International Journal of Evaluation and Research in Education (IJERE)
Vol. 12, No. 1, March 2023, pp. 284~291
ISSN: 2252-8822, DOI: 10.11591/ijere.v12i1.23779

Design and development of critical thinking learning strategy in integral calculus

Nurul Shida[1,2], Abdul Halim Abdullah[1], Sharifah Osman[1], Norulhuda Ismail[1]
[1]School of Education, Faculty of Social Sciences and Humanities, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
[2]Department of Mathematics, Science and Computer, Polytechnic Ibrahim Sultan, Pasir Gudang, Malaysia

Article Info

Article history:

Received Jan 20, 2022
Revised Sep 28, 2022
Accepted Oct 14, 2022

Keywords:

Critical thinking
Integral calculus
Learning strategy

ABSTRACT

Difficulty in understanding problem solving is due to the absence of critical thinking. Students lack knowledge in assessing critical thinking during problem solving. Hence, there is a need to study critical thinking infused through a learning strategy to enhance problem solving. Critical thinking (CThink) is a learning strategy designed which combines critical thinking and Integral Calculus. The development process of CThink combines the critical thinking process and questioning for critical thinking using the analysis, design, development, implementation, and evaluation (ADDIE) model. In the learning strategy, questions were applied based on CThink processes which consist of interpretation, analysis, inference, evaluation, explanation, and self-regulation. Besides, different questioning for CThink is presented based on the critical thinking process. CThink has achieved a content validity of 94.12% with a coefficient value of 0.94, and the value is above 70% or 0.70. Based on the result, the contents in the CThink are considered of good validity. From the calculation of the percentage from the expert given score, CThink has achieved the validity measurement for the language of 97.50% with a coefficient value of validity is 0.975, which is above 70 or 0.70. Based on the result, the activities and syllabus used in CThink achieved good validity measurements. The experts concluded that this CThink meets the content of Integral Calculus, in line with the level of polytechnic students, allowing students to think critically to solve problems as well as activities in CThink help to enhance student problem solving.

Corresponding Author:

Abdul Halim Abdullah
School of Education, Faculty of Social Sciences and Humanities, Universiti Teknologi Malaysia
Johor Bahru, Johor, Malaysia
Email: p-halim@utm.my

1. INTRODUCTION

Student solving seems to be lacking among Malaysian students including problem solving in Integral Calculus. The circumstance worsened after it was found that the difficulties are due to their inadequate problem-solving abilities such as a lack of using a suitable problem-solving framework and weakness in recalling previous knowledge [1]. Students' difficulties were due to the passive activities in the class [2] that does not stimulate learning and neglected the thinking skills and problem-solving abilities. Besides, difficulty in understanding problem solving is due to the absence of critical thinking. Students lack knowledge in accessing critical thinking during problem solving. Hence, there is a need to study critical thinking infused through a learning strategy to enhance problem solving. In problem solving, students employ critical thinking skills in the analyses of problems and applications of previously learned concepts. As problem solving complements critical thinking, it is important to embed this skill.

Critical thinking (CThink) skills are important because they enable students to deal usefully with social, scientific, and practical problems [3]. Confidence and aptitude in critical thinking and problem solving will assist students to achieve higher grades across all subjects [4]. Thus, critical thinking by Facione which is interpretation, analysis, inference, evaluation, explanation, and self-regulation is used to integrate with the questioning for critical thinking. The design phase involves the establishment of the critical thinking process in Integral Calculus. When CThink was designed, it needed some suitable methods to be developed and to be used in teaching and learning activities. Developing critical thinking skills in a student allows the student to be able to solve problems [5]. The objectives of the development of CThink will determine the selection of activities and resources appropriate to the teaching. Activities in this learning strategy use questioning for critical thinking for stimulating and supporting critical thinking. In CThink, each activity consists of questions in the form of problem solving which are non-routine and real-life application problems. CThink with questioning for critical thinking aims to improve students solving problems.

Social constructivism theory is used to support the design and development that will afford students meaning making in the learning process. For this study, the learning strategy was designed based on Social Constructivism by Vygotsky which implements individual questioning or by peer questioning to teach Integral Calculus. This shows that problem solving can be developed through social constructivism learning that emphasizes active learning and thus encourages students to explore the skills they have. This study involves integral calculus since it has the highest number of failures based on topics in the engineering mathematics 2 course at the polytechnic. Besides, students will also learn the application of integral calculus in life such as in engineering, science, medicine, and business. The discussion in this paper addresses the question of the study: i) What are the components needed to develop a learning strategy with critical thinking for teaching integral calculus among polytechnic students?; ii) Which critical skill is suitable to use in the learning strategy for teaching Integral Calculus among polytechnic students?

The application of thinking skills in teaching and learning mathematics is fundamental in line with the demands of the national philosophy of education. Critical thinking in learning mathematics is a cognitive process in an attempt to gain knowledge [6], think critically, become mathematically proficient [7], uncover problems solved [8], and can increase grades [9]. This is supported by previous study [10] that the mathematics performance of the students is positively correlated to the level of critical thinking skills and problem solving skills, which Li [11] mentions is related to applying prior knowledge, logical thinking, and reflective thinking. By improving the critical thinking skills of students, they will be able to understand things more easily and ask in-depth questions [12], and justify answers in writing when solving mathematics problems [13]. Thereby, in line with the objective, this study was designed to explore the effectiveness of critical thinking learning strategy developed towards enhancement of problem solving. Therefore, it is necessary to develop learning material that infuses critical thinking to enhance problem solving in the classroom. The goal of mathematics education should be to develop critical thinking and mathematical understanding among all students and is also vital in the teaching and learning of engineering mathematics [14]. Recent evidence suggests that critical thinking can be incorporated into mathematics instruction. It can be promoted by learning strategies that consist of concept mapping, prompts, question and answer, and real-life case studies. These elements have led to developments of learning strategy that equip critical thinking.

2. RESEARCH METHOD

2.1. Research design

For the research purpose that aims to develop the learning strategy, an instructional design strategy has been chosen by adopting the design and development research (DDR) using analysis, design, development, implementation, evaluation (ADDIE). The evaluation was conducted using a quantitative research method of quasi-experimental group pre-test and post-test and qualitative interviews. The pre-test was collected before the intervention started and the post-test data was collected six weeks which was immediately after the intervention.

2.2. Sample and population

The location of the study was based on the selection was due to research purposes. In this study, the location is at a polytechnic in Johor State which includes the preliminary investigation, pilot, and actual study. For the pilot study, 35 students enrolled in the engineering mathematics 2 courses from the polytechnic were selected. The number of 30 students is sufficient to determine the reliability of an instrument [15] and pilot sample sizes do not need to be large but sufficient to meet the purpose of competent early discussion of the test. The selection of polytechnic students is carried out on the participants of the study which is equivalent to the actual study covering the aspects of the location, and the profile of the study participants. It provides an excellent opportunity to uncover such problems ahead of time, minimizing the need to adopt procedures or to develop contingency plans on short notice when a larger study is being conducted [16]. For pilot study, students are engaged in the CThink learning activities, pre-test, post-test, and preliminary investigation. There were three lecturers selected in order to assist in the development of CThink, to identify the problems and obstacles encountered when teaching integral calculus to polytechnic students. The interviews with the lecturers were vital in the analysis phase for the design and development of the CThink learning strategy. The criteria to choose the lecturers are experienced in teaching integral calculus, an expert in the topic of engineering mathematics, and having a bachelor's qualification or above. To validate the CThink, the researcher asked for expert validation. The expert is the professional who has acquired mastery of different dimensions of knowledge. An expert review is a process of asking the opinions, suggestions, feedback, or comments from experts. Content validation for CThink was performed by six experts.

2.3. CThink learning strategy development

CThink was developed using design and development by the ADDIE model, which is the analysis, designing, developing, implementing, and evaluating phases. This section subsequently discusses the procedures of the development, as well as establishing the reliability and validity of the learning strategy. ADDIE model is very systematic [16] and a flexible guide for constructing an active training and instructional design [17] and is both useful and practical for course development [18]. In the mapping of CThink, all tasks and activities were designed by emphasizing the critical thinking process in the learning strategy. Learning strategy helps to strengthen metacognitive abilities and improve student learning [19]. It contributes to optimizing the strategy used by students and increases their control of learning beliefs [20]. The use of a learning strategy has been repeatedly demonstrated to correlate positively with academic performance [21].

In this study, the postures of using questioning for critical thinking have been shown based on critical thinking. Appropriate questioning has been introduced for integral calculus in each critical thinking process. The learning strategy highlights how questioning can be blended to design CThink. According to Misrom *et al.* [22], the use of questioning can be helpful to develop a learning strategy based on critical thinking. Promoting critical thinking is asking appropriate questions framed at the right cognitive level in the teaching and learning of mathematics [23]. Moreover, question prompts to assist students to provide meaningful feedback to their peers and developing critical thinking skills [3]. Prompts are a specific strategy that can help facilitate critical thinking. Question prompts afforded opportunities for engaging in critical thinking such as evaluating resources and making justifications [24]. It encourages students to ask questions, predict, and explain during activities that could encourage deep approaches [25]. Moreover, prompts or questions support responses, contribute new perspectives about topics to the group, and demonstrate critical inquiry in their responses [26]. The ADDIE model was used to develop the proposed learning strategy, CThink. It is a design model that involves basic stages which are simple and easy to learn. The researcher adopted the ADDIE model because this model is very useful as it has clearly defined stages that implement instructions practical, save time and money, and is easy to fix [26]. The overview of the five phases in ADDIE is outlined in sub-section.

2.3.1. Analysis phase

The objective of the analysis phase was to identify problems, gap identification needs identification, and analysis of the detailed tasks based on the needs [27] for the integral calculus topic under the engineering mathematics 2 syllabus. To find the call for developing the learning strategy, an interview was conducted with three engineering mathematics lecturers. The selection of lecturers was based on their years of experience and their vast knowledge in the field of teaching and learning integral calculus in polytechnic. Three broad themes emerged from the analysis transcripts which are the importance of learning integration, difficulties in teaching and learning integral calculus, and improvements in teaching integral calculus.

2.3.2. Design phase

This phase is carried out after analyzing the findings of the first phase. The design can begin after the difficulties are identified and the capabilities of critical thinking are identified and obtained to enhance student problem solving in Integral Calculus. The learning strategy developed in this study refers to critical thinking [28], namely interpretation, analysis, inference, evaluation, explanation, and self-regulation. It is in line with the objectives stated in the research [29] which require critical thinking that can enhance creative problem solving. Belecina and Ocampo [30] stated critical thinking encourages seeking new strategies and solving mathematical problems. Therefore, it is rigorously designed to foster critical thinking to reach the intended student outcome. In the design phase, there are several important aspects to be considered based on the needs analysis that has been implemented. Learning strategy design refers to an important aspect of learning theory and this phase involves several steps such as determining the learning objectives, learning outcomes, and learning activities. Based on the information obtained from the analysis phase, the learning objectives are set to achieve the learning outcomes. Once the objectives are determined, then specific activities are developed. The development of this learning strategy is transformed in the form of activities according to the learning objectives developed by the curriculum development division of the polytechnic.

The contents of the designed learning strategy based on questioning covered the critical thinking process. Integral calculus was adopted with CThink in the preparation for questioning. These concepts were presented through interpretation, analysis, inference, evaluation, explanation, and self-regulation as the components of the critical thinking process. Question prompts are used to guide, and facilitate learning, offering both cognitive and metacognitive guidance. It helps in important cognitive functions, such as focusing attention, stimulating prior knowledge, enhancing comprehension, and facilitating problem-solving processes [31]. Questions have long been used as a teaching tool by teachers and preceptors to assess students' knowledge, promote comprehension, and stimulate critical thinking. Thus, questioning has the potential to promote critical thinking and to foster reflection, deep thinking, and the construction of conceptual knowledge [20]. Teachers' questions and responses may constitute support for students' reflection [18]. CThink was asked to present the interpretation, analysis, inference, evaluation, explanation, and self-regulation in front of the class, individually, with the peer, or with the lecturer to see if there was an agreement of understanding in the process of problem solving by questions for all students.

Designing questioning for critical thinking is modified from the questions to ignite critical thinking skills and adapted in integral calculus. For this study, the questions for critical thinking skills have been adapted in integral calculus. The appropriate questions for each step of the critical thinking process have been developed and these questions are general in developing a learning strategy for integral calculus.

The development of this flowchart is designed to illustrate the flow of the course which will be experienced by the students in this learning strategy. Each activity is implemented by the six critical thinking skills and mapping into each phase of problem solving, starting with the understanding phase and followed by combining with a device a plan, carrying out the plan, and looking back.

2.3.3. Development phase

After the design phase has been completed, the development of CThink learning activities begins. The development phase in the ADDIE model addresses the tools and processes used to create instructional material. The content is created according to the decisions taken in the design phase, and the validated learning resources. The guidelines used to prepare the learning strategy are presented in this section. The method for developing integral calculus based on CThink is questioning critical thinking with face-to-face learning in the class individually or with a peer. Questioning to promote critical thinking has been widely used [5], [32]–[35]. In this study, students were encouraged to use verbal and written questioning for critical thinking as the guide. Questions are being used to initiate mathematical communication between the students and the lecturer [36]. Teacher questioning plays a critical role in mathematics classes for cultivating critical thinking skills and fostering deeper learning [37]. Moreover, questioning helps in reviewing prior knowledge, creating new knowledge, developing understanding, developing thinking skills, and motivating them to higher thinking.

Students are guided to questions for critical thinking in the activities to solve the non-routine problems. Interpretation questioning guide students to be able to interpret the hidden meaning in the statements. Furthermore, the analysis questioning is formulated to bring out the essential elements in the statements. The students are asked to identify the intended and actual inferential relationship among statements. Immediately after that, students are navigated by inference questioning to reason based on relevant criteria and standards. After reasoning out, the students are regulated by evaluation questioning to critically look at the method, procedures used, and whether it is logical. The students were recommended then by evaluation questioning to justify the reasons and lastly by self-regulated questioning to reassess work by cross-checking the procedures and the answers. The CThink booklet also stated the learning objectives for the subtopic and learning outcomes that should be achieved by students. Stating the objectives and outcomes is important for students to perform and focus on achieving the expected learning outcomes. The questions used in the booklet were extracted from the textbook with modifications to fit the activities' needs. The activities developed were based on the findings in the analysis phase which are creating questioning, peer questioning, providing the solution, and demonstrating their solution. The problem solving takes place in demonstration and solutions from the students by following each phase in problem solving determined.

2.4. Validity and reliability

In addition, content validation and face validation were also conducted. The content validation was carried out to determine the validity of the CThink contents, the suitability of the session, and the activities in CThink. The questionnaires for expert validation were adapted and modified to suit the need of the CThink validation processes. Scale rating was used to evaluate the validity and the recommendations by the experts. The calculated value of the rating would describe the level of validity of the developed learning strategy. The results were then calculated using the percentage calculation method (PCM) [37], and the content validity is considered acceptable if the value exceeds 70%.

Intercoder reliability which is also referred to as a member check was conducted where another coder is requested to code the transcripts based on the lists of themes and coding. Each interview transcript was reviewed by the interview participants if further clarification is needed. Three inter-rater who has a research background in the field of mathematics education were involved in the interview data analysis process. Taking the findings back to the subjects being studied, where these people verify the findings helps the researcher to be more confident of the data validity (respondent validation). The transcribed qualitative data from the focus group discussions and one-to-one interviews were analyzed using NVivo 10. The texts were read word for word to gather themes related to the research questions. Inter-rater reliability and inter-rater agreement were calculated to determine the degree of agreement between the three raters.

2.5. Inter-rater agreement of interview data

The transcribed interviews were inter-coded to determine inter-rater reliability and inter-rater agreement. Both measures were used because the inter-rater agreement does not take into account agreements that may occur by chance. Inter-rater agreement is an agreement that might be based on whether two or more raters agree on codes used for the same passages in the text. To establish an inter-rater agreement, one of the transcribed interviews was coded by three different researchers. The inter-rater agreement was 58.3%. Expert reviews using the Fleiss Kappa inter-rater reliability technique were employed to complete and ensure the validity of the interview. The finding of the overall Kappa coefficient value is 0.55 which indicates moderate agreement.

3. RESULTS AND DISCUSSION

A learning strategy that has been assessed by an expert should be calculated the PCM method [37]. The good content validation percentage was set at 70% [37]. Critical thinking has achieved the content validity of 94.12% with a coefficient value of 0.94, and the value is above 70% or 0.70. Based on the result, the contents in the CThink are considered of good validity. From the calculation of the percentage from the expert given score, CThink has achieved the validity measurement for the language of 97.50% with a coefficient value of validity is 0.975, which is above 70 or 0.70. Based on the result, the activities and syllabus used in CThink achieved good validity measurements. The experts concluded that this CThink meets the content of Integral Calculus, in line with the level of polytechnic students, allowing students to think critically to solve problems as well as activities in CThink help to enhance student problem solving. Next, comments and suggestions for the improvement of the CThink provided by experts from the validation form. A few comments for improvements to the CThink have been resolved as described in the improvement space.

3.1. Implementation phase

CThink was conducted for a pilot study with 12 meetings from September until October 2018. This pilot study was conducted for six weeks with a total of 24 hours of learning time. Within CThink development, a pilot test is conducted to identify usability issues in the learning strategy. The data collected, and issues identified during the pilot study are used to revise the learning strategy before it is released. Moreover, the purpose is to test the CThink developed in the previous steps with the targeted audience and to ensure that everything functions properly. Pilot studies provide opportunities for the researcher to evaluate student reactions to the procedures, the suitability of the questions used in each activity, the use of the critical thinking process used, and the situation to be carried out in the real situation. Moreover, the aim is also to make estimates of the time required for each learning session. From the pilot study of the learning strategy used, feedback and comments, and suggestions were obtained from the students involved in the form of open-ended interviews. Once the CThink was revised and completed, the implementation phase of the research study began. The data collection that occurred during this phase was used for the improvement of CThink. The deliverables for the implementation phase are all the learning activities in the CThink which consist of ten activity units. The rationale of ten activities is developed because the polytechnic syllabus has ten subtopics in integral calculus and each subtopic affords an opportunity to address the student's difficulties in problem solving. Activities are conducted for 45 minutes and the rest is for lectures. The experimenter was able to meet with students for six weeks for four hours per week.

CThink refers to three learning objectives and ten activities. Data is taken through a pre-test which is given before the students pursue the intervention. After the intervention, the group of students was given a post-test to assess whether CThink can improve problem solving difficulties within integral calculus. A post-test was taken at the end of the teaching period. The test required to answers all questions which only involve calculation and problem solving. This instrument was assumed fit to measure the problem solving of students. The students were given two hours to answer all the questions. Each problem should be solved with the complete solution to determine the effectiveness of CThink to enhance problem solving.

3.2. Evaluation phase

Evaluation is an ongoing process and may take place at any time during course development and delivery. It is the process to see whether the learning strategy developed succeeds, in line with the expectation of the study. A developed learning strategy is appropriate when passing through certain credentials. In this regard, this assessment is focused on identifying CThink that has been developed with good validity and high-reliability coefficients before testing their efficiency in mathematical learning. CThink which has been through improvement in terms of content also tested its reliability. Evaluation for CThink is measured using the questionnaire developed. After completing the implementation phase, students are given a questionnaire to evaluate the CThink learning strategy. In the aspect of student evaluation of CThink, it can say that students are of the view that they are interested in resolving the problem in CThink. Moreover, using CThink with questioning for critical thinking helps to solve problems. Thereby, the student's critical thinking in Integral Calculus was taught.

4. CONCLUSION

This paper describes in detail the learning activities which have been broken down into three learning objectives based on critical thinking skills. Based on the phases of the ADDIE design model, the procedure of designing a learning strategy through CThink can be more organized and systematic. In summary, CThink contains three objectives and involves 10 learning activities. CThink is implemented to illustrate the application of critical thinking process and critical thinking questioning in learning strategy. The critical thinking process needs to be implemented in each phase of solve problem solving. The effectiveness of CThink in improving problem solving is through problem solving tests where the use of critical thinking process is identified through the coding that has been built. In addition, interviews and rubrics are also used as an advanced extension of CThink.

CThink is allow students to use their ideas and strategy as well as to encourage discussions during their learning process. Likewise, an analysis of the student assessment in pilot studies shows that CThink is appropriate for use in the classroom. They argue that page layout, text size, picture, charts, tables, and content texts, as well as easy-to-understand sentence instructions and step-by-step questioning for critical thinking, are also easy to follow. Consequently, referring to the validity assessment results of experts and students indicates that CThink can be applied in the classroom and tested on other topics in Engineering Mathematics subjects. The students' view towards CThink, as demonstrated by their general comments, was also positive. Overall responses to the perception questionnaire indicated that CThink was endorsed as a more exciting and fruitful teaching and learning method. The CThink group decided that they could readily understand the Integral Calculus taught to them through CThink which made it much easier for them to make sense of the problem solving. In this situation, problem solving is regarded as intelligible for CThink learners when they can explain the solution in their own step. The results of the questionnaire helped to explain the students' perceptions toward learning by CThink respectively.

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Higher Education and Universiti Teknologi Malaysia for their financial support. This work was supported by the UTM Fundamental Research Grant no. Q.J130000.3813.21H85.

REFERENCES

[1] A. H. Abdullah and E. Zakaria, "The activities based on van hiele's phase-based learning: Experts' and preservice teachers' views," *Journal of Mathematics and Statistics*, vol. 8, no. 3, pp. 385–395, Mar. 2012, doi: 10.3844/jmssp.2012.385.395.

[2] S. Khalid, M. Alias, W. Razally, and Z. Suradi, "The influence of multimedia supported courseware with collaborative learning in algebraic fractions and problem solving skills among Pre-University students," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 2, no. 3, pp. 1–4, 2007.

[3] T. K. Clark, "Analyzing agricultural education student teachers' critical thinking skills through blogs in an online community of practice," Thesis, Iowa State University, 2015.

[4] K. Hong and S. M. Jacob, "Critical thinking and Socratic questioning in asynchronous mathematics discussion forums," *Malaysian Journal of Educational Technology*, vol. 12, no. 3, pp. 17–26, 2012.

[5] J. S. Nappi, "The importance of questioning in developing critical thinking skills," *Delta Kappa Gamma Bulletin*, vol. 84, no. 1, pp. 30–41, 2017.

[6] A. H. Abdullah, N. H. Ibrahim, J. Surif, M. Ali, and M. H. Hamzah, "Non-routine mathematical problems among in-service and pre-service mathematics teachers," in *Proceedings of IEEE International Conference on Teaching, Assessment and Learning for Engineering: Learning for the Future Now, TALE 2014*, Dec. 2015, pp. 18–24. doi: 10.1109/TALE.2014.7062620.

[7] E. Aizikovitsh-Udi and D. Cheng, "Developing critical thinking skills from dispositions to abilities: mathematics education from early childhood to high school," *Creative Education*, vol. 06, no. 04, pp. 455–462, 2015, doi: 10.4236/ce.2015.64045.

[8] A. Prayitno, "Characteristics of students' critical thinking in solving mathematics problem," *The Online Journal of New Horizons in Education*, vol. 8, no. 1, pp. 46–55, 2018.

[9] G. Aksu and N. Koruklu, "Determination the effects of vocational high school students' logical and critical thinking skills on mathematics success," *Eurasian Journal of Educational Research*, vol. 15, no. 59, pp. 181–206, Apr. 2015, doi: 10.14689/ejer.2015.59.11.

[10] E. Alcantara, E. C. Alcantara, J. Marie, and P. Bacsa, "Critical thinking and problem solving skills in mathematics of grade-7 public secondary students," *Asia Pacific Journal of Multidisciplinary Research*, vol. 5, no. 4, pp. 21–27, 2017.

[11] T. Li, "Critical thinking in the content and language integrated classroom: perceptions of secondary mathematics teachers in overseas Canadian curriculum contexts," University of British Columbia, 2017, doi: 10.14288/1.0349189.

[12] S. A. Go, "Mathematics: developer of critical thinking, problem solving and character," MGC New Life Christian Academy, 2013.

[13] A. Brown, "Critical thinking to justify an answer in mathematics classrooms," Walden Dissertations and Doctoral Studies, Walden University, Jan. 2016.

[14] S. M. Jacob, B. Lee, and G. R. Lueckenhausen, "Measuring critical thinking skills in Engineering Mathematics using online forums," in *2009 International Conference on Engineering Education, ICEED2009 - Embracing New Challenges in Engineering Education*, 2009, pp. 225–229. doi: 10.1109/ICEED.2009.5490577.

[15] Intergovernmental Panel on Climate Change, "Summary for Policymakers," in *Climate Change 2013 – The Physical Science Basis*, Cambridge University Press, 2014, pp. 1–30. doi: 10.1017/CBO9781107415324.004.

[16] W. Viechtbauer *et al.*, "A simple formula for the calculation of sample size in pilot studies," *Journal of Clinical Epidemiology*, vol. 68, no. 11, pp. 1375–1379, Nov. 2015, doi: 10.1016/j.jclinepi.2015.04.014.

[17] H. Basri and A. R. As'ari, "Improving the critical thinking ability of students to solve mathematical task," *JIPM (Jurnal Ilmiah Pendidikan Matematika)*, vol. 7, no. 1, p. 13, Sep. 2018, doi: 10.25273/jipm.v7i1.3013.

[18] A. Dekker-Groen, M. Van der Schaaf, and K. Stokking, "Teachers' questions and responses during teacher-student feedback dialogues," *Scandinavian Journal of Educational Research*, vol. 59, no. 2, pp. 231–254, Aug. 2015, doi: 10.1080/00313831.2014.937359.

[19] D. R. Hidayanto, Munir, E. F. Rahman, and J. Kusnendar, "The application of ADDIE model in developing adventure game-based multimedia learning to improve students' understanding of basic programming," in *Proceeding - 2017 3rd International Conference on Science in Information Technology: Theory and Application of IT for Education, Industry and Society in Big Data Era, ICSITech 2017*, Oct. 2017, vol. 2018, pp. 307–312. doi: 10.1109/ICSITech.2017.8257130.

[20] J. Osborne, "Teaching critical thinking? New directions in science education," *School Science Review*, vol. 95, no. 352, pp. 53–62, 2014.

[21] N. Dinuţă, "The use of critical thinking in teaching geometric concepts in primary school," *Procedia - Social and Behavioral Sciences*, vol. 180, pp. 788–794, May 2015, doi: 10.1016/j.sbspro.2015.02.205.

[22] N. S. Misrom, M. S. Abdurrahman, A. H. Abdullah, S. Osman, M. H. Hamzah, and A. Fauzan, "Enhancing students' higher-order thinking skills (HOTS) through an inductive reasoning strategy using geogebra," *International Journal of Emerging Technologies in Learning*, vol. 15, no. 3, pp. 156–179, Feb. 2020, doi: 10.3991/ijet.v15i03.9839.

[23] S. Chikiwa, L. Westaway, and M. Graven, "Learning from Practice: What Mathematics Knowledge Is Needed for Developing Number Sense?" *Proceedings of the 23rd Annual National Congress of the Association for Mathematics Education of South Africa*, 2017, pp. 55–67.

[24] D. R. Tobergte and S. Curtis, "The effect of nature of science metacognitive prompts on science students' content and nature of science knowledge metacognition, and self-regulatory efficacy," *Journal of Chemical Information and Modeling*, vol. 53, no. 9, pp. 1689–1699, 2013.

[25] A. Lumpkin, R. Achen, and R. Dodd, "Using Technology-nested instructional strategies to enhance student learning," *InSight: A Journal of Scholarly Teaching*, vol. 10, pp. 114–125, Aug. 2015, doi: 10.46504/10201509lu.

[26] N. F. Jumaat, N. Ahmad, N. A. Samah, Z. M. Ashari, D. F. Ali, and A. H. Abdullah, "Facebook as a platform of social interactions for meaningful learning," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 14, no. 04, p. 151, Feb. 2019, doi: 10.3991/ijet.v14i04.9363.

[27] D. Ampera, "Addie model through the task learning approach in textile knowledge course in dress-making education study program of State University of Medan," *International Journal of GEOMATE*, vol. 12, no. 30, pp. 109–114, Feb. 2017, doi: 10.21660/2017.30.TVET005.

[28] P. A. Facione and N. C. Facione, "Critical thinking for life," *Inquiry: Critical Thinking Across the Disciplines*, vol. 28, no. 1, pp. 5–25, 2013, doi: 10.5840/inquiryct20132812.

[29] Ministry of Education Malaysia, "Malaysia education blueprint 2015-2025 (higher education)," Kementerian Pendidikan Malaysia, Putrajaya, Malaysia, 2015.

[30] R. R. Belecina and J. M. Ocampo, "Effecting Change on Students' Critical Thinking in Problem Solving," *EDUCARE*, vol. 10, no. 2, pp. 109–118, Feb. 2018, doi: 10.2121/EDU-IJES.V10I2.949.

[31] M. Nizam, "Strategi Pembelajaran Pembezaan Berfokuskan Metakognitif Bagi Mempertingkatkan Penaakulan Matematik," Unpublished Thesis, Universiti Teknologi Malaysia, 2018.

[32] A. Luksanasakul and A. Chanthong, "Questioning techniques promote the critical thinking in engineering education: Case study in microcontroller course of electrical engineering," in *IEEE Global Engineering Education Conference, EDUCON*, Apr. 2017, pp. 1054–1057. doi: 10.1109/EDUCON.2017.7942978.

[33] T. Santoso, L. Yuanita, and E. Erman, "The role of student's critical asking question in developing student's critical thinking skills," *Journal of Physics: Conference Series*, vol. 953, p. 012042, 2018.

[34] T. Saeed and A. Ahmed, "Development of students' critical thinking: The educators' ability to use questioning skills in the baccalaureate programmes in nursing in Pakistan," *Journal of Pakistan Medical Association*, vol. 62, no. 3, 2015.

[35] H. Kashefi, Z. Ismail, and Y. M. Yusof, "The impact of blended learning on communication skills and teamwork of engineering students in multivariable calculus," *Procedia - Social and Behavioral Sciences*, vol. 56, pp. 341–347, Oct. 2012, doi: 10.1016/j.sbspro.2012.09.662.

[36] C. Chikiwa and M. Schäfer, "Promoting critical thinking in multilingual mathematics classes through questioning," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 14, no. 8, 2009, doi: 10.29333/ejmste/91832.

[37] B. S. Afifi, M. T. Nor'ain, A. Mazlini, and M. S. Ikhwan, "Adventure based learning module: content validity and reliability process," *International Journal of Academic Research in Business and Social Sciences*, vol. 7, no. 2, pp. 615–623, 2017.

BIOGRAPHIES OF AUTHORS

Nurul Shida received the Ph.D. degree in Mathematics Education from the Universiti Teknologi Malaysia (UTM). She has over 14 years of experience as a lecturer with the polytechnic. Her current research interest includes critical thinking and problem solving. She can be contacted at email: drnurulshida@gmail.com.

Abdul Halim Abdullah received his B.Sc. (Edu) and M.Sc. (Edu) degrees in Mathematics Education from Universiti Teknologi Malaysia (UTM). He obtained his PhD degree in Mathematics Education from Universiti Kebangsaan Malaysia (UKM). He has been serving at the School of Education, UTM since 2006. His research areas are geometry thinking, higher order thinking skills (HOTS) in mathematics and technology-aided teaching and learning in mathematics. He can be contacted at email: p-halim@utm.my.

Sharifah Osman received the Ph.D. degree in Engineering Education from Universiti Teknologi Malaysia. She is currently a Senior Lecturer at the School of Education, Faculty of Social Sciences and Humanities, Universiti Teknologi Malaysia. Her research interests include qualitative research, grounded theory, critical thinking, mathematical thinking, engineering education, and mathematics education. She can be contacted at email: sharifah.o@utm.my.

Norulhuda Binti Ismail is a Senior Lecturer and Coordinator for Mathematics Education at the School of Education, Faculty of Social Sciences and Humanities, Universiti Teknologi Malaysia. She can be contacted at email: p-norulhuda@utm.my.