kesesuaian Kendall (W) pada tahap konsensus $\geq 75\%$. Model ORT telah disahkan dalam fasa tiga menggunakan reka bentuk penjelasan pelbagai cara. Kesahan dalaman model dijalankan untuk menentukan kesesuaian dan kebolehgunaan komponen model menggunakan kaedah Fuzzy Delphi (FDM). Data kualitatif dikumpul menggunakan soal selidik fuzi Delphi daripada 14 pakar yang diambil secara bersebab daripada pelbagai disiplin berkaitan, dan kesahan luaran telah dijalankan untuk menentukan kebolehgunaan model ORT dalam bilik darjah sebenar menggunakan kaedah ujian lapangan (FTM) dengan lima orang pensyarah kimia dan 40 pelajar dari lima kolej matrikulasi di Malaysia. Data kualitatif dikumpul menggunakan soal selidik terbuka, yang dianalisis menggunakan analisis bertema.

Dapatan dalam fasa satu menunjukkan pembolehubah yang dikaji, sebab kesukaran ORM, dan kesilapan biasa pelajar dari literatur lepas. Analisis temu bual pakar mendedahkan lima tema yang menunjukkan kepentingan ORM, cabaran dalam pengajaran ORM, strategi pengajaran yang diguna pakai oleh guru, kesilapan pelajar, dan cara untuk menambah baik pengajaran ORM. Selain itu, kegagalan untuk mengekalkan cas, kedudukan anak panah ke belakang, pembentukan atom hipervalen dan anak panah yang hilang adalah ralat biasa yang dikenal pasti daripada analisis manuskrip pelajar. Penemuan ini menekankan keperluan untuk membangunkan model alternatif khusus untuk mengajar tindak balas organik. Dapatan fasa dua menunjukkan model yang dibangunkan terdiri daripada 30 aktiviti pengajaran, 5 konstruk pengajaran termasuk penggunaan simbol, potong silang, mekanisma, visualisasi, dan refleksi dengan penyesuaian min masing-masing (χ = 25.00, 22.35, 21.76, 18.47, & 14.41). dan 3 domain pengajaran untuk pengelakan, gangguan dan pembetulan dengan penyesuaian min (χ = 35.00, 33.53, & 31.47) pada tahap konsensus ($W = 0.511$, $p<0.001$) dan korelasi dalam kestabilan pusingan (rho = 0.41, $p< 0.01$). Penyesuaian min mengutamakan domain dan binaan untuk memudahkan pelaksanaan model dalam bilik darjah sebenar. Keputusan daripada fasa tiga menunjukkan model tersebut sah kerana keputusan fuzi Delphi menunjukkan persetujuan konsensual terhadap kesesuaian komponen model pada nilai ambang 98.1% dan nilai kekaburan 13.20, 12.80, dan 12.30 masing-masing untuk kebolehgunaan aktiviti pengajaran, konstruk pengajaran, dan domain. Ini menunjukkan bahawa komponen model secara konsisten boleh dipercayai untuk pengajaran untuk meminimumkan kesilapan pelajar dalam ORM. Selain itu, dapatan daripada kaedah ujian lapangan mendedahkan bahawa model tersebut boleh digunakan dalam tetapan berbeza, seperti yang dinyatakan oleh pandangan pensyarah kimia selepas melaksanakan model

tersebut di 5 kolej matrikulasi. Kesesuaian model, kejelasan model, kecekapan model dan tema fleksibiliti model menunjukkan kebolehgunaan model ini dalam bilik darjah. Hasilnya juga menunjukkan potensi model dalam meminimumkan kesilapan biasa pelajar dalam ORM dan meningkatkan prestasi akademik mereka pada skor purata keseluruhan 84.4%.

Penemuan daripada fasa analisis keperluan memberikan pelbagai pandangan oleh pakar-pakar dan kekurangan dalam pengajaran kimia organik, yang memerlukan pembangunan model pengajaran tindak balas organik. Model ini dibangunkan dalam fasa dua, dan komponen secara konsep telah dipersetujui oleh pakar. Juga, kedua-dua kesahan dalaman dan luaran model telah dipastikan dalam fasa 3 kajian. Oleh itu, hasil kajian itu merapatkan jurang antara penyelidikan dan amalan, kerana pengamal, sebagai pengguna akhir model, terlibat sepenuhnya dalam semua peringkat kajian. Tambahan lagi, kajian ini menyediakan garis panduan bagi model pengajaran untuk membantu guru merancang pengajaran langkah demi langkah untuk meminimumkan kesilapan dalam ORM, dan domain model boleh diguna pakai untuk mengelakkan, mengganggu dan membetulkan kesilapan pelajar. Selain itu, komponen model membantu memudahkan perancangan dan pelaksanaan pelajaran di dalam bilik darjah dan mengembangkan pemahaman model Johnstone dari segi perwakilan eksplisit mekanisme tindak balas organik daripada 3 hingga 5 peringkat. Lebih penting lagi, ORTM menyepadukan prinsip konsep ambang dan membaiki teori pembelajaran ke dalam pengajaran untuk mengatasi kesilapan biasa pelajar dalam tindak balas organik. Tambahan pula, penggunaan pendapat pakar dalam pendekatan penyelidikan reka bentuk dan pembangunan yang diguna pakai menggunakan Fuzzy Delphi dan kaedah ujian lapangan adalah penting dalam kurikulum dan pengajaran. Akhir sekali, adalah disyorkan agar kajian lanjut dijalankan oleh pihak berkepentingan dalam kurikulum dan pengajaran serta komuniti pendidikan sains antarabangsa untuk merancang, membangun, mengesahkan dan melaksanakan modul alternatif, alat e-pembelajaran, dan instrumen pengukur berdasarkan komponen ORTM.

Kata kunci: Mekanisme Tindak Balas Organik (ORM), kesalahan lazim pelajar, Penyelidikan Reka Bentuk dan Pembangunan (DDR).

ACKNOWLEDGEMENTS

I like to show appreciation to my supervisor, Dr. Othman Talib, who has been very supportive for me from the last three years and whose supports have kept me focused and motivated to get to the finishing line. I also appreciated members of the supervisory committee; Dr. Nurzatulshima Kamarudin and Dr. Norizah Abdul Rahman for their kind support, constructive supervision, and timely feedback for the improvement of my work. I am very thankful for the funding from Management of Federal University Dutsin-Ma (FUDMA) in the sponsorship through the Academic Staff Training and Development (AST & D) Tetfund Grants. My appreciation to all the respondents that participated in this research for their excellent feedbacks and valuable inputs in completing my model development. I am also very appreciative to my friends, Dr. Ibrahim Abdullahi, Dr. Ibrahim Abdulrahman Alkhaldi, Dr. Nur Farhana Ramli, Dr. Nor Tutiaini Ab. Wahid Dr Azraai Othman, Dr Amal Saudi, Adnan Omani and Salisu Bala Abubakar, who assisted me in one wy or another during the period of this study. My deepest appreciation to my father Alhaji Sabitu Sabiu and my late mother Malama Mariya Nuhu for always cheering me to trail and realize my dream. Finally, to my lovely wife, Fadilah Bello Tunau who has been supporting me throughout the Ph.D. journey. Then to my lovely children Muhammad Jawwad and Muhammad Bello for their patience and prayers for me in my absences within their mixed.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Othman bin Talib, PhD
Senior Lecturer
Faculty of Educational Studies
Universiti Putra Malaysia
(Chairperson)

Nurzatulshima binti Kamarudin, PhD
Senior Lecturer
Faculty of Educational Studies
Universiti Putra Malaysia
(Member)

Norizah binti Abdul Rahman, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Member)

____
ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 9 June 2022

Declaration by Graduate Student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ___________________________ Date: ___________________________

Name and Matric No.: Abdulmalik Sabitu

Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ______________________________

Name of Chairman of Supervisory Committee: Dr. Othman bin Talib

Signature: ______________________________

Name of Member of Supervisory Committee: Dr. Nurzatulshima binti Kamarudin

Signature: ______________________________

Name of Member of Supervisory Committee: Dr. Norizah Abdul Rahaman

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BAP	Budget Allocation Process
CC	Crosscutting Construct
CV	Coefficient of Variance
DDR	Design and Development Research
EAD	Error Avoidance Domain
ECD	Error Correction Domain
EID	Error Interference Domain
FDM	Fuzzy Delphi Method
IQR	Inter Quartile Range
MC	Mechanisms Construct
MOE	Ministry of Education
OR	Organic Reaction
ORM	Organic Reaction Mechanisms
ORTM	Organic Reaction Teaching Model
RC	Reflection Construct
RLT	Repair Learning Theory
SC	Symbolic Construct
TCs	Threshold Concepts
TCT	Threshold Concept Theory
VC	Visualisation Construct

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Global awareness has shown how science and technology played an important role in supporting nation-building through training future scientists towards attractiveness and brand recognition (Beumer, 2019; Fantke et al., 2019; Jasanoff, 2003; Lay & Kamisah Osman, 2018; Massaquoi, 2019; Möllers, 2020; Raub, Shukor, Arshad, & Rosli, 2015). Improving scientific knowledge and its applications in technological innovation is a continuing process that strengthens the pressing need for training of more scientists for national growth and economic development (Pedrdetti, 2018). Besides, Achimugu (2018) described science as a significant field of study that is very crucial for the development of the global economy. As a result, science education has been embraced as an instrument per excellence for national growth and development by many countries in the world. These are some of the reasons why researchers in science education need to concentrate on designing and developing alternative education models and strategies to improve the teaching of science subjects for national growth at the micro-level (Afolabi et al., 2017; James & Singer, 2016; Marginson, 2018; Nnakwe et al., 2018).

To achieve the exponentially rising need of specialists in scientific and technological areas for opportunities in the STEM-based jobs, such as software development for nation-building, it is therefore important to train more worker force in sciences. Many developed nations have been witnessing dramatic changes in their education system through curriculum innovation and policy formulation to boost college students' enrolment and success in science subjects (Howard, 2015; Olatoye, Fatokun, Olasehinde, & Sabitu, 2019; Parahakaran, 2015; Ponniah & Nawastheen, 2020; Shultz; Gottfried, & Winschel, 2015). Malaysia is not left behind, as seen by the number of progressive and ambitious changes to the education system targeted at the improvement in students' enrolment and success in science. A clear evidence is in the establishment of Curriculum Development Centre in Malaysian Education Ministry that was saddled the responsibility to carry out studies on advancement, identify the institutional needs, empirical results, and associated publications that have highlighted these findings (Bahrum et al., 2017; Haji Ahmad, 1998; Rauf et al., 2013; Sikas, 2017). These efforts further supported by the on-going curriculum reforms on the presentation of science subjects to suit the need of the local Malaysian, so that the Malaysian Vision 2020 to have one million individuals with science-related training can be achieved to compete in the globalized age (Mohtar et al., 2019; Ramlee, 2017; Ramli & Talib, 2017; Raub et al., 2015; Tutiaini et al., 2018).

Matriculation programme is one of the most important programme among the post-secondary schools' programmes in Malaysia for securing addimission into the Universities. Two other programs at the post-secondary education level in Malaysia were; the Higher Schools Certificate, and the Certificate programme (Alfan & Othman, 2005; Azraai, 2016). The Higher School Certificate is awarded to those that offered academic, technical, and religious subjects. The Certification program is a one or two-year curriculum primarily tailored to educate students in specialized fields (Ramlee, 2017). The pre-university programme also known as the Matriculation programme in Malaysia is a two-semester one-year programme offered at Matriculation College and some Universities especially the Bumiputera to prepare students for the Universities programs. The curriculum content of the matriculation combined both academic and co-curricular activities (Azraai & Talib, 2015; Malaysia Education Blueprint Malaysia, 2013; Veloo et al., 2015). The matriculation programme has been the transition stage for many students from secondary schools to universities as contained in the its jurisdiction gazzeted by Ministry of Education in 1998. The curriculum is developed following the programme philosophy and the Malaysian National Policy of Education. The objective of the matriculation curriculum is to serve as a foundation programme for students to gain admission into Malaysian and foreign (Blueprint, 2016).

The chemistry subject is among the core subjects for student in the science-related programmes to equip them with basic knowledge for understanding advanced science courses in the Universities (Academy of Sciences Malaysia, 2015; Fantke et al., 2020; Fleer, 2019; Marginson, 2018; Mensah & Jackson, 2018; Veloo et al., 2015). Chemistry subject was considered central for studying science programmes including agricultural science, biochemistry, engineering, forestry, and food processing (Flynn & Amellal, 2015; Gilmanshina, Sagitova, & Gilmanshin, 2018; Grove, Hershberger, & Bretz, 2008; Saido et al., 2018; Webber & Flynn, 2018). Moreover, organic chemistry content comprised 50% of the chemistry curriculum in matriculation college, compulsory for student majoring in science-based programs.

The section of chemistry that concerned with the study of carbon compounds is termed as organic chemistry (Anzovino & Bretz, 2016). It covers all functional groups like hydrocarbons, benzene, haloalkane, carbonyl and amines (Azraai et al., 2015). Knowledge learned from organic chemistry comprises were crucial in various fields of national developments (Bodé, Deng, & Flynn, 2019; Cooper, Stowe, Crandell, & Klymkowsky, 2019). The rationale for inclusion of organic chemistry components in the matriculation programme is to creat a connection between the principles of general chemistry at all levels of education (Azraai & Talib, 2015). Correspondingly, it broadens, strengthen and enhanced the students' interest to prepare adequately for careers in STEM subjects. However, there has been serious concern by both local and foreign researchers about the challenges encountered by student in learning the reactions mechanisms. Learning ORM has been challenging and very difficult for students to understand leading to errors of serious concern. Scholars are concerned about common errors in ORM among students, as the most affected concept of organic chemistry due to its central role and spiral nature in the curriculum relative to other chemistry concepts (Berg & Ghosh, 2013; Caspari, Weinrich, et al., 2018; Osman et al., 2013b). For example, Talib, Othman, and Putri (2014) observed that a meaningful learning in reaction mechanisms is needed for understanding synthesis and fundamental in learning more advanced organic chemistry.

Nevertheless, there is no adequate teaching models for explicit presentation of the basic concepts (Bongers et al., 2019; Gilbert, 2005). For example, chemical triangle proposed by Johnstone (1993), is the model dominantly used for teaching chemistry. This model suggestes interpretation and communication of chemistry knowledge based on macro, micro, and symbolic levels to describe objects as observable and recognizable in our environment. Other models used were particulate matter model, and chemical and mathematical signs (Gabel, 1999a; Gilbert & Treagust, 2009; Johnstone, 1991; Talanquer, 2011). Yet, chemical representation model has been adapted reinterpreted by many reseachers. For instance, reporting on the study of Johnstone's writings Talanquer (2011) reveals that Johnstone described the components of chemistry in different forms such as thought levels (Johnstone, 1991), modes or components (Johnstone, 1993), and subjects matter type (Johnstone, 2000). Talanquer (2011) added that researchers like Gabel and colleagues who took a parallel opinion of chemistry representation with Johnstone were they used of additional labels including teaching levels (Gabel, 1993), and levels of representation (Gabel, 1999a; Gilbert & Treagust, 2009). In addition, Jensen (1998) used electrical levels; finally, Ladhams (2004) used molar, and intermolecular levels. Though, the interpretation of Gilbert and Treagust (2009) was dominantly used in teaching chemistry in the last couple of years. Yet, in the planning of chemistry lessons, it required teachers to focus more comprehensively on novel models, specifically for teaching organic chemistry that involves abstract and invisible processes as part of the adaption of the classical model to minmize confusion and misunderstanding of the students in learning (Talanquer, 2011). Likewise, basic concepts were taught to the students as independent topics because they appeared first in the syllabus without connection, integration and transformation in teaching and learning of related concepts (Talanquer, 2015).

Many textbooks have been published on the teaching of organic reaction. For instance, in his book Grossman (2003) explained the clear presentation of reaction mechanisms and warned teachers about common error alerts in reaction mechanisms. The use of curved arrow to illustrate transfer of electron is the strategy typically used in teaching reaction mechanisms (Tsaparlis & Sevian, 2013). Arrow-pushing technique and electron-pushing formalism have been used interchangeably by scholars to described this strategy (Wilson and Varma-Nelson, 2018). The term arrow pushing technique is defined as the use of arrows to indicate movement of electron from an electron reach species to an electron defiecient species (Levy, 2008). Similarly, Bhattacharyya (2013) electron-pushing formalisms is the use of symbolisms and mechanistic reasoning in writing organic reactions mechanisms. Therefore, both electron-pushing formalism and electron-pushing technique were illustrative and projecting methods for the mechanisms of organic reactions. However, the dominant use of arrows in demonstrating electrons transfer rises the student’s cognitive load (Talib et al., 2012) and contributes to learning by memorization of reaction mechanisms as an indivisible entity, despite teacher’s efforts to motivate student interest in learning the paradigmatic sequence of steps in ORM (Bhattacharyya, 2019).

Another important issue in chemistry and science education has been the disconnection between researches conducted and real classroom practices. Most chemistry education researches focus more on determining the causal-and-effect relationships between variables through a controlled study with limited sample size and less or no involvement of teachers (e.g Aidoo, Boateng, Kissi, & Ofori, 2016; Mack, Hensen, & Barbera, 2019; Sabitu & Francis, 2016; Schultz, Duffield, Rasmussen, & Wageman, 2014; Webber & Flynn, 2018; Yoruk, Morgil, & Secken, 2009). Findings obtained from experimental and laboratory educational studies were limited scientifically in their ability to predict, explain, and generalize to a large population because of the weakness of their results to withstand the threats to both internal and external validity associated with their methodologies. Thus, these studies cannot address the problem of difficulties in learning chemistry such as students' common errors in ORM (Plomp & Nieveen, 2013). On this basis, scholars including Amiel and Reeves (2008); Gurvitch and Metzler (2010); Herrington (2012); Kelly, Wills, Jester, and Speller (2017), and Klein (2013) emphasized the need to implement a methodological approach which relates disciplines, researches, and practices in partnership to establish alternative ways of seeking solutions to the phenomenon of education.

1.2 Statement of the Problem

One of the worrying issue in science education has been the inadequacy of instructional models that integrate concepts in teaching of abstract science subjects (Bongers et al., 2019). Hence, rising the need for researches to minimize this problem by improving science instruction to bridge the gap through the development of novel teaching models (Sevian et al., 2015). Thus, it is helpful in teaching of science concepts to develop models that will integrate visual and verbal representations to simplify the teaching of abstract science concepts to the students. As such, this study, aimed at developing a model for minimising students' common errors in reaction mechanisms that hinders students from understanding advance organic chemistry. Organic reaction mechanisms (ORM) has been perceived as one of the abstract and complex concepts that often make the learning of chemistry more challenging and confusing to students. Thus, the lack of an alternative model of instruction makes it harder for students to link their previous experiences (Bhattacharyya, 2013, 2019; Bongers et al., 2019). This resulted in learning by memorization, and many of the students cannot retain and recall the knowledge memorized during examinations (Ferguson & Bodner, 2008).

Though several textbooks discussed about the organic chemistry teaching and learning methods, the ability to understand and remember mystifying structure of organic compounds and peculiar properties of carbon, such as catenation added to its learning difficulties (Grossman, 2003; Levy, 2008; Scudder, 2013). Catenation is the ability of carbon to form the vast number of organic compounds as straight, branched, cyclic, alicyclic, and many other forms that make memorization very difficult if not impossible (Anzovino & Lowery Bretz, 2015; Popova & Bretz, 2018b). To many scholars and particularly curriculum implementers, therefore, reforming the current chemistry instructional models, approaches, and strategies adopted in schools to reflect the uniqueness of the carbon compounds seems crucial (Bongers et al., 2019; Cooper & Klymkowsky, 2013; Saido et al., 2018; Teichert, Tien, Dysleski, & Rickey, 2017). Thus, critical aspects have been recognized in science instruction that deters effective teaching and learning and has resulted in the low performance of students in science subjects (Talib et al., 2012). It is essential, particularly for concepts of organic reaction to being transformative, integrative, and bounded to provide an explicit presentation of the concept. This is necessary because organic reactions have been most influenced by many abstract and troublesome concepts such as lone pair, nucleophilic and electrophilic concepts.

Equally, the number of student's error in reactions mechanisms is increasing (Flynn & Featherstone, 2017) and several of this errors have been reported in the recent literature including; wrong arrow positioning, arrow shortage, the formation of hypervalent carbon, errors due to mixing reaction media and poor conservation of charges (Andrés et al., 2016; Bodé et al., 2019; Caspari, Kranz, et al., 2018; Flynn & Featherstone, 2017; Galloway et al., 2019). Major factors identified as the causes of these errors were the overuse of teacher-centred instruction (Grove & Lowery Bretz, 2012; Hrin, Milenković, & Segedinac, 2016; Lo & Tang, 2018) as many lessons were based on presentation of logical fact through indirect instruction. Likewise, the half-hazard coverage of large course contents (Andrés et al., 2017); and the student's perception of organic reaction mechanisms as the most complicated and abstract concepts to grasp as well as the spiral nature of the concepts in the chemistry curriculum (Hrin, Milenković, Segedinac, et al., 2016; O'Dwyer & Childs, 2011) and these factors resulted to the low enrolment of students particularly into chemistry and the science stream in general (Alias et al., 2015; Osman et al., 2013a). For instance, students' enrolment into science in Malaysian secondary schools decreases to as low as 44% and 21% in 2011 and 2014 respectively (Meng, Idris, & Eu, 2014; Mohtar et al., 2019; Tutiaini et al., 2018) and these figures are far from the targeted 60% in the science stream and 40% in the non-science disciplines in Malaysian schools (Kamisah Osman, Zanaton Haji Iksan, & Lilia Halim, 2007 & Ramli & Talib, 2017). This was a key issue, as many nations had seen science education as the driving force behind their economic and social development (Logan & Skamp, 2008; Marginson, 2018; Massaquoi, 2019; Nnakwe et al., 2018).

Thus, there is a need for science education researches to empower teacher to adapt novel models of instruction in their lessons, regardless the settings and the types of curriculum he is implementing (Cheng & Gilbert, 2017). Instructional model is a philosophical representation of realities constructed by researchers to create meanings of t ideas for meaningful learning (Akaygun, 2016). Teachers have adopted various teaching models to create and prepare alternative instructions for the teaching of chemistry (Talanquer, 2011; Talanquer & Pollard, 2010). For example, Johnstone's chemical representation model is a popular conceptual model implemented by science teachers to simplify abstract concepts. It is a model of representation that has undergone modifications due to the complexity of some science concepts leading to ambiguity and misunderstanding (Hannah Sevian & Talanquer, 2014). This is because students are becoming more confused and found it challenging to move across different representational levels of Johnstone's representation model and this resulted in learning through memorization (Popova & Bretz, 2018a). Student lacks the intellectual capacity to conceptualize the chemical triangle, and see no sense and value in the three levels of representation adopted by the teachers during the lesson (Aidoo et al., 2016; Akaygun, 2016; Bongers et al., 2019).

Also, there was no relationship between theoretical understanding and actual practices in science education (Fleer, 2019; Rejab et al., 2018). While scholars focused on comparing the effectiveness of existing teaching methods, science teachers continue to adhere to conventional methods that have demonstrated to be boring and uninteresting in their experience in the classroom (Achiemugu, 2018). Therefore, the main objective of the study was the development and validation of organic reaction teaching model based on the practices of the students that leads to errors in reaction mechanisms and experts' collective opinions who are professionals in chemistry and, curriculum and instructions.

1.3 Objectives of the Study

The main objective of this study was to develop an organic reaction teaching model (ORTM) to minimise common errors among matriculation students. Thus, the investigator chose to develop and validate a model for teaching organic reaction mechanism, a concept offered by Malaysian Matriculation Colleges. The study, therefore, has the following specific objectives:

1. To determine the needs for developing the ORTM to minimize matriculation students' common error based on the students' practices and experts' collective opinion.

2. To develop the ORTM for minimizing students' common errors based on experts' collective opinion.

3. To validate the suitability and usability of the ORTM components based on experts' collective opinion.

4. To validate the practicability and potentiality of the ORTM in minimising students' errors in ORM.

1.4 Research Questions

The research questions were developed agreeing to the phases of the study, based on the specific objectives of this study:

Phase 1:

Phase one aimed to offer answers to the research questions about the needs for the development of the ORTM from the practices of the students and the collective opinion of the experts:

1. What are the outcomes of the previous studies conducted on teaching and learning of organic reaction?

2. To what extent is it necessary to develop ORTM to minimise common errors in organic reactions, based on the experts' collective opinion?

3. What are the matriculation students' common errors in ORM?

Phase 2:

This is the design and development phase that proposed answers to the following research questions:

1. What are the opinions of experts on the instructional activities and constructs to be included in the development of the ORTM?

2. Based on the experts' opinions, how would the model components (instructional activities, constructs and domains) be arranged according to their relevance and weight?

Phase 3:

To validate the organic reaction teaching model (ORTM). The validation phase was sought to address the following questions:

1. What are the collective opinion of the experts about the suitability of the instructional activities included in the ORTM?

2. What are the collective opinion of the experts on the classification of the instructional activities into the five respective constructs proposed in the model?

3. What are the collective opinion of the experts on the instructional activities grouped under the three error correction domains (error avoidance, error interference, and error correction) proposed in the model?

4. What are the experts' collective opinion on the overall usability of the ORTM components?

5. How does the ORTM help lecturers to improve students' understanding of organic reaction mechanisms?

6. What is the potential of ORTM in helping students to minimize common errors and improve their academic performance in organic reaction mechanisms?

1.5 The Rationale of the Study

This study's objective aimed develop and validate organic reaction teaching model (ORTM). The rationale for conducting this study was the desire to help matriculation students, in particular, to have a conceptual knowledge of organic reaction mechanisms (ORM), which was an important concept in learning organic chemistry. This was reported by Talib, Othman, and Putri (2014) that a meaningful learning of ORM is critical in synthesizing advanced organic compounds. Therefore, the highest cognitive learning outcomes of organic chemistry depend on students' ability to solve problems with the organic reaction mechanisms. So it is clear, that the organic reaction mechanism is necessary to understand the more advanced concepts of organic chemistry. In any case, those who have a meaningful understanding of mechanisms for the organic reaction will be able to access and recall the basic information for learning advanced concepts. This may be the most important clear understanding of organic reaction mechanism. Thus, information learned from the organic reaction mechanism is easier to be transformed, so that the knowledge would be applied to solve problems in advanced organic chemistry.

In this study, a teaching model was developed by integrating instructional activities that will encourage students to use mechanistic reasoning and language symbolisms that would increase their understanding of reaction mechanisms. Mechanistic reasoning is depiction of electron movement in showing the step-by-step transformation of reactants into products (Bhattacharyya, 2013). Whilst language symbolisms are unique systems of representation using alphanumeric characters, Greek symbol, line, dot, arrows, and/or geometric shape to explicitly explain reaction of organic compound. Meanwhile, instructional activities are referred to as the classroom actions and behaviours that link mechanistic reasoning and the language symbolisms for conceptual understanding of organic reaction. These constructs were recommended in the previous studies for the implementation of the organic chemistry curriculum (Dood et al., 2020; Hsiao et al., 2019; Liu & Taber, 2016; Otter, 2020). As instructional constructs, they are also, essential for conceptual understanding of reaction mechanisms by decreasing cognitive load to assist students in recalling and applying the knowledge learned in understanding advanced organic chemistry courses (Caspari, Kranz, et al., 2018).

Secondly, to increase conceptual knowledge of organic reactions, the aim of organic chemistry should not be only on the teaching of basic concepts, laws, and theories in conventional teaching methods. Bhattacharyya, (2019) stated that teaching and assessment approaches have historically been aimed at memorizing materials leading to errors in the organic reactions. This is because conventional chemistry teaching approaches are typically aimed at teachers who attempt in a limited time to cover a significant amount of curriculum materials. The conceptual understanding of organic reaction mechanisms requires approaches that provide the student with the opportunity to construct a mental model for practical understanding that can be retrieved and used in the future. This study, therefore, aimed to create an ORTM focusing on instructional activities that will allow the students to minimise common error in organic reactions.

Thirdly, its stated earlier, in 2013 that, the Malaysian education system has been revised addressing challenges in 21st century, which was primarily based on teaching for conceptual understanding of science subjects including organic chemistry. However, the method of teaching adopted for teaching organic chemistry in Matriculation Colleges is commonly a direct instruction approaches such as lecturing. Thus, the researcher became interested in selecting the study sample from the Malaysian Matriculation Colleges. Lastly, organic reaction mechanisms are concepts that are highly valued throughout the world for being a key topic for learning advanced organic reactions in chemistry and other science-related disciplines such as microbiology, food technology, and medical sciences.

1.6 Significance of the Study

Educators have long considered errors as a catalyst for successful learning (Steuer et al., 2013). The development of a teaching model based on the practices of students would therefore assist curriculum designers and teachers in chemistry education to prevent future consequences of errors. This research could help chemistry teachers in determining common errors in organic reaction mechanisms among the students that would offer strong indications of what the students think and what distracts them from the right answers. Thus, understanding the mistakes of the students will help teachers concentrate on the aspects of topics requiring further explanations. The study also provides an alternative way to manage common errors among students, with anticipation that curriculum specialist would recognize student's common error as one of the aspects of error avoidance strategies in designing curriculum content, especially for abstract science concepts.

The study will therefore contribute to the field of research methodology, in particular the three phases adopted, namely need analysis, design and development, and validation using the Delphi fuzzy method. This will help the researcher to remain concentrated and allow reflection at any point in the study. Besides, the findings of this study will also enrich the theoretical information concerning the representation of chemical concepts as a basis for the conceptualization of science teaching by integrating two models and three theories including the Novak Model of Education, Johnstone's Model of Chemical Representation, Threshold Concepts Theory, and Repair Learning Theory. Of this purpose, the study will help chemical educators to improve their judgment on the extension of the Johnstone chemical triangle to satisfy the implicit characteristics of organic reactions for simplification of its abstractness.

1.7 Scope and Limitation of the Study

The development of ORTM was proposed as an example of how related principles could be incorporated into the teaching of organic reactions to enhance understanding of organic chemistry content. In the scope of organic chemistry, the study chose reaction mechanisms of basic organic reactions in the matriculation chemistry curriculum as the focus of the study. The study was primarily concerned with the context of organic reaction mechanisms in the chemistry matriculation curriculum (Akker, 2006; Baker et al., 2006; Richey & Klein, 2005) where it was developed for a specific phenomenon of common errors in organic reaction mechanisms.

Concerning methodology, this study used research findings from previous studies, the collective view of experts, and the common errors of students in judging the need for the model development was the phase one. In the second phase, the study adopted the conventional Delphi method to obtain the components for the model, and determine the level of relevance and weightage of the model components, and the fuzzy Delphi field testing methods were used to validate the suitability, usability, practicability and effectiveness of the model. These methods are primarily based on experts' collective views. Thus, the validity of the model components depends on the experts' experiences and their opinions on the phenomenon of student's common error in the mechanisms of organic reactions. In the first Delphi round, twenty-one (21) experts (10 matriculation chemistry lecturers, 4 university chemistry lecturers, 3 science education lecturers, and 4 curriculum and instruction experts) were involved. The second phase comprised of seventeen (17) experts (8 from matriculation colleges, 3 from chemistry, and 6 from education fields).

The internal validation involved 14 experts, the majority of them were matriculation chemistry lecturers (n= 8), 4 from education fields, and 2 were university chemistry lecturers. External validation was conducted with 5 chemistry lecturers and 40 students from five matriculation colleges. It indicates that the findings vary because the analysis was performed using a different number of experts with different experiences from a different setting. The model should not, therefore, be applied to all higher institutions. This could, however, be repeated to establish a similar instructional model adapted to a particular level of education at various institutions and for different concepts. Another limitation of the study is that ORTM was focused on incorporating instructional activities as the model's major component. Other components of the ORTM primarily established the relationship between the instructional activities with other variables such as the implementers' role, teaching and learning strategies, and context.

1.8 Definition of Key Terms

The following are important terminologies considered very significant in this research, and are therefore defined based on the perspective of this study:

An Error: Error is a natural by-product of trying to minimise learning tasks and can, in particular, provide students with learning opportunities (VanLehn, 1990). An error is also described as students' behaviours that may have had negative effects that could have been avoided (Tulis, Steuer, & Dresel, 2016, p. 103)". In this study, students' error is defined as the variation observed from the students' attempts to solve organic reaction mechanisms tasks that result in an unacceptable disparity between the processes expected that could have been prevented.

Teaching Model: Is the widest level of teaching practice that gives instruction a logical coordination. Generally used to choose and arrange instructional task, technique, and skill that allow students' interactions with a specific focus on instruction (Richey & Klein, 2005). In this situation, a teaching model is defined as a collection of structured instructional activities that would be used by chemistry teachers in scheming and planning instructions for teaching mechanisms of organic reactions with the aim of minimizing errors to improve students' performance.

Symbolism: is defined as a series of unique grammatical symbols that explicitly explain specialized forms of knowledge that can be understood more than using the natural language (Liu & Taber, 2016). In this study, symbolism is referred to as a unique symbol of representation such as alphanumeric character, Greek symbol, line, dot, a curved arrow, and geometric shape for explicit explanation of what is happening in the reaction of organic compound.

Crosscutting: This is a construct which is described in a similar way to a gateway of understanding, opening a new way of thinking about the previously challenging concepts (Meyer & Land, 2003). It is a changed way of thinking, or remembering, or experiencing things that students must understand for learning to progress. In this study, crosscutting construct is considered as verging core concepts that are critically needed for understanding organic reaction mechanisms without which students cannot progress in learning advanced organic chemistry.

Visualization: This is an effective way for learner to access a complex concept through drawing graphing, sketching, expanding or putting numbers on a number line to make complex ideas in more explicit, whether online or offline (Gilbert, 2005). Visual representation in this study, entails the explicit presentation of the abstract and salient features of the organic reaction mechanism using diagrams, sketches, simulations, short videos, computer applications, tools, and colors.

Mechanisms: is described as the mechanistic steps to explain how and why a reaction occurs and from which entities and activities they were generated (Hsiao et al., 2019). In this study, mechanisms construct describes how the formation of radical, and movement of electrons, as well as the systematic conversion of reactant into the product occurred during the reactions.

Reflection: This is referred to as considering and recalling the previous issues in classroom practices for improving the learning outcome (Chacón, 2018). Reflection is also defined as a practice in which teachers, and students, learn from past classroom experiences to gain new insight for better outcome (Finlay & Gough, 2008). The reflection construct in this study refers to the recalling issues from previous instructional classroom activities through a structured evaluation process that help teacher guide student to correct some mistakes from previous instructions.

1.9 Organisation of the Study

This study was structured into seven chapters and each chapter is focusing on an important part of the thesis. Chapter one addresses the topic of the subject under investigation and the scholars' claims about the research problem. Chapter two examines and critically reviews the related literature by highlighting the opinions of scholars on the research variables and defining areas that received less attention or lack of studies that concentrate on organic chemistry instruction to minimise the common errors of students. To bridge this gap, the development and validation of organic reactions teaching model from perspectives of students' practices and experts' consensus is justified. It is then followed by an explanation of how the relevant variables are underpinned by both learning and development theories and models which are combined and included in the research framework of the study.

Chapter three outlines the methodologies adopted in the study, which comprises of three phases, including the need analysis by experts' interviews, scoping review and errors identification from students' manuscripts; the model development process, the composition of the experts' panel, and the execution of the Delphi rounds, as well as the procedures for the model validation through Fuzzy Delphi and field-testing methods. The findings of the study were elaborated at Section A, B, C and D of Chapters 4, respectively. Chapter 5 summarises the research implications, offers recommendations, and suggestions for future research directions.

1.10 Summary

This chapter discusses the issue specifically related to the topic under study, the whole chapter provides background information and explains the existing situations related to common errors in organic reaction mechanisms among matriculation students. The study objectives, the intended contributions, and the operational definition of terms were outlined based on the argument presented. The subsequent chapter is on the review of related literatures and a thorough description of underlying theories and models surrounding the development of the organic reaction teaching model (ORTM).

REFERENCES

Abdallah, M., & Wegerif, R. (2014). *Design-Based Research (DBR) in educational inquiry and technological studies*: A version for Ph.D. students targeting the integration of new technologies and Literacies into Educational Contexts. (Unpublished?), 1–25.

Abdelgawad, M., & Fayek, A. R. (2010). Risk management in the construction industry using combined fuzzy FMEA and fuzzy AHP. *Journal of Construction Engineering and Management*, 136(9), 1028–1036.

Abdullah, M. R. T. L., & Siraj, S. (2018). The evaluation of mLearning implementation model for English Language learning via the Fuzzy Delphi method. *Pertanika Journal of Social Sciences and Humanities*, 26(January), 33–54.

Abdullah, M. R. T. L., Siraj, S., Asra, & Hussin, Z. (2014). Interpretive structural modeling of mlearning curriculum implementation model of English language communication skills for Undergraduates. *Turkish Online Journal of Educational Technology*, 13(1), 151–161.

Abdullahi, M. R. T. L. (2014). *Development of Activity-based mLearning Implementation Model for Undergradute English Language Learning* (Issue c) [University Malaya].

Abolhasan, F., Aryan, G., Mohammad, A. A., Hasan, G. A., & Asghar, A. (2019). Validation of Dimensions and Component of Risk Culture: Using the Fuzzy Delphi Method. *General Management Research*, 11(42), 5–31.

Academy of Sciences Malaysia. (2015). *Science Outlook 2015: Action Towards Visio*n (Academy of Sciences Malaysia (Ed.)). Ministry of Science, Technology And Innovation.

Achimugu, L. (2018). Effectiveness of Enriched Demonstration and Lecture Instructional Strategies on Senior Secondary School Students ' *Achievement in Chemistry*. January, 1–9.

Adler, M., & Ziglio, E. (1996). *Gazing into the oracle: The Delphi method and its application to social policy and public health* (First). Jessica Kingsley Publishers.

Afolabi, M. O., Kareem, F. A., Okubanjo, I. O., Ogunbanjo, O. A., & Aninkan, O. O. (2017). Effect of Entrepreneurship Education on Self-Employment Initiatives among Nigerian Science & Technology Students. *Journal of Education and Practice*, 8(15), 44–51.

Aidoo, B., Boateng, S. K., Kissi, P. S., & Ofori, I. (2016). Effect of Problem-Based Learning on Students' Achievement in Chemistry. *Journal of Education and Practice*.

Ali, W. (2020). Online and remote learning in higher education institutes: A necessity in light of COVID-19 pandemic. *Higher education studies*, 10(3), 16-25.

Akaygun, S. (2016). Is the oxygen atom static or dynamic? the effect of generating animations on students' mental models of atomic structure. *Chemistry Education Research and Practice*, 17(4), 788–807.

Akker, J. Van Den. (2006). Educational Design Research_ The Design, Development and Evaluation of Programs, Processes and Products (2006). *Educational Design Research*.

Akkerman, S., Admiraal, W., Simons, R. J., & Niessen, T. (2006). Considering diversity: Multivoicedness in international academic collaboration. *Culture & Psychology*, 12(4), 461-485.

Alfan, E., & Othman, N. (2005). Undergraduate students' performance: The case of University of Malaya. *Quality Assurance in Education*, 13(4), 329–343.

Alias, M., Masek, A., & Salleh, H. H. M. (2015). Self, Peer and Teacher Assessments in Problem Based Learning: Are They in Agreements? *Procedia - Social and Behavioral Sciences*, 204(2015), 309–317.

Altschuld, J. W., & Hines, C. V. (1982). Factors Affecting the Validity of Field Tests in Education. *Educational Evaluation and Policy Analysis*, 4(3), 331–339.

Altschuld, J. W., & Witkin, B. R. (2000). *From needs assessment to action*: Transforming needs into solution strategies. Sage.

Ameyaw, E. E., Hu, Y., Shan, M., Chan, A. P. C., & Le, Y. (2016). Application of Delphi method in construction engineering and management research: A quantitative perspective. *Journal of Civil Engineering and Management*, 22(8), 991–1000.

Amiel, T., & Reeves, T. C. (2008). Design-based research and educational technology: Rethinking technology and the research agenda. *Journal of Educational Technology & Society*, 11(4), 29–40.

Anderson, C. R. (1979). Long-Range Forecasting: From Crystal Ball to Computer. *In Academy of Management Review* (Vol. 4, Issue 3, pp. 474–475).

Andrés, J., Berski, S., & Silvi, B. (2016). Curly arrows meet electron density transfers in chemical reaction mechanisms: From electron localization function (ELF) analysis to valence-shell electron-pair repulsion (VSEPR) *inspired interpretation. Chemical Communications*, 52(53), 8183–8195.

Andrés, J., González-Navarrete, P., Safont, V. S., & Silvi, B. (2017). Curly arrows, electron flow, and reaction mechanisms from the perspective of the bonding evolution theory. *Physical Chemistry and Chemical Physics*, 19(43), 29031–29046.

Mohd Said, A. (2015). *Curriculum model based on orang asli knowledge of herbal medicine for future primary school*/Aniza Binti Mohd Said (Doctoral dissertation, University of Malaya).

Anzovino, M. E., & Bretz, S. L. (2015). Research and Practice Organic chemistry students ' ideas about nucleophiles and electrophiles : the role of charges and mechanisms. *Chemistry Education Research and Practice*.

Anzovino, M. E., & Bretz, S. L. (2016). Organic chemistry students' fragmented ideas about the structure and function of nucleophiles and electrophiles: A concept map analysis. *Chemistry Education Research and Practice*, 17(4), 1019–1029.

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology: Theory and Practice*, 8(1), 19–32.

Arslan, A. (2017). Basic Needs as a Predictors of Prospective Teachers' Self-actualization. *Universal Journal of Educational Research*, 5(6), 1045–1050.

Ary, T. C. (2009). *Trafficking in Persons in Three Dimensions*: Evolution, Globalization and the Brazil-Europe Route. 1–159.

Attieh, R., Gagnon, M. P., Estabrooks, C. A., Légaré, F., Ouimet, M., Vazquez, P., & Nuño, R. (2014). Organizational readiness for knowledge translation in chronic care: A Delphi study. *BMC Health Services Research*, 14(1), 1–12.

Avella, J. R. (2016). Delphi Panels : Research Design , Procedures , Advantages , and Challenges. *International Journal of Doctoral Studies*, 11, 305–321.

Avery, A. J., Savelyich, B. S. P., Sheikh, A., Cantrill, J., Morris, C. J., Fernando, B., Bainbridge, M., Horsfield, P., & Teasdale, S. (2005). Identifying and establishing consensus on the most important safety features of GP computer systems: e-Delphi study. *Informatics in Primary Care*, 13(1), 3–11.

Awusabo-Asare, K., Doku, D. T., Kumi-Kyereme, A., & Esia-Donkoh, K. (2017). From Paper to Practice: Sexuality Education Policies and Their Implementation in Ghana. *Sexuality Education*, 1(April), 93.

Azevedo, S. G., Govindan, K., Carvalho, H., & Cruz-Machado, V. (2012). An integrated model to assess the leanness and agility of the automotive industry. *Resources, Conservation and Recycling*, 66, 85–94.

Azraai, O. (2016). *Modeling Relationships of Matriculation Students' Affective and Cognitive Factors and Achievement in Organic Chemistry*. A PhD Thesis In Universitas Putra Malaysia. University Putra Malaysia.

Othman, A., Ibrahim, D. A., & Talib, O. (2015). Teaching and Learning Based on Organic Chemistry Taxonomy Bloom (12-21). *Jurnal Pendidikan Bitara UPSI*, 8(1), 12-21.

Azraai, O., & Talib, O. (2015). Level of basic understanding of organic chemistry of technical stream matriculation college students. *Jurnal Pendidikan Sains & Matematik Malaysia*, 5(2), 86–97.

Bader, R. F. W., Popelier, P. L. A., & Keith, T. A. (1994). Theoretical Definition of a Functional Group and the Molecular Orbital Paradigm. Angewandte Chemie *International Edition in English*, 33(6), 620–631.

Bahrum, S., Wahid, N., & Ibrahim, N. (2017). Integration of STEM Education in Malaysia and Why to STEAM. *International Journal of Academic Research in Business and Social Sciences*, 7(6), 645–654.

Bailie, J. L. (2012). The criticality of verbal immediacy in online instruction: A modified Delphi study. *Journal of Educators Online*, 9(2).

Baines, T., & Shi, V. G. (2015). A Delphi study to explore the adoption of servitization in UK companies. *Production Planning and Control*, 26(14–15), 1171–1187.

Baker, J., Lovell, K., & Harris, N. (2006). How expert are the experts? An exploration of the concept of "expert" within Delphi panel techniques. *Nurse Researcher*, 14(1), 59–70.

Balasubramanian, R., & Agarwal, D. (2013). Delphi technique-A review. *International Journal of Public Health Dentistry*, 3(2), 16–25.

Barrett, M. J., Harmin, M., Maracle, B., Patterson, M., Thomson, C., Flowers, M., & Bors, K. (2017). Shifting relations with the more-than-human: Six threshold concepts for transformative sustainability learning. *Environmental Education Research*, 23(1), 131–143.

Belkin, A. C. (2001). *The Construction and Validation of an Instructional Systems Design Model Incorporating Multiple Intelligences*. PhD Dissertation,Wayne State University 274.

Benítez, J. M., Martín, J. C., & Román, C. (2007). Using the fuzzy number for measuring quality of service in the hotel industry. *Tourism Management*, 28(2), 544–555.

Berg, S., & Ghosh, A. (2013). Six impossible mechanisms before breakfast: Arrow pushing as an instructional device in inorganic chemistry. *Journal of Chemical Education*, 90(11), 1446–1451.

Betancourt-Ṕerez, R., Olivera, L. J., & Rodríguez, J. E. (2010). Assessment of organic chemistry students' knowledge of resonance-related structures. *Journal of Chemical Education*, 87(5), 547–551.

Beumer, K. (2019). Nation-Building and the Governance of Emerging Technologies: the Case of Nanotechnology in India. *NanoEthics*, 13(1), 5–19.

Bhattacharyya, G. (2013). From source to sink: mechanistic reasoning using the electron-pushing formalism. *Journal of Chemical Education*, 90(10), 1282-1289.

Bhattacharyya, G. (2019). Construction by De-construction. *Journal of Chemical Education*.

Bhattacharyya, G., & Bodner, G. M. (2005). " It gets me to the product": How students propose organic mechanisms. *Journal of Chemical Education*, 82(9), 1402.

Blueprint, M. E. (2016). *Blueprint* 2013-2025. (2013). Ministry of Education, Malaysia, 27.

Bodé, N. E., Deng, J. M., & Flynn, A. B. (2019). Getting Past the Rules and to the WHY: Causal Mechanistic Arguments When Judging the Plausibility of Organic Reaction Mechanisms. *Journal of Chemical Education*, 96(6), 1068–1082.

Bode, N. E., & Flynn, A. B. (2016). Strategies of Successful Synthesis Solutions: Mapping, Mechanisms, and More. *Journal of Chemical Education*

Bodner, G. M. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education*, 63(10), 873.

Bogdan, R., & Biklen, S. K. (1997). *Qualitative research for education*. Boston, MA: Allyn & Bacon.

Bolger, F., & Wright, G. (2011). Improving the Delphi process: Lessons from social psychological research. *Technological Forecasting and Social Change*, 78(9), 1500–1513.

Bongers, A., Northoff, G., & Flynn, A. B. (2019). Working with mental models to learn and visualize a new reaction mechanism. *Chemistry Education Research and Practice*, 20(3).

Boulkedid, R., Abdoul, H., Loustau, M., Sibony, O., & Alberti, C. (2011). Using and reporting the Delphi method for selecting healthcare quality indicators: *a systematic review*. PloS One, 6(6).

Bretz, S. L., & Murata Mayo, A. V. (2018). Development of the flame test concept inventory: Measuring student thinking about atomic emission. *Journal of Chemical Education*, 95(1), 17–27.

Brown, J. S., & VanLehn, K. (1980). Repair Theory: A Generative Theory of Bugs in Procedural Skills. *Cognitive Science*, 4(4), 379–426.

Bryman, A. (2004). Qualitative research on leadership: A critical but appreciative review. *The Leadership Quarterly*, 15(6), 729–769.

Büyüközkan, G., & Ruan, D. (2008). Evaluation of software development projects using a fuzzy multi-criteria decision approach. *Mathematics and Computers in Simulation*, 77(5–6), 464–475.

Cantel, S., Le Chevalier Isaad, A., Scrima, M., Levy, J. J., DiMarchi, R. D., Rovero, P., Halperin, J. A., D'Ursi, A. M., Papini, A. M., & Chorev, M. (2008). Synthesis and conformational analysis of a cyclic peptide obtained via i to i+ 4 intramolecular side-chain to side-chain azide- alkyne 1, 3-dipolar cycloaddition. *The Journal of Organic Chemistry*, 73(15), 5663–5674.

Carle, M. S., Visser, R., & Flynn, and A. B. (2018). Nitrogen-doped Carbon Nanodots for bioimaging and delivery of paclitaxel. *Journal of Materials Chemistry*. B, 6(35).

Carole, A. (1992). Classrooms: Goals, Structures, and Student Motivation. *In Journal of Educational Psychology* (Vol. 84, pp. 261–271).

Carroll, G. (2006). Book reviews. *Journal of Higher Education Policy and Management*, September 2015, 1–11.

Carter, N., Bryant-Lukosius, D., Dicenso, A., Blythe, J., & Neville, A. J. (2014). The use of triangulation in qualitative research. *Oncology Nursing Forum*, 41(5), 545–547.

Carcary, M. (2009). The research audit trial—enhancing trustworthiness in qualitative inquiry. Electronic *Journal of Business Research Methods*, 7(1), pp11-24.

Caspari, I., Kranz, D., & Graulich, N. (2018). Resolving the complexity of organic chemistry students' reasoning through the lens of a mechanistic framework. *Chemistry Education Research and Practice,* 19(4).

Caspari, I., Weinrich, M. L., Sevian, H., & Graulich, N. (2018). This mechanistic step is "productive": organic chemistry students' backward-oriented reasoning. *Chemistry Education Research and Practice,* 19(1).

Cattano, C. (2013). *Development of a rating system to measure the vulnerability of residential homes to natural hazards*. ProQuest Dissertations and Theses, 258.

Chacón, C. T. (2018). Reflective Teaching. *The TESOL Encyclopedia of English Language Teaching*, 1–5.

Chang, P. T., Huang, L. C., & Lin, H. J. (2000). The fuzzy Delphi method via fuzzy statistics and membership function fitting and an application to the human resources. *Fuzzy Sets and Systems*, 112(3), 511–520.

Cheng, M. M. W., & Gilbert, J. K. (2017). Modelling students' visualisation of chemical reaction. *International Journal of Science Education*, 39(9).

Ching-Hsue, C., & Yin, L. (2002). Evaluating the best main battle tank using fuzzy decision theory. *European Journal of Operational Research*, 142, 174–186.

Chia Yi Quah & Kher Ng (2021). A Systematic Literature Review on Digital Storytelling Authoring Tool in Education: January 2010 to January 2020. *International Journal of Human–Computer Interaction.*

Cohen, M. E., & Carr, W. J. (1975). Facial recognition and the von Restorff effect. *Bulletin of the Psychonomic Societ*y, 6(4), 383–384.

Cooper, M. M., Stowe, R. L., Crandell, O. M., & Klymkowsky, M. W. (2019). Organic Chemistry, Life, the Universe and Everything (OCLUE): A Transformed Organic Chemistry Curriculum. *Journal of Chemical Education*.

Coppola, B. P., & Pontrello, J. K. (2014). Using errors to teach through a two-staged, structured review: Peer-reviewed quizzes and "what's wrong with me?" *Journal of Chemical Education*, 91(12), 2148–2154.

Cornforth, J. W. (1993). The trouble with synthesis. *Australian Journal of Chemistry*, 46(2), 157–170.

Cornish, E., & others. (1977). *The study of the future: An introduction to the art and science of understanding and shaping tomorrow's world*. Transaction Publishers.

Cousin, G. (2006). *Threshold concepts, troublesome knowledge and emotional capital. In Overcoming Barriers to Student Understanding Threshold concepts and troublesome knowledge* (Vol. 2004, Issue 2, pp. 134–147). Routledge Abingdon.

Cramer, C. K., Klasser, G. D., Epstein, J. B., & Sheps, S. B. (2008). The Delphi process in dental research. *Journal of Evidence-Based Dental Practice*, 8(4), 211–220.

Creswell, J. W. (2013). *Steps in conducting a scholarly mixed methods stud*y. SAGE publications

Creswell, J. W. (2014). *A concise introduction to mixed methods research*. SAGE publications.

Creswell, J. W., & Clark, V. L. P. (2017). *Designing and conducting mixed methods research*. Sage publications.

Crimmins, M. T., & Midkiff, B. (2017). High Structure Active Learning Pedagogy for the Teaching of Organic Chemistry: Assessing the Impact on Academic Outcomes. *Journal of Chemical Education*.

Cruz-Ramírez De Arellano, D., & Towns, M. H. (2014). Students' understanding of alkyl halide reactions in undergraduate organic chemistry. *Chemistry Education Research and Practice*, 15(4), 501–515.

Cyr, A. A., & Anderson, N. D. (2015). Mistakes as stepping stones: Effects of errors on episodic memory among younger and older adults. *Journal of Experimental Psychology*: *Learning Memory and Cognition*, 41(3), 841–850.

Czinkota, M. R., & Ronkainen, I. A. (2005). A forecast of globalization, international business and trade: a report from a Delphi study. *Journal of World Business*, 40(2), 111–123.

Day, J., & Bobeva, M. (2005). A generic toolkit for the successful management of Delphi studies. *The Electronic Journal of Business Research Methodology*, 3(2), 103–116.

De Villiers, M. R., de Villiers, P. J. T. T., & Kent, A. P. (2005). The Delphi technique in health sciences education research. *Medical Teacher*, 27(7), 639–643.

Djoko Dwiyogo, W. & Ligya Radjah, C. (2020). Effectiveness, Efficiency and Instruction Appeal of Blended Learning Model. *International Association of Online Engineering*.

Dejene, W. (2019). The practice of modularized curriculum in higher education institution: *Active learning and continuous assessment in focus. Cogent Education*, 6(1),201-221.

Delbecq, A. L., de Ven, A. H., & Gustafson, D. H. (1975). *Group techniques for program planning: A guide to nominal group and Delphi processes*. Scott Foresman.

Deldjoo, Y., Anelli, V. W., Zamani, H., Bellogin, A., & Di Noia, T. (2021). A flexible framework for evaluating user and item fairness in recommender systems. *User Modeling and User-Adapted Interaction*, 31(3), 457-511.

Denzin, N. K. (2012). Triangulation 2.0*. *Journal of Mixed Methods Research*, 6(2), 80–88.

Donkoh, S. (2017). What Students Say About Senior High School Organic Chemistry. *International Journal of Environmental & Science Education*, 12(10), 2139–2152.

Donohoe, H. M. (2011). Defining culturally sensitive ecotourism: a Delphi consensus. *Current Issues in Tourism*, 14(1), 27–45.

Dood, A. J., Dood, J. C., Cruz-Ramírez De Arellano, D., Fields, K. B., & Raker, J. R. (2020). Analyzing explanations of substitution reactions using lexical analysis and logistic regression techniques. *Chemistry Education Research and Practice*, 21(1), 267–286.

Duis, J. M. (2011). Organic chemistry educators' perspectives on fundamental concepts and misconceptions: An exploratory study. *Journal of Chemical Education*, 88(3), 346–350.

Dutt, A., Tan, M., Alagumalai, S., & Nair, R. (2019). Development and Validation of the Ability in Behavior Assessment and Interventions for Teachers Using Delphi Technique and Rasch Analysis. *Journal of Autism and Developmental Disorders*, 49(5), 1976–1987.

Englander, M. (2016). The interview: Data collection in descriptive phenomenological human scientific research. *Journal of Phenomenological Psychology*, 47(1), 13–35.

Esselman, B. J., & Hill, N. J. (2016). Integration of Computational Chemistry into the Undergraduate Organic Chemistry Laboratory Curriculum. *Journal of Chemical Education*.

Fantke, P., von Goetz, N., Schlüter, U., Bessems, J., Connolly, A., Dudzina, T., Ahrens, A., Bridges, J., Coggins, M. A., Conrad, A., Hänninen, O., Heinemeyer, G., Kephalopoulos, S., McLachlan, M., Meijster, T., Poulsen, V., Rother, D., Vermeire, T., Viegas, S., … Bruinen de Bruin, Y. (2020). Building a European exposure science strategy. *Journal of Exposure Science and Environmental Epidemiology*, 30(6), 917–924.

Ferguson, R., & Bodner, G. M. (2008). Making sense of the arrow-pushing formalism among chemistry majors enrolled in organic chemistry. *Chemistry Education Research and Practice*, 9(2), 102–113.

Finlay, L., & Gough, B. (2008). *Reflexivity: A practical guide for researchers in health and social sciences*. John Wiley & Sons.

Flick, U., von Kardoff, E., & Steinke, I. (Eds.). (2004). *A companion to qualitative* research. Sage..

Fleer, M. (2019). Scientific Playworlds: a Model of Teaching Science in Play-Based Settings. *Research in Science Education*, 49(5), 1257–1278.

Flynn, A. B. (2014). How do students work through organic synthesis learning activities? *Chemistry Education Research and Practice*, 15(4), 747–762.

Flynn, A. B., & Amellal, D. G. (2015). Chemical Information Literacy: pK a Values・Where Do Students Go Wrong? *Journal of Chemical Education*, 93(1), 39–45.

Flynn, A. B., & Featherstone, R. B. (2017). Language of mechanisms: exam analysis reveals students' strengths, strategies, and errors when using the electron-pushing formalism (curved arrows) in new reactions. *Chem. Educ. Res. Prac*t.

Flynn, A. B., & Ogilvie, W. W. (2015). Mechanisms before reactions: A mechanistic approach to the organic chemistry curriculum based on patterns of electron flow. *Journal of Chemical Education*, 92(5), 803–810.

Forsyth, D. R. (2010). Delphi Therapy. *Encyclopedia of Group Processes & Intergroup Relations, 1*.

Fortemps, P., & Roubens, M. (1996). Ranking and defuzzification methods based on area compensation. *Fuzzy Sets and Systems*, 82(3), 319–330.

Fosso Wamba, S., & Ngai, E. W. T. (2015). Importance of issues related to RFID-enabled healthcare transformation projects: Results from a Delphi study. *Production Planning and Control*, 26(1), 19–33.

Franco, A. T., Friedman, D. B., Nagy, T. A., Romero-Gallo, J., Krishna, U., Kendall, A., Israel, D. A., Tegtmeyer, N., Washington, M. K., & Peek, R. M. (2009). Delineation of a carcinogenic Helicobacter pylori proteome. *Molecular and Cellular Proteomics*, 8(8), 1947–1958. https://doi.org/10.1074/mcp.M900139-MCP200

Frese, M., Brodbeck, F., Heinbokel, T., Mooser, C., Schleiffenbaum, E., & Thiemann, P. (1991). Errors in training computer skills: On the positive function of errors. *Human-Computer Interaction*, 6(1), 77–93.

Friesen, J. B. (2008). Saying what you mean: Teaching mechanisms in organic chemistry. *Journal of Chemical Education*, 85(11), 1515–1518.

Fusch, P., Fusch, G. E., & Ness, L. R. (2018). Denzin's paradigm shift: Revisiting triangulation. Denzin's Paradigm Shift: *Revisiting Triangulation*, 10(1), 19–32.

Gabel, D. (1999). Improving Teaching and Learning through Chemistry Education Research: A Look to the Future. *Journal of Chemical Education*, 76(2–4), 548–554.

Gabel, D. L. (1993). *Handbook of Research on Science Teaching and Learning Project*. Macmillan Publishing Company, division of Macmilan, Inc., 866 Third Avenue, New York, NY 10022.

Galloway, K. R., Leung, M. W., & Flynn, A. B. (2018). A Comparison of How Undergraduates, Graduate Students, and Professors Organize Organic Chemistry Reactions.*Journal of Chemical Education*.

Galloway, K. R., Leung, M. W., & Flynn, A. B. (2019). Patterns of reactions: A card sort task to investigate students' organization of organic chemistry reactions. *Chemistry Education Research and Practice*, 20(1), 30–52.

Galloway, K. R., Stoyanovich, C., & Flynn, A. B. (2017a). Students' interpretations of mechanistic language in organic chemistry before learning reactions. *Chemistry Education Research and Practice*, 18(2), 353–374.

Galloway, K. R., Stoyanovich, C., & Flynn, A. B. (2017b). Students' Understanding of Mechanistic Language Prior to Learning Organic Reactions. *Chemistry Education: Research and Practice*.

Garrod, B. (2012). Applying the Delphi method in an ecotourism context: A response to Deng et al.s Development of a point evaluation system for ecotourism destinations: A Delphi method. *Journal of Ecotourism*, 11(3), 219–223.

Garson, G. D. (2014). *The Delphi method in quantitative research* (Statistical Associates Blue Book series)[Kindle version]. Retrieved from Amazon. Com.

Ghani, I. B. A., Ibrahim, N. H., Yahaya, N. A., & Surif, J. (2017). Enhancing students' HOTS in laboratory educational activity by using concept map as an alternative assessment tool. *Chemistry Education Research and Practice*, 18(4), 849–874.

Giangregorio, L. M., McGill, S., Wark, J. D., Laprade, J., Heinonen, A., Ashe, M. C., MacIntyre, N. J., Cheung, A. M., Shipp, K., Keller, H., Jain, R., & Papaioannou, A. (2015). Too Fit To Fracture: outcomes of a Delphi consensus process on physical activity and exercise recommendations for adults with osteoporosis with or without vertebral fractures. *Osteoporosis International*, 26(3), 891–910. https://doi.org/10.1007/s00198-014-2881-4.

Giannarou, L., & Zervas, E. (2014). Using Delphi Technique to Build Consensus in Practice. *International Journal of Business Science & Applied Management* (IJBSAM), 9(2), 65–82.

Gilbert, J. K. (2005). Visualization: *A Metacognitive Skill in Science and Science Education. In Visualization in Science Education*. Springer Netherlands.

Gilbert, J. K., Boulter, C. J., & Elmer, R. (2000). *Positioning Models in Science Education and in Design and Technology Education*. In Developing Models in Science Education (Issue 1982, pp. 3–17). Kluwer Academic Publishers.

Gilbert, J. K., & Treagust, D. (2009). *Multiple representations in chemical education* (Vol. 4). Springer.

Gilbert, K. J., & Treagust, D. (2013). Multiple Repreaentation in Chemical Education. In *Journal of Chemical Information and Modeling* (Vol. 53, Issue 9).

Gilmanshina, S. I., Sagitova, R. N., & Gilmanshin, I. R. (2018). Science education: Development of environmental thinking. *European Research Studies Journa*l, 21(3), 690–704.

Goyena, R. (2019). Multiple Representation in Chemical Education. *In Journal of Chemical Information and Modeling* (Vol. 53, Issue 9).

Graham, C. (2010). Hearing the voices of general staff: A delphi study of the contributions of general staff to student outcomes. *Journal of Higher Education Policy and Management,* 32(3), 213–223.

Graham, K. J., Jones, T. N., Schaller, C. P., & McIntee, E. J. (2014). Implementing a student-designed green chemistry laboratory project in organic chemistry. *Journal of Chemical Education*.

Graulich, N. (2015). The tip of the iceberg in organic chemistry classes: How do students deal with the invisible? In Chemistry Education Research and Practice.

Greenwood, N. N., & Earnshaw, A. (2012). *Chemistry of the Elements*. Elsevier.

Grossman, R. B. (2003). The Art of Writing Reasonable Organic Reaction Mechanisms, 2nd Edition (Grossman, Robert B.). *In Journal of Chemical Education* (Vol. 80, Issue 11).

Grove, N. P., Cooper, M. M., & Rush, K. M. (2012). Decorating with arrows: Toward the development of representational competence in organic chemistry. *Journal of Chemical Education*, 89(7), 844–849.

Grove, N. P., Hershberger, J. W., & Bretz, S. L. (2008). Impact of a spiral organic curriculum on student attrition and learning. *Chemistry Education Research and Practice*, 9(2), 157–162.

Grove, N. P., & Lowery Bretz, S. (2012). A continuum of learning: From rote memorization to meaningful learning in organic chemistry. *Chemistry Education Research and Practice*, 13(3), 201–208.

Guba, E. G., & Lincoln, Y. S. (1989). *Fourth generation evaluation*. Sage.

Guo, E. (2012). *Running Head : Analysis of Student Errors Type and Frequency of Errors Student Make While Solving Organic Chemistry Mechanisms Eunice Guo Course*: CHEM 415 The University of British Columbia Project Supervisor : Jackie Stewart Date of Project : January 20. April.

Gupta, V. K., Gupta, B., Rastogi, A., Agarwal, S., & Nayak, A. (2011). Pesticides removal from wastewater by activated carbon prepared from waste rubber tire. *Water Research*, 45(13), 4047–4055.

Gurvitch, R., & Metzler, M. (2010). Theory into Practice: Keeping the Purpose in Mind: The Implementation of Instructional Models in Physical Education Settings. *Strategies*, 23(3), 32–35.

Habibi, A., Sarafrazi, A., & Izadyar, S. (2014). Delphi Technique Theoretical Framework in Qualitative Research. T*he International Journal Of Engineering And Science* (IJES) ||, 8–13.

Hackett, S., Masson, H., & Phillips, S. (2006). Exploring consensus in practice with youth who are sexually abusive: Findings from a delphi study of practitioner views in the United Kingdom and the Republic of Ireland. *Child Maltreatment*, 11(2), 146–156.

Hailikari, T. K., & Nevgi, A. (2010). How to diagnose at-risk students in chemistry: The case of prior knowledge assessment. *International Journal of Science Education*, 32(15), 2079–2095.

Haji Ahmad, R. (1998). Educational development and reformation in Malaysia: Past, present and future. *Journal of Educational Administration*, 36(5), 462–475.

Hallowell, M. R., & Gambatese, J. A. (2010a). Population and initial validation of a formal model for construction safety risk management. *Journal of Construction Engineering and Management*, 136(9), 981–990.

Hallowell, M. R., & Gambatese, J. A. (2010b). Qualitative research: Application of the Delphi method to CEM research. *Journal of Construction Engineering and Management*, 136(1), 99–107.

Hanefar, S. B. (2015). *Development of Spiritual Intelligence Model for Adolescents in Malaysia Shamsiah Banu Binti Mohamad Hanefar*. Thesis Submitted in Fulfilment of the Requirements for the Degree of Doctor of Philosophy Institute of the Graduate Studies University of Malaya. 289.

Hasson, F., & Keeney, S. (2011). Enhancing rigour in the Delphi technique research. *Technological Forecasting and Social Change*, 78(9), 1695–1704.

Helmer, O., & Helmer-Hirschberg, O. (1983). *Looking forward: a guide to futures research*. Sage Publications, Inc.

Herrington, J. (2012). Design-based research: Implementation issues in emerging scholar research. *EdMedia+ Innovate Learning*, 1–6.

Hiebert, J., Stigler, J. W., & Manaster, A. B. (1999). *Mathematical features of lessons in the TIMSS Video Study*. ZDM, 31(6), 196–201.

Hinchliffe, L. J., Rand, A., & Collier, J. (2018). Predictable information literacy misconceptions of first-year college students. *Communications in Information Literacy*.

Hitt, D. H., & Tucker, P. D. (2016). Systematic Review of Key Leader Practices Found to Influence Student Achievement: A Unified Framework. *Review of Educational Research*, 86(2), 531–569.

Hoffman, R. V., & Solomons, T. W. . (2004). Organic Chemistry. *In Systematic biology*. https://doi.org/10.1093/sysbio/sys109.

Holey, E. A., Feeley, J. L., Dixon, J., & Whittaker, V. J. (2007). An exploration of the use of simple statistics to measure consensus and stability in Delphi studies. *BMC Medical Research Methodology*, 7, 1–10.

Howard, K. (2015). *Educating cultural heritage information professionals for Australia's galleries, libraries, archives and museum*s: *A grounded Delphi study*. Office of Education Research; Faculty of Education; School of InformationSystems; Science & Engineering Faculty.

Hrin, T. N., Milenković, D. D., & Segedinac, M. D. (2016). The Effect of Systemic Synthesis Questions [SSynQs] on Students' Performance and Meaningful Learning in Secondary Organic Chemistry Teaching. *International Journal of Science and Mathematics Education*, 14(5), 805–824.

Hrin, T. N., Milenković, D. D., Segedinac, M. D., & Horvat, S. (2016). Enhancement and assessment of students' systems thinking skills by application of systemic synthesis questions in the organic chemistry course. *J. Serb. Chem. Soc.*, 81(12), 1455–1471.

Hsiao, L., Lee, I., & Klopfer, E. (2019). Making sense of models: How teachers use agent-based modeling to advance mechanistic reasoning. *British Journal of Educational Technology*, 50(5), 2203–2216.

Hsieh, T.-Y., Lu, S.-T., & Tzeng, G.-H. (2004). Fuzzy MCDM approach for planning and design tenders selection in public office buildings. *International Journal of Project Management*, 22(7), 573–584.

Hsiu-Fang, H., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, 15(9), 1277–1288.

Hsu, C., & Sandford, B. A. (2010). *Delphi technique. encyclopedia of research design*. Ed. Neil J. Salkind. Thousand Oaks, CA: SAGE Reference Online.

Huang, H. C., Lin, W. C., & Lin, J. D. (2008). Development of a fall-risk checklist using the Delphi technique. *Journal of Clinical Nursing*, 17(17), 2275–2283.

Hudson, R. D., & Treagust, D. F. (2013). Which form of assessment provides the best information about student performance in chemistry examinations? *Research in Science and Technological Education*.

Jamelaa Bibi, A., & Siti Ilyana, M. Y. (2018). A Fuzzy Delphi Method-Developing High-Performance Leadership Standard for Malaysian School Leaders. *Journal of Education and Social Sciences*, 9(2), 1–10.

James, S. M., & Singer, S. R. (2016). From the NSF: The national science foundation's investments in broadening participation in science, technology, engineering, and mathematics education through research and capacity building. *CBE Life Sciences Education*, 15(3), 1–8.

Jasanoff, S. (2005). *Technologies of humility: Citizen participation in governing science. In Wozu Experten*? (pp. 370-389). VS Verlag für Sozialwissenschaften.

Jensen, W. B. (1998). Logic, history, and the chemistry textbook: I. Does chemistry have a logical structure? *Journal of Chemical Education*, 75(6), 679.

Johnstone, A. (1993). Symposium on Evolution in Chemical Education. The Development of Chemistry the Teaching. *The Forum*, 70(9), 701–705.

Johnstone, A. H. (1991). Seldom What They Seem. *Journal of Computer Assisted Learning*, 7, 75–83.

Johnstone, Alex H. (2000). Teaching of Chemistry - Logical or Psychological? *Chem. Educ. Res. Pract.*, 1(1), 9–15.

Johnstone, Alex H. (1991). Why is Chemistry Difficult to Learn? Things are Seldom What They Seem. *Journal of Computer Assisted Learning*, 7, 75–83.

Johnstone, Alex H. (2000). Teaching of chemistry-logical or psychological? *Chemistry Education Research and Practice*, 1(1), 9–15.

Jones, H., & Twiss, B. C. (1978). *Forecasting technology for planning decisions* (No. 658.4 J6).

Judd, R. C. (1972). Use of Delphi methods in higher education. *Technological Forecasting and Social Change*, 4(2), 173–186.

Kamisah Osman, Lilia Halim, Z. H. I. (2012). The critical thinking attitudinal profile of some Malaysian secondary students: A reflection of scientific attitudes. *Journal of Science and Mathematics Education in Southeast Asia*, 26(2), 143–166.

Kamisah Osman, -, Zanaton Haji Iksan, -, & Lilia Halim, -. (2007). Attitudes towards science and scientific attitudes among science students. *Jurnal Pendidikan Malaysia.*

Kaplan, B., & Maxwell, J. A. (2005). *Qualitative research methods for evaluating computer information systems. In Evaluating the organizational impact of healthcare information systems* (pp. 30-55). Springer, New York, NY.

Kardaras, D. K., Karakostas, B., & Mamakou, X. J. (2013). Content presentation personalisation and media adaptation in tourism web sites using Fuzzy Delphi Method and Fuzzy Cognitive Maps. *Expert Systems with Applications*, 40(6), 2331–2342.

Keeney, S., McKenna, H., & Hasson, F. (2011). *The Delphi technique in nursing and health research*. John Wiley & Sons.

Kelly, M., Wills, J., Jester, R., & Speller, V. (2017). Should nurses be role models for healthy lifestyles? Results from a modified Delphi study. *Journal of Advanced Nursing*, 73(3), 665–678.

Khalil, M. K., & Elkhider, I. A. (2016). Applying learning theories and instructional design models for effective instruction. *Advances in Physiology Education*.

Khazai, B., Merz, M., Schulz, C., & Borst, D. (2013). An integrated indicator framework for spatial assessment of industrial and social vulnerability to indirect disaster losses. *Natural Hazards*, 67(2), 145–167.

Kim, A. H., Roberts, C., Feagan, B. G., Banerjee, R., Bemelman, W., Bodger, K., Derieppe, M., Dignass, A., Driscoll, R., Fitzpatrick, R., Gaarentstroom-Lunt, J., Higgins, P. D., Kotze, P. G., Meissner, J., O'Connor, M., Ran, Z. H., Siegel, C. A., Terry, H., van Deen, W. K., … Travis, S. P. L. (2018). Developing a Standard Set of Patient-Centred Outcomes for inflammatory Bowel Disease-an international, cross-disciplinary consensus. *Journal of Crohn's and Colitis*, 12(4), 408–418.

Klein, R. C. R. and J. D. (2013). *Design and Development Research*. Handbook of Research on Educational Communications and Technology: Fourth Edition, 141–150.

Klir, G. J., & Yuan, B. (1996). *Fuzzy sets and fuzzy logic: theory and applications*. In Kybernetika (Ed.), Upper Saddle River (Vol. 32, Issue 2). Prentice Hall.

Kolb, D. (1978). Acids and bases. *Journal of Chemical Education*, 55(7), 459.

Kozma, R. B. (2003). Technology and classroom practices: An international study. *Journal of Research on Technology in Education*, 36(1), 1–14.

Kozma, R. B., & Russell, J. (1997). Multimedia and understanding: Expert and novice responses to different representations of chemical phenomena. *Journal of Research in Science Teaching*: The Official Journal of the National Association for Research in Science Teaching, 34(9), 949–968.

Kristiono, I. D., Dwiyogo, W. D., & Hariadi, I. (2019). Blended Learning -Based Sports Nutrition Science Learning for Physical Education, Health, and Recreation Students. *Jurnal Pendidikan: Teori, Penelitian*, Dan Pengembangan, 4(2), 235-241.

Krippendorff, K. (2004). Reliability in content analysis: Some common misconceptions and recommendations. *Human Communication Research*, 30(3), 411–433.

Kumar, A., Kaviani, M. A., Hafezalkotob, A., & Zavadskas, E. K. (2017). Evaluating innovation capabilities of real estate firms: a combined fuzzy Delphi and DEMATEL approach. *International Journal of Strategic Property Management*, 21(4), 401–416.

Ladhams, Z. M. (2004). *Teaching and learning about reaction mechanisms in organic chemistry*. In PhD Thesis (Issue June). The University of Western Australia.

Lamichhane, D. (2014). *Design of Delphi technique integrated with social media to make consensus-based on expert s' opinion*. in Masters Dissertation University of Oulu 1–76.

Land, R., Meyer, J. H., & Flanagan, M. T. (Eds.). (2016). Threshold concepts in practice. Springer.

Davies, P., & Mangan, J. (2008). Embedding threshold concepts: From theory to pedagogical principles to learning activities. *In Threshold concepts within the disciplines* (pp. 37-50). Brill

Landeta, J. (2006). Current validity of the Delphi method in social sciences. *Technological Forecasting and Social Change*, 73(5), 467–482.

Landeta, J., Barrutia, J., & Lertxundi, A. (2011). Hybrid Delphi: A methodology to facilitate contribution from experts in professional contexts. *Technological Forecasting and Social Change*, 78(9), 1629–1641.

Lay, A.-N., & Kamisah Osman. (2018). Developing 21st Century Chemistry Learning through Designing Digital Games. *Journal of Education in Science, Environment and Health*.

Legendre, P. (2005). Species associations: The Kendall coefficient of concordance revisited. *Journal of Agricultural, Biological, and Environmental Statistics*, 10(2), 226–245.

Levy, D. E. (2008). *Arrow-pushing in organic chemistry: an easy approach to understanding reaction mechanisms*. John Wiley & Sons.

Li, S., Davies, B., Edwards, J., Kinman, R., & Duan, Y. (2002). Integrating group Delphi, fuzzy logic and expert systems for marketing strategy development: the hybridisation and its effectiveness. *Marketing Intelligence & Planning*, 20(5), 273–284.

Lin, H. Y., Hsu, P. Y., & Sheen, G. J. (2007). A fuzzy-based decision-making procedure for data warehouse system selection. *Expert Systems with Applications*, 32(3), 939–953.

Linstone, H. A. (1978). *The Delphi technique*. Handbook of futures research. J. Fowlers. Westport, CT, Greenwood Press, 273–300.

Linstone, H. A., & Turoff, M. (2011). Delphi: A brief look backward and forward. *Technological Forecasting and Social Chang*e, 78(9), 1712–1719.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. sage.

Liu, Y., & Taber, K. S. (2016). Analysing symbolic expressions in secondary school chemistry: their functions and implications for pedagogy. *Chemistry Education Research and Practice*, 17(3), 439–451.

Lo, C. M., & Tang, K. Y. (2018). Blended Learning with Multimedia e-Learning in Organic Chemistry Course. Proceedings - 2018. *International Symposium on Educational Technology*, ISET 2018.

Logan, M., & Skamp, K. (2008). Engaging students in science across the primary secondary interface: Listening to the students' voice. *Research in Science Education*, 38(4), 501–527.

Loh, J. (2013). Inquiry into issues of trustworthiness and quality in narrative studies: A perspective. *Qualitative Report*, 18(33).

Lopez, E. J., Nandagopal, K., Shavelson, R. J., Szu, E., & Penn, J. (2013). Self-regulated learning study strategies and academic performance in undergraduate organic chemistry: An investigation examining ethnically diverse students. *Journal of Research in Science Teaching*, 50(6), 660–676.

Lou, S. J., Lin, H. C., Shih, R. C., & Tseng, K. H. (2012). Improving the Effectiveness of Organic Chemistry Experiments through Multimedia Teaching Materials for Junior High School Students. *Turkish Online Journal of Educational Technology*-TOJET, 11(2), 135-141.

Mama, M., & Hennessy, S. (2013). Developing a typology of teacher beliefs and practices concerning classroom use of ICT. *Computers & Education*, 68, 380-387

Machamer, P., Darden, L., & Craver, C. F. (2000). Thinking about mechanisms. *Philosophy of Science*, 67(1), 1–25.

Mack, M. R., Hensen, C., & Barbera, J. (2019). Metrics and Methods Used to Compare Student Performance Data in Chemistry Education Research Articles. *Journal of Chemical Education*.

Mays, N., & Pope, C. (1995). Qualitative research: rigour and qualitative research. *Business management journal*, 311(6997), 109-112.

Malaysia Education Blueprint Malaysia. (2013). Malaysia Education Blueprint 2013 - 2025. *Education*, 27(1), 1–268.

Norouzian-Maleki, S., Bell, S., Hosseini, S. B., & Faizi, M. (2015). Developing and testing a framework for the assessment of neighbourhood liveability in two contrasting countries: Iran and Estonia. *Ecological Indicators*, 48, 263-271.

Marginson, S. (2018). National/Global Synergy in the Development of Higher Education and Science in China since Introduction: "The Most Crucial of the Four Modernizations." *Frontiers of Education in China*, 13(4), 486–512.

Massaquoi, J. G. (2008). *Science and Technology Human Resource Capacity Building in Africa–The Role of Regional Cooperation*. In Universities as Centres of Research and Knowledge Creation: An Endangered Species? (pp. 59-70). Brill Sense.

McKillip, J. (1987). *Need analysis: Tools for the human service and education*. Applied Social Research Methods Series.

McCambridge, J., Witton, J., & Elbourne, D. R. (2014). Systematic review of the Hawthorne effect: new concepts are needed to study research participation effects. *Journal of clinical epidemiology*, 67(3), 267-277.

Mead, D., & Moseley, L. (2001). The use of the Delphi as a research approach. *Nurse Researcher* (through 2013), 8(4), 4.

Mechefske, C. K., & Wang, Z. (2001). Using fuzzy linguistics to select optimum maintenance and condition monitoring strategies. *Mechanical Systems and Signal Processing*, 15(6), 1129–1140. https://doi.org/10.1006/mssp.2000.1395

Meijering, J. V., Kampen, J. K., & Tobi, H. (2013). Quantifying the development of agreement among experts in Delphi studies. *Technological Forecasting and Social Change*, 80(8), 1607–1614.

Melanie, C., & Michael, K. (2013). Chemistry, life, the universe, and everything: A new approach to general chemistry, and a model for curriculum reform. *Journal of Chemical Education*, 90(9), 1116–1122.

Melnyk, S. A., Lummus, R. R., Vokurka, R. J., Burns, L. J., & Sandor, J. (2009). Mapping the future of supply chain management: A delphi study. *International Journal of Production Research*, 47(16), 4629–4653.

Meng, C. C., Idris, N., & Eu, L. K. (2014). Secondary students' perceptions of assessments in science, technology, engineering, and mathematics (STEM). Eurasia *Journal of Mathematics, Science and Technology Education*, 10(3), 219–227.

Mensah, F. M., & Jackson, I. (2018). Whiteness as property in science teacher education. Teachers College Record, 120(1), 1–38.

Merrienboer, J. J. G. Van, Kirschner, P. A., Kester, L., & Merriënboer, J. J. G. Van. (2010). Taking the Load Off a Learner's Mind: Instructional Design for Complex Learning Taking the Load Off a Learner' s Mind: *Instructional Design for Complex Learning. Educational Psychologist,* 38(1), 37–41.

Merriam, S. B., &, R. S. (Eds.). (2019). *Qualitative research in practice*: Examples for discussion and analysis. John Wiley & Sons.

Metcalfe, J. (2017). Learning from Errors

Meyer, J., & Land, R. (2003). *Threshold concepts and troublesome knowledge*: Linkages to ways of thinking and practising within the disciplines. University of Edinburgh Edinburgh.

Meyer Jan, H. F. (2016). Threshold concepts and pedagogic representation. *Education and Training*.

Meyer Jan, H. F., & Land, R. (2005). Threshold concepts and troublesome knowledge (2): Epistemological considerations and a conceptual framework for teaching and learning. *Higher Education*, 49(3), 373–388.

Michael, C. (2002). *Book review. Phytochemistry*, 60(99), 264–267.

Michaeli, T., & Romeike, R. (2019a). Debuggen im Unterricht--Ein systematisches Vorgehen macht den Unterschied. Informatik Für Alle.

Michaeli, T., & Romeike, R. (2019b). *Improving Debugging Skills in the Classroom: The Effects of Teaching a Systematic Debugging Proces*s. Proceedings of the 14th Workshop in Primary and Secondary Computing Education, 15.

Mohamed-Salah, B., & Alain, D. (2016). To what degree does handling concrete molecular models promote the ability to translate and coordinate between 2D and 3D molecular structure representations? A case study with Algerian students. *Chemistry Education Research and Practic*e, 17(4), 862–877.

Mohtar, L. E., Halim, L., Rahman, N. A., Maat, S. M., Iksan, Z. H., & Osman, K. (2019). A model of interest in stem careers among secondary school students. *Journal of Baltic Science Education*.

Möllers, N. (2020). Making Digital Territory: Cybersecurity, Techno-nationalism, and the Moral Boundaries of the State. *Science Technology and Human Values*, 1–27.

Moore, C. B., Abella, I. D., Abraham, N. B., George, B., Denton, D. D., & Doyle, M. P. (1997). *Science Teaching Reconsidered. In Science Teaching* Reconsidered (First). National Academy Press.

Morales, J., Rosana, M., Noe, Z., Duran, J., Francisco, H., & 1. (2018). *The Use of Fuzzy Linguistic Information and Fuzzy Delphi Method to Validate by Consensus a Questionnaire in a Blended-Learning Environment*. Springer International Publishing AG, Part of Springer Nature 2018 J. Medina et Al. (Eds.), 855, 137–149.

Morse, J. M. (2000). Determining Sample Size. *Qualitative Health Research*, 10(1), 3–5.

Mourhir, A., Rachidi, T., & Karim, M. (2014). River water quality index for Morocco using a fuzzy inference system. *Environmental Systems Research*, 3(1), 1–12.

Mukherjee, N., Hugé, J., Sutherland, W. J., Mcneill, J., Van Opstal, M., Dahdouh-Guebas, F., & Koedam, N. (2015). The Delphi technique in ecology and biological conservation: Applications and guidelines. *Methods in Ecology and Evolution*, 6(9), 1097–1109.

Ahmad, A. M., Hussin, Z., Yusof, F., & Jamil, M. R. M. (2017). Nominal group technique (Ngt) and its application to the construction of ethical elements and values (Akhlak) based on inquiry activities in Polytechnics & Community Colleges. *Journal of Social Sciences and Humanities*, 2(1), 125-145.

Murray, T. J., Pipino, L. L., & van Gigch, J. P. (1985). A pilot study of fuzzy set modification of Delphi. *Human Systems Management*, 5(1), 76–80.

Musa, H. D., Yacob, M. R., Abdullah, A. M., & Ishak, M. Y. (2017). Sustainable city: assessing the community happiness of residents in Putrajaya municipality Malaysia. *Rev. Eur. Stud*., 9, 31.

Nathan, A. J., & Scobell, A. (2012). How China sees America. *In Foreign Affairs* (Vol. 91, Issue 5, pp. 129–137).

Näyhä, A., & Pesonen, H.-L. (2014). Strategic change in the forest industry towards the biorefining business. *Technological Forecasting and Social Change*, 81, 259–271.

Nicholas Bode. (2018). *Exploring undergraduate organic chemistry students' strategies and reasoning when solving organic synthesis problems*. Thesis.

Nnakwe, C. C., Cooch, N., & Huang-Saad, A. (2018). Investing in Academic Technology Innovation and Entrepreneurship: Moving Beyond Research Funding through the NSF I-CORPS TM Program. *Technology & Innovation*, 19(4), 773–786.

Nworgu, C., & Oluwuo, S. O. (2019). Time resource management and teachers' task performance in public senior secondary schools in Rivers state. *International Journal of Education and Evaluation*, 5(6), 36-48.

Nøkleby, H. (2011). Triangulation with diverse intentions. KAPET. Karlstads *Universitets Pedagogiska Tidskrift*, 7(1), 140–156.

Novak, J. D. (2009). *Learning creating and using knowledge: Concept maps as facilitative tools in schools and corporations*: Second edition. Learning Creating and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations: Second Edition, 6(September 2010), 1–317.

Novak, J. D. (2010). *The need for a theory of education*. In Learning, creating, and using knowledge (pp. 28–38). Routledge.

Novakowski, N., & Wellar, B. (2008). Using the Delphi technique in normative planning research: methodological design considerations. *Environment and Planning*, 40(6), 1485–1500.

Nur Farhana Ramli, & Othman Talib. (2017). Can Education Institution Implement STEM? From Malaysian Teachers' View. *International Journal of Academic Research in Business and Social Sciences*, 7(3), 12.

O'Dwyer, A., & Childs, P. (2011, September). Second level Irish pupils' and teachers' view of difficulties in organic chemistry. *In IOSTE Mini-Symposium* (Vol. 17, No. 4, pp. 99-105).

O'Dwyer, A., & Childs, P. (2015). Organic Chemistry in Action! What Is the Reaction? *Journal of Chemical Education*, 92(7), 1159-1170.

Okoli, C., & Pawlowski, S. D. (2004). The Delphi method as a research tool: An example, design considerations and applications. *Information and Management*, 42(1), 15–29.

Olatoye, R. A., Fatokun, V. K., Olasehinde, K. J., & Sabitu, A. (2019). Female Students' Participation and Performance in Science Subjects in Senior Secondary Schools in Katsina State. Nigeria. *International Journal of Educational Benchmark* (IJEB), 4(1), 57–71.

Ordoobadi, S. M. (2008b). Fuzzy logic and evaluation of advanced technologies. Industrial Management and Data Systems, 108(7), 928–946.

Osborn, M., & Claire, P. (1999). and English Primary Schools. Learning from Comparing: *New Directions in Comparative Education Research*: Volume 1: Contexts, Classrooms and Outcomes, 1, 261.

Osman, K., Halim, L., & Meerah, S. M. (2006). What Malaysian Science Teachers Need to Improve their Science Instruction. A Comparison across Gender, School Location and Area of Specialization. *Eurasia Journal of Mathematics, Science and Technology Education*, 2(2), 58-81.

Osman, K., Hiong, L. C., & Vebrianto, R. (2013a). 21st Century Biology: An Interdisciplinary Approach of Biology, Technology, Engineering and Mathematics Education. *Procedia - Social and Behavioral Sciences*, 102(22), 188–194.

Othman Talib, Azraai Othman, & Tengku Putri Norishah. (2014). OCRA - Authentic mobile application for enhancing the value of mobile learning in organic chemistry. *European Conference on E-Learning.* Academic Conferences Limited, 527–535.

Otter, C. A. (2020). *The Use of Drama in A Level Chemistry*: A study into the effects of simulation-role-play on the quality of, and student attitudes towards, learning of organic reaction mechanisms (Doctoral dissertation, University of Leeds).

Pao-Long, C., Hsu, C.-W., & Chang, P.-C. (2011). Fuzzy Delphi method for evaluating hydrogen production technologies. *International Journal of Hydrogen Energy*, 36(21), 14172–14179.

Parahakaran, S. (2015). An Urgent Need for Policy Change: Reform in Curriculum and Practice Through Values-Based Pedagogies and Cooperative Learning in the Curriculum in Malaysia, Japan and Thailand. *In The Malaysia-Japan Model on Technology Partnership* (pp. 225-233). Springer, Tokyo.

Pedretti, E. (2018). Environmental Education and Science Education: Ideology, Hegemony, Traditional Knowledge, and Alignment. Tạp Chí Nghiên Cứu Dân Tộc, 14(24), 305–314.

Penn, J. H., & Al-Shammari, A. G. (2008). Teaching Reaction Mechanisms Using the Curved Arrow Neglect (CAN) Method. *Journal of Chemical Education*.

Plomp, T. (SLO), & Nieveen, N. (SLO). (2013). Educational Design Research Educational Design Research. *Educational Design Research*, 1–206.

Polites, G. L., Roberts, N., & Thatcher, J. (2012). Conceptualizing models using multidimensional constructs: A review and guidelines for their use. European *Journal of Information Systems*, 21(1), 22–48.

Ponniah, K., & Nawastheen, F. M. (2020). Multigrading Classes Application and Teacher’s Preparation in Low Enrolment Schools In Malaysia. January.

Popova, M., & Bretz, S. L. (2018a). “it’s only the Major Product That We Care about in Organic Chemistry”: An Analysis of Students’ Annotations of Reaction Coordinate Diagrams. *Journal of Chemical Education*.

Popova, M., & Bretz, S. L. (2018b). Organic chemistry students’ challenges with coherence formation between reactions and reaction coordinate diagrams. *Chemistry Education Research and Practice*, 19(3), 732–745.

Ramlee, M. (2017). Education in Malaysia, Education in the Asia-Pacific: Skills Training and Vocational Education in Malaysia. *Educations in Malaysia*, 137–153.

Rasheed, S. P., Younas, A., & Sundus, A. (2019). Self-awareness in nursing: A scoping review. *Journal of Clinical Nursing*, 28(5–6), 762–774.

Raub, L. A., Shukor, N. A., Arshad, M. Y., & Rosli, M. S. (2015). An integrated model to implement contextual learning with virtual learning environment for promoting higher order thinking skills in Malaysian secondary schools. *International Education Studies*, 8(13), 41–46.

Rauf, R. A. A., Rasul, M. S., Mansor, A. N., Othman, Z., & Lyndon, N. (2013). Inculcation of science process skills in a science classroom. *Asian Social Science*, 9(8), 47–57.

Razak, N. S. A., Samad, N., & Ramli, M. F. M. (2018). Experts' Validation on Arabic Language for Specific Purposes Course Content Using Fuzzy Delphi Technique. *Advanced Science Letters*, 24(4), 2425–2428.

Rejab, M. M., Chuprat, S., & Azmi, N. huda F. M. (2018). Proposed Methodology using Design Development Research (DDR) Improving Traceability Model with Test Effort Estimation. *International Journal of Academic Research in Business and Social Sciences*, 8(8), 686–699.

Richey, R. C., & Klein, J. D. (2014). *Design and development research*: Methods, strategies, and issues. Routledge.

Richey, R C, & Klein, J. D. (2008). *Research on design and development*. Handbook of Research on Educational Communications and Technology, 748–757.

Richey, Rita C., & Klein, J. D. (2005). Developmental research methods: Creating knowledge from instructional design and development practice. *Journal of Computing in Higher Education*, 16(2), 23–38.

Ridhuan, M. B. M. J. (2016). Development of Skives Training Curriculum Model for Work -Based Learning Engineering Study Program. In PhD Thesis. University Malaya, Malaysia.

Rinner, C., & Hussain, M. (2011). Toronto's urban heat island-exploring the relationship between land use and surface temperature. *Remote Sensing*, 3(6), 1251–1265.

Roslinda Alias. (2016). Development and Validation of A Model of Technology Supported Learning for Special Educational Needs Learners in Malaysian Institutions of Higher Learning. March.

Rutherford, K. M., Donald, R. D., Lawrence, A. B., & Wemelsfelder, F. (2012). Qualitative Behavioural Assessment of emotionality in pigs. *Applied animal behaviour science*, 139(3-4), 218-224.

Rowe, G., & Wright, G. (1999). The Delphi technique as a forecasting tool: issues and analysis. *International Journal of Forecasting*, 15(4), 353–375.

S. A. Alserri, Zin, A. M., & T.S.M.Wook. (2017). Gender enrolment factors in ict studies. SOFTAM Postgraduate Symposium December, December 2016, 7.

Sabitu, A., & Francis, T. T. (2016). Impact of Class-Wide Peer-Tutoring Strategy on Secondary School Slow Learners' Performance in Redox Reactions in Funtua, Katsina State-Nigeria. *Issues and Ideas in Education*, 4(2), 83–97.

Saha, S., Koley, M., Ganguly, S., Rath, P., Roy Chowdhury, P., & Hossain, S. I. (2014). Developing the criteria for evaluating quality of individualization in homeopathic clinical trial reporting: a preliminary study. *Journal of Integrative Medicine*, 12(1), 13–19.

Sahrir, M. S. (2011). Formative evaluation of an Arabic online vocabulary learning games prototype: Lessons from a Malaysian higher learning institution experience. Instructional Technology Research, Design and Development: Lessons from the Field, Id, 357–369.

Saido, G. A. M., Siraj, S., Dewitt, D., Siraj, S., Dewitt, D., & Development, O. S. A. (2018). Development of an instructional model for higher order thinking in science among secondary school students: a fuzzy Delphi approach thinking in science among secondary school students: a fuzzy. *International Journal of Science Education*, 0(0), 1–20.

Salame, I. I., Patel, S., & Suleman, S. (2019). Examining some of the students' challenges in learning organic chemistry. *International Journal of Chemistry Education Research*, 3(1), 6–14.

Sandelowski, M. (1986). The problem of rigor in qualitative research. Advances in nursing science.

Santagata, R. (2005). Practices and beliefs in mistake-handling activities: A video study of Italian and US mathematics lessons. *Teaching and Teacher Education*, 21(5), 491–508.

Schleppenbach, M., Flevares, L. M., Sims, L. M., & Perry, M. (2007). Teachers' responses to student mistakes in Chinese and US mathematics classrooms. 108(2), 131–147.

Schmidt, R. C. (1997). Managing Delphi surveys using nonparametric statistical techniques. *Decision Sciences*, 28(3), 763–774.

Schultz, D., Duffield, S., Rasmussen, S. C., & Wageman, J. (2014). Effects of the flipped classroom model on student performance for advanced placement high school chemistry students. *Journal of Chemical Education*, 91(9), 1334–1339.

Scudder, P. H. (2013). *Electron Flow in Organic Chemistry* (Second). John Wiley & Sons, Inc., Hoboken, New Jersey Published simultaneously in Canada No.

Seel, N. M. (2003). Model-centered learning and instruction. Technology, Instruction, Cognition and Learning, 1(1), 59–85.

Serene Olin, S., Kutash, K., Pollock, M., Burns, B. J., Kuppinger, A., Craig, N., Purdy, F., Armusewicz, K., Wisdom, J., & Hoagwood, K. E. (2014). Developing quality indicators for family support services in community team-based mental health care. *Administration and Policy in Mental Health and Mental Health Services Research*, 41(1), 7–20.

Seung, B. H. (2016). A Foundation for Spatial Thinking: Towards a Threshold Concept Framework in GIScience and its Implication for STEM Education. Waterloo.

Sevian, H, Bernholt, S., Szteinberg, G. A., Auguste, S., & Pérez, L. C. (2015). Use of representation mapping to capture abstraction in problem solving in different courses in chemistry. *Chemistry Education Research and Practice*, 16(3), 429–446.

Sevian, Hannah, & Couture, S. (2018). Epistemic games in substance characterization. *Chemistry Education Research and Practice*, 19(4), 1029–1054.

Sevian, Hannah, & Talanquer, V. (2014). Rethinking chemistry: A learning progression on chemical thinking. *Chemistry Education Research and Practice*, 15(1), 10–23.

Shamsudin, N. M., Abdullah, N., & Yaamat, N. (2013). Strategies of Teaching Science Using an Inquiry based Science Education (IBSE) by Novice Chemistry Teachers. *Procedia - Social and Behavioral Sciences*.

Shuib, A. S. (2011). Identifying Hardware, Electronic Services and Supporting Equipment for Implementing Mobile Learning in Secondary School: A Delphi Technique. 11(1), 23–34.

Shultz, G. V., Gottfried, A. C., & Winschel, G. A. (2015). Impact of General Chemistry on Student Achievement and Progression to Subsequent Chemistry Courses: A Regression Discontinuity Analysis. *Journal of Chemical Education*.

Sikas, N. (2017). Enhancing Scientific Literacy through Implementation of Inquiry-Based Science Education (IBSE) in Malaysia Science Curriculum. International *Journal of Academic Research in Business and Social Sciences*, 7(2), 769.

Silverman, D. (2020). *Applying the qualitative method to clinical care*. In Researching health care (pp. 176-188). Routledge.

Singh, O. B. (2009). *Development and validation of a web-based module to teach metacognitive learning strategies to students in higher education*. ProQuest Dissertations and Theses, 277-n/a.

Siti Farhah, A. A., Siraj, S., Hussin, Z., Norman, N. 'Ain, & Nur Izzah, N. (2017). Development of a Garden-Based Curriculum Content Model for Indigenous Primary School Students. *Science Journal of Business and Management*, 5(5), Skulmoski, G. J., Hartman, F. T., & Krahn, J. (2007). The Delphi method for graduate research. *Journal of Information Technology Education: Research*, 6(1), 1–21.

Smart, K. M., Blake, C., Staines, A., & Doody, C. (2010). Clinical indicators of "nociceptive", "peripheral neuropathic" and "central" mechanisms of musculoskeletal pain. A Delphi survey of expert clinicians. *Manual Therapy*, 15(1), 80–87.

Soares, D., & Amaral, L. (2011). Information systems interoperability in public administration: Identifying the major acting forces through a Delphi study. *Journal of Theoretical and Applied Electronic Commerce Research*, 6(1), 61–94.

Sourani, A., & Sohail, M. (2015). The Delphi method: Review and use in construction management research. *International Journal of Construction Education and Research*, 11(1), 54–76.

Steinert, M. (2009). A dissensus based online Delphi approach: An explorative research tool. *Technological Forecasting and Social Change*, 76(3), 291–300.

Steuer, G., Rosentritt-Brunn, G., & Dresel, M. (2013). Dealing with errors in mathematics classrooms: Structure and relevance of perceived error climate. *Contemporary Educational Psycholog*y, 38(3), 196–210.

Stolz, M., Witteck, T., Marks, R., & Eilks, I. (2013). Reflecting socio-scientific issues for science education coming from the case of curriculum development on doping in chemistry education. *Eurasia Journal of Mathematics, Science and Technology Education*, 9(4), 361–370.

Sulaiman, H. F., Ismail, R., Mohd Yusoff, H., Anuar, N., Mohd Jamil, M. R., & Daud, F. (2020). Validation of Occupational Zoonotic Disease Questionnaire Using Fuzzy Delphi Method. *Journal of Agromedicine*, 25(2), 166–172.

Taber, K. S. (2013a). *Modelling Learners and Learning in Science Education*. In Modelling Learners and Learning in Science Education. Springer.

Taber, K. S. (2013b). Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice*, 14(2), 156–168.

Talanquer, V. (2011). Macro, submicro, and symbolic: The many faces of the chemistry "triplet." *International Journal of Science Education*, 33(2), 179–195.

Talanquer, V. (2015). Threshold concepts in chemistry: The critical role of implicit schemas. *Journal of Chemical Education*, 92(1), 3–9.

Talanquer, V., & Pollard, J. (2010). Let's teach how we think instead of what we know. *Chemistry Education Research and Practice*, 11(2), 74–83.

Talib, M. H. N., Ibrahim, Z., Rahim, N. A., Hasim, A. S. A., & Zainuddin, H. (2014). *Performance improvement of induction motor drive using simplified FLC method*. 2014 16th International Power Electronics and Motion Control Conference and Exposition, 707–712.

Talib, O., Nawawi, M., Ali, W. Z. W., & Mahmud, R. (2012). Simple Explicit Animation (SEA) Approach in Teaching Organic Chemistry. *Procedia - Social and Behavioral Sciences*.

Taylor, R. E., Judd, L. L., & others. (1989). *Delphi method applied to tourism*. Delphi Method Applied to Tourism., 95–98.

Tobin, K., & Gallagher, J. J. (1987). What happens in high school science classrooms? *Journal of Curriculum studies*, 19(6), 549-560.

Teichert, M. A., Tien, L. T., Dysleski, L., & Rickey, D. (2017). Thinking Processes Associated with Undergraduate Chemistry Students' Success at Applying a Molecular-Level Model in a New Context. *Journal of Chemical Education*, 94(9), 1195–1208.

Thomaidis, N. S., Nikitakos, N., & Dounias, G. D. (2006). The evaluation of information technology projects: A fuzzy multicriteria decision-making approach. *International Journal of Information Technology & Decision Making*, 5(01), 89–122.

Tracey, M. W. (2009). Design and development research: A model validation case. *Educational Technology Research and Development*, 57(4), 553–571.

Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (2003). The role of submicroscopic and symbolic representations in chemical explanations. *International Journal of Science Education*, 25(11), 1353–1368.

Treagust, J. K., David, G. and, & Goyena, R. (2019). Multiple Representation in Chemical Education. In *Journal of Chemical Information and Modeling* (Vol. 53, Issue 9).

Tsaparlis, G., & Sevian, H. (2013). *Concepts of matter in science education* (Vol. 19). Springer.

Tulis, M., Steuer, G., & Dresel, M. (2016). Learning from Errors: A Model of Individual Processes. *Frontline Learning Research*, 4(2), 12-26.

Tutiaini, N., Wahid, A., Talib, O., Sulaiman, T., Hazwan, M., Tutiaini, N., Wahid, A., Talib, O., & Sulaiman, T. (2018). A Systematic Literature Review on the Problem-Posing Strategies for Biology Problem-Posing Multimedia Module Design. 8(12). *IJARBSS*.

Umoren, G., & Ogong, A. S. (2007). Prior presentation of behavioural objectives and students achievement in Biology. *Educational Research and Reviews*, 2(2), 022-025.

VanLehn, K. (1990). *Mind bugs: The origins of procedural misconceptions*. MIT press.

Veloo, A., Hong, L. H., & Lee, S. C. (2015). Gender and Ethnicity Differences Manifested in Chemistry Achievement and Self-Regulated Learning. *International Education Studies*.

von der Gracht, H. A. (2012). Consensus measurement in Delphi studies. Review and implications for future quality assurance. *Technological Forecasting and Social Change*, 79(8), 1525–1536.

Webber, D. M., & Flynn, A. B. (2018). How Are Students Solving Familiar and Unfamiliar Organic Chemistry Mechanism Questions in a New Curriculum? [Research-article]. *Journal of Chemical Education*, 95(9), 1451–1467.

Weidman, J. E., Miller, K. R., Christofferson, J. P., & Newitt, J. S. (2011). Best Practices for Dealing with Price Volatility in Commercial Construction. International *Journal of Construction Education and Research*, 7(4), 276–293.

Weinrich, M. L., & Sevian, H. (2017a). Capturing students' abstraction while solving organic reaction mechanism problems across a semester. *Chemistry Education Research and Practice*, 18(1), 169–190.

Weinrich, M. L., & Sevian, H. (2017b). Capturing students' abstraction while solving organic reaction mechanism problems across a semester. *Chem. Educ. Res. Pract.*

Wenzel, M. (2002). The impact of outcome orientation and justice concerns on tax compliance: The role of taxpayers' identity. *Journal of Applied Psychology*, 87(4), 629.

Whitehead, L. (2008). *The Fading Regional Consensus on Democratic Convergence*. Dom{\'\i} nguez and Shifter (Eds.), Constructing Democratic Governance, 32.

Wilhelm, W. J. (2001). Alchemy of the oracle: The Delphi technique. *Delta Pi Epsilon Journal*, 43(1), 6–26.

Williams, L. p., White, N., Klem, R., Wilson, S. E., & Bartholomew, P. (2006). *Radiography*, 12(3), 215–224.

Wilson, S. B., & Varma-Nelson, P. (2018). Characterization of first-semester organic chemistry peer-led team learning and cyber peer-led team learning students' use and explanation of electron-pushing formalism. *Journal of Chemical Education*, 96(1), 25–34.

Wilson, S. B., & Varma-Nelson, P. (2019). Characterization of First-Semester Organic Chemistry Peer-Led Team Learning and Cyber Peer-Led Team Learning Students' Use and Explanation of Electron-Pushing Formalism. *Journal of Chemical Education*.

Wright, R., Cotner, S., & Winkel, A. (2009). Minimal impact of organic chemistry prerequisite on student performance in introductory biochemistry. *CBE—Life Sciences Education*, 8(1), 44–54.

Wright, S. L., Jenkins-Guarnieri, M. A., & Murdock, J. L. (2013). Career Development Among First-Year College Students: College Self-Efficacy, Student Persistence, and Academic Success. *Journal of Career Development*, 40(4), 292–310.

Wong, K. K. H., & Day, J. R. (2009). A comparative study of problem-based and lecture-based learning in junior secondary school science. *Research in Science Education*, 39(5), 625-642.

Wu, H. Y., Wu, H. S., Chen, I. S., & Chen, H. C. (2014). Exploring the critical influential factors of creativity for college students: A multiple criteria decision-making approach. *Thinking Skills and Creativity*, 11, 1–21.

Xiao, Y., & Watson, M. (2019). Guidance on Conducting a Systematic Literature Review. *Journal of Planning Education and Research*, 39(1), 93–112.

Xu, Y., Yeung, J. F. Y., Chan, A. P. C., Chan, D. W. M., Wang, S. Q., & Ke, Y. (2010). Developing a risk assessment model for PPP projects in China—A fuzzy synthetic evaluation approach. *Automation in Construction*, 19(7), 929–943.

Yeung, J. F. Y., Chan, A. P. C., Chan, D. W. M., & Li, L. K. (2007). Development of a partnering performance index (PPI) for construction projects in Hong Kong: A Delphi study. *Construction Management and Economics*, 25(12), 1219–1237.

Yoruk, N., Morgil, I., & Secken, N. (2009). The Effects of Science, Technology, Society and Environment (STSE) Education on Students' Career Planning. *Online Submission*, 6(8), 68–74.

Yu-Lung, H., Lee, C.-H., & Kreng, V. B. (2010). The application of Fuzzy Delphi Method and Fuzzy AHP in lubricant regenerative technology selection. *Expert Systems with Applications*, 37(1), 419–425.

Zakaria, B., Abdullah, R., Ramli, M. F., & Latif, P. A. (2013). Selection criteria using the Delphi method for siting an integrated hazardous waste disposal facility in Malaysia. *Journal of Environmental Planning and Management*, 56(4), 512–530.

Zhao, B. (2011). Learning from errors: The role of context, emotion, and personality. *Journal of Organizational Behavior*, 32(3), 435–463.

Zhao, Z. G., Cheng, J. Q., Xu, S. L., Hou, W. L., & Richardus, J. H. (2015). A quality assessment index framework for public health services: A Delphi study. *Public Health*, 129(1), 43–51.