A review for threshold concept identification methods in science

R Hendrawati*, S Mulyani* and W Wiji

Program Studi Pendidikan Kimia, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudhi No. 229, Bandung, Jawa Barat, 40154, Indonesia

*rini.hendrawati@upi.edu, srimulyani@upi.edu

Abstract. The research of threshold concept has been vastly developed in various discipline including in the field of science during the last two decades. This causes the method to identify threshold concept increases in its variety. This research attempts to provide a general description of several methods used to identify the threshold concept in science. Method used in this research is document analysis method, which analyzes published articles and focuses on threshold concept identification method in science. Based on article analysis, it is obtained that the most often used method in threshold concept identification researches is interview, followed by survey, focus-group discussion, content analysis, test, workshop, concept maps and quiz. Therefore, researchers should have a good background knowledge regarding various method used in threshold concept research, so they can choose which method that would be effective and give the most optimal result for their own research.

1. Introduction

During the last two decades, education researchers have done various researches about threshold concept in various discipline including in science. The term threshold concept emerged from a research project called ‘Enhancing Teaching and Learning Environments in Undergraduate Courses’ (ETL), done by Economics researchers in United Kingdom. The notion of a threshold concept was first introduced by Meyer and Land in their paper which was presented at ETL Symposium in 2002. They stated that there are certain concepts that the students would find not only difficult to understand, but also serve as a ‘portal’ to open new ways of thinking and has not been accessed before [1].

Threshold concept is often regarded to be similar with core concept, even though threshold concept is more complex, due to its characteristics such as: transformative (to cause the changes in cognitive development and way of thinking), integrative (to connect various concepts), irreversible (the concepts become the center of an individual’s way of thinking and this would not be easily forgotten), troublesome (contra-intuitive and difficult to understand) and bounded (many threshold concept are specific for a certain discipline) [2].

Threshold concept is defined as a concept that binds a certain discipline, to be the foundation for the ways of thinking and practices inside the discipline itself. If an individual has internalized the threshold concept, they would be better in integrating various discipline aspects in a problem analysis. Students who have not been able to internalize the threshold concept often learn new ideas with a more fragmented or uncompleted ways [3]. The identification of threshold concepts is important for the research community, for educational designers and for teachers as explicit attention to the concepts may help to address the misconceptions that often lie at the troublesomeness of concepts [4]. This is also an

---

*Published under licence by IOP Publishing Ltd

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

1806 (2021) 012192 doi:10.1088/1742-6596/1806/1/012192
important step in designing curriculum and lesson planning in order to help students resolve their own difficulty and to develop appropriate teachings [5,6,7].

For threshold concept to give a significant contribution in learning, teachers and lecturers must be able to identify these concepts in their own subjects [5]. As research regarding threshold concept develops, methods to identify threshold concept also becomes diverse. Researchers need to design a research method that allows variations in student’s experiences of threshold concept [8]. Therefore, researchers need to have a good background knowledge in common methods used in threshold concept researches. So that, they can choose a more effective method or one that can give an optimal result for their research.

This article gives general description of several methods used to identify threshold concept in science. Reviews are made by analyzing scientific research literature that shows varieties of methods used in the identification process of threshold concept.

2. Method
This research investigates published articles in the field of science education to obtain data on threshold concept identification. To identify relevant articles, a systematic search with document analysis method is done. The process includes several stages that is, each article was identified based on title (must contain “threshold concept”), then based on keywords and abstract contents to ensure that the journal is related to science, then followed by identifying them based on research methods and finally the articles that focus on threshold concept identification in science are used. From about 70 articles related to threshold concept, there are only 30 articles that identify threshold concept and 19 of them are in science. The articles obtained are thoroughly analyzed in terms of threshold concept identification method.

3. Result and Discussion
As explained above, the existence of threshold concept is important in the education field. Therefore, the threshold concept research must be done by collecting data from participants who have teaching and learning experience, which are students and teachers. Various methods have been used in threshold concept identification researches. Table 1 summarize several methods to identify threshold concept based on analysis on various research articles in science. Below is the explanation on methods used to identify threshold concept in science based on Table 1.

3.1. Interview
Based on Table 1 it is obtained that interview is the most common method used to identify threshold concept in science, because it gives an opportunity to investigate thoroughly and to adjust the interview questions with the student’s answers. There are two types of interview that used to identify threshold concepts in science, which are: (1) Structured interview. Cruz’s research has used this method with think aloud protocol. The questions are planned and made before the interview. All participants are asked with the same questions with the same order. Based on their teaching practices, teachers are asked to identify “tricky topics” that are problematic for students [10]; and (2) Semi-structured interview. There are several main questions that have been determined before the interview and the rest of the questions are unplanned. Students were probed for their deeper understanding of the concepts and their relationship. Questions are focused on things that are difficult to learn [6,15,22,23,25]

Like researches in the field of science, interview method is also found in threshold concepts identification research in non-scientific fields, including in economic disciplines [2, 26], healthcare [27] and engineering [28 – 30]. However, the thing that distinguishes it is in the non-scientific field found another method commonly called unstructured interview. In this type of interview, questions are not prepared before the interview, but rises spontaneously in free-flowing conversations, which also means that different participants will each have different sets of question [31].
### Table 1. Several methods to identify threshold concept in science

| Disciplines       | Authors                      | Methods to Identify Threshold Concept |
|-------------------|------------------------------|---------------------------------------|
|                   |                              | Interview | Survey | Focus-Group Discussion | Content Analysis | Test | Workshop | Concept Maps | Quiz |
| Mathematics       | Worsley et al. [9]           | ✓          | ✓       | ✓                   | ✓               |      |          |            |      |
|                   | Cruz et al. [10]             | ✓          |         | ✓                   |                 |      |          |            |      |
|                   | Oates et al. [11]            | ✓          | ✓       |                     |                 |      |          |            |      |
|                   | Thornton [4]                 |            | ✓       |                     |                 |      |          |            | ✓    |
| Physics           | Moss et al. [12]             | ✓          | ✓       | ✓                   |                 |      |          |            |      |
|                   | Akerlind et al. [13]         | ✓          |         |                     |                 |      |          |            | ✓    |
|                   | Wilson et al. [14]           | ✓          |         |                     |                 |      |          |            | ✓    |
| Biology           | Moss et al. [12]             | ✓          | ✓       |                     |                 |      |          |            |      |
|                   | Waleck et al. [15]           | ✓          |         |                     |                 |      |          |            | ✓    |
| Chemistry         | Moss et al. [12]             | ✓          | ✓       | ✓                   |                 |      |          |            |      |
|                   | Park & Light [6]             | ✓          | ✓       | ✓                   |                 |      |          |            |      |
|                   | Park [16]                    | ✓          | ✓       | ✓                   |                 |      |          |            |      |
|                   | Wiji & Mulyani [17]          | ✓          | ✓       | ✓                   |                 |      |          |            |      |
|                   | Delisma et al. [18]          | ✓          | ✓       | ✓                   |                 |      |          |            |      |
|                   | Ulfa et al. [19]             | ✓          | ✓       | ✓                   |                 |      |          |            |      |
| Biochemistry      | Loertscher et al. [20]       | ✓          | ✓       | ✓                   |                 |      |          |            |      |
|                   | Green et al. [21]            | ✓          | ✓       | ✓                   |                 |      |          |            |      |
| Neuroscience      | Holley [22]                  | ✓          |         | ✓                   |                 |      |          |            |      |
| Geoscience        | Ryan & Gass [23]             | ✓          |         | ✓                   |                 |      |          |            |      |
| Nanoscience       | Park et al. [24]             | ✓          |         | ✓                   |                 |      |          |            |      |
|                   | Chen et al. [25]             |            | ✓       |                     |                 |      |          |            |      |

#### 3.2. Survey

Worsley’s research [9] conducted a survey aimed at determining what was considered problematic or difficult by students and potentially as a threshold concept. Before making the survey items, interviews are conducted with several teachers to gain insight into areas that are considered troublesome. From this interview, three difficult concepts were obtained. Furthermore, this concept is used as items for the survey. 124 students were asked to answer three questions about “What do you think is difficult or problematic?” in understanding these three difficult concepts.

Meanwhile, Park [16] conducted a threshold concept research through giving questionnaires to teachers. The questionnaire contained 11 questions sent by email, with the following details: items 1-4 gather background information; items 5-8 ask about thoughts and experiences about important and difficult concepts in chemistry; item 9 ask the teacher to identify concepts considered as “thresholds” in chemistry; item 10 ask about the teacher's reflection on their experience in overcoming the threshold concept; and item 11 ask about the relationship between understanding threshold concept and teaching.

Survey methods are also used in non-scientific disciplines such as in health sciences [32, 27] and in engineering [33]. In Hill [27] and Cope [32] research, questionnaires were used with methods that were almost similar to Park [16] research.

#### 3.3. Focus Group Discussion

Focus-group is a discussion focused on a small group to discuss a certain problem. In Moss’s research [12], a number of students were asked questions to find out: What are the concepts students find difficult
or troublesome? What concepts have transformed their understanding? What are the gaps the perceive in their knowledge? What are the concepts they are most hard to identify and why?

This method is also used in non-scientific disciplines [30], focus group consisting of students and accompanied by a co-facilitator, namely an academician who is familiar with the students and is an expert in engineering disciplines. Facilitator introduces threshold concept theory and ask students to identify and discuss the potential of threshold concept.

3.4. Content Analysis
Content analysis can be in the form of lecture notes, tutorial pages, and daily assignments, with a goal to obtain some knowledges of areas that can potentially be a threshold concept [9]. Meanwhile, Holley’s research [22] conducted a curriculum analysis, by identify 50 of the best programs in neuroscience based on National Research Council (NCR). Data collected from documents, including student description and learning (with related syllabus). The analysis considers how the practitioners plan and design the curriculum to introduce the concepts of threshold concept to beginners.

Content analysis are also used in non-scientific disciplines such as health sciences [31]. Documentary analysis of course material was used to enhance awareness of the context in which the students were developing.

3.5. Test
The DToM-POE (Diagnostic Test of Mental Model - Prediction, Observation, and Explanation) in the form of essay test was used by researcher [17]. In the predicting stage, students were required to give reasons based on their knowledge. Furthermore, they were facilitated to prove predictions by observing the phenomena. Finally, in the third stage, they provide explanations in three levels of representation. The obtained student’s answers are grouped into mental model profiles that is scientifically correct, partially correct, incorrect answers and no response. Then the answers were analyzed further to determine the threshold concept.

In Moss’s research [12], fifty students were asked to complete a diagnostic test to check where there were conceptual difficulties. The question types included multiple choice, multiple completion and pairing. The questions were derived in part from an earlier diagnostic test (based on the RSC Question Bank). Several topics that are considered difficult by students are analyzed to determine the threshold.

3.6. Workshop
Workshop can involve discussion between lecturers in a certain major or even different majors, between teachers, or between students [20]. The workshop consists of several steps, which are: 1) Interdisciplinary workshop (biology, chemistry, biochemistry): resulted in a draft of threshold concept lists for biochemistry; 2) Workshop between teachers and biochemistry lecturers: revising threshold concept draft for biochemistry and designing an interview for students; 3) Student interviews: investigates student’s understandings about temporary threshold concept; and 4) Determining the biochemistry threshold concept list with a discussion between researchers and expert lecturers [20].

This method is also used in engineering disciplines [29, 30]. Workshop enables further identification of various concepts that have the potential to become threshold concept, especially allowing discussion among many participants at a relatively short time. Facilitator keeps the workshop focused and asks questions, so the discussion is deeper [30].

3.7. Concept Maps
A concept map consists of nodes (concepts) and labelled arrow (linking words). Concept maps reveal students’ knowledge of facts, ideas and how they are related to each other [24]. Park et al. [24] identifying threshold concepts from students’ concept maps. Students were asked to construct and explain concept maps exploring the troublesome nature characterizing their understanding of fundamental nanoscience concepts. The key concepts have been provided by researchers, then students were asked to connect these concepts. Key concepts were obtained from experts’ concept maps
constructed by course professors before the research is conducted. Students were then asked to select concepts from their own maps and to identify these concepts with respect to three different categories (important, difficult and threshold) to provide reason for their responses.

3.8. Quiz
Quiz consists of open-ended questions, which are presented on presentation slides. Meanwhile, students answer questions on a provided answer sheet. This quiz is designed to test students’ conceptual understanding and their understanding of procedural knowledge. Conceptual understanding questions are made in open-ended format to allow various answers. Meanwhile, procedural knowledge question tends to be in a true or false format [9].

4. Conclusion
As research on threshold concept develops, the method to identify threshold concept also increasingly diverse. Various methods have been used in threshold concept identification research in science. Based on article analysis, it is obtained that the most often used method in threshold concept identification researches in the field of science is interview (structured and semi-structured), followed by survey, focus-group discussion, content analysis, test, workshop, concept maps and quiz. Interview is the most frequently used method for identifying threshold concept because it provides opportunities to investigate deeply and adjust questions with the students’ answers. Therefore, researchers should have good background knowledge regarding the method commonly used for threshold concept research in science, so they can choose an effective method that can provide optimal result to meet their research goal.

5. References
[1] Entwistle N 2003 Concepts and conceptual frameworks underpinning the ETL project ETL Project Occasional Report 3 (Edinburgh: Teaching and Learning Research Program)
[2] Meyer J H F and Land R 2003 Threshold concepts and troublesome knowledge: linkages to ways of thinking and practising within the disciplines Improv. Stud. Learn. Theory and Pract. 4 p 412–424
[3] Land R, Cousin G, Meyer J H and Davies P 2005 Threshold concepts and troublesome knowledge (3): implications for course design and evaluation Improv. Stud. Learn. Diversity & Inclusivity 4 p 53-64
[4] Thornton S 2020 Threshold concepts in primary school maths and science: an investigation of some underlying ideas of stem STEM Educ. Across Learn. Continuum p 233-247
[5] Davies P 2003 Threshold concepts: how can we recognise them? Eur. Assoc. in Learn. Instr. (EARLI) Conf. (Padova: IEPR)
[6] Park E J and Light G 2009 Identifying atomic structure as a threshold concept: student mental models and troublesomeness Int. J. of Sci. Educ. 31 2 p 233–258
[7] Talanquer V 2014 Threshold concepts in chemistry: the critical role of implicit schemas J. of Chem. Educ. 92 1 p 3-9
[8] Meyer J H F and Land R 2005 Threshold concepts and troublesome knowledge (2): epistemological considerations and a conceptual framework for teaching and learning High. Educ. 49 p 373-388
[9] Worsley S, Bulmer M and O’Brien M 2008 Threshold concepts and troublesome knowledge in a second-level mathematics course. In Hugman A and Placing K (Eds.) Symp. Proc. Visualisation and Concept Development (Sydney: UniServe Science) p 139-144
[10] Cruz S, Lencastre J A, Coutinho C, Clough G and Adams A 2016 The problem distiller tool: supporting teachers in uncovering why their students have problems understanding threshold concepts Int. Conf. on Comput. Supported Educ. p 380-401
[11] Oates G N, Reaburn R L, Brideson M A and Dharmadasa H K 2018 Understanding of limits and differentiation as threshold concepts in a first-year mathematics course The Eleventh Southern Hemisphere Conf. Teach. and Learn. of Undergraduate Math. and Statistics p 108-120
[12] Moss K, Greenall C, Rockcliffe A, Crowley M and Mealing A 2007 Threshold concepts, misconceptions and common issues Proc. Sci. Learn. Teach. Conf. p 190-196
[13] Akerlind G, McKenzie J and Lupton M 2010 A threshold concepts focus to first year law curriculum design: supporting student learning using variation theory 13th Pacific Rim First Year in High. Educ. Conf. (Australia: Australian Learning and Teaching Council)
[14] Wilson A, Akerlind G, Francis P, Kirkup L, McKenzie J A, Pearce D and Sharma M 2010 Measurement uncertainty as a threshold concept in physics Uniserve Sci. Annual Conf. Uniserve Science
[15] Wailek-Shannon E, Batzli J, Pultorak J and Boehmer H 2019 Biological variation as a threshold concept: can we measure threshold crossing? CBE—Life Sci. Educ. 18 3 p 1-15
[16] Park E J 2015 Impact of teachers’ overcoming experience of threshold concepts in chemistry on pedagogical content knowledge (PCK) development J. Korean Chem. Soc. 59 p 308-319
[17] Wiji W and Mulyani S 2018 Student’s mental model, misconceptions, troublesome knowledge, and threshold concept on thermochemistry with DToM-POE J. Phys.Conf. Ser. 1013 p 1-5
[18] Delisma D, Wiji W and Widhiyanti T 2020 Conception, threshold concept and troublesome knowledge in redox reaction J. Phys.Conf. Ser. 1521 p 1-6
[19] Ulfa A M, Wiji W and Mulyani S 2020 Conception, threshold concepts and troublesome knowledge in chemical reactions topic J. Phys.Conf. Ser. 1521 p 1-6
[20] Loertscher J, Green D, Lewis J E, Lin S and Minderhout V 2014 Identification of threshold concepts for biochemistry CBE—Life Sci. Educ. 13 3 p 516-528
[21] Green D A, Loertscher J, Minderhout V and Lewis J E 2017 For want of a better word: unlocking threshold concepts in natural sciences with a key from the humanities? High. Educ. Res. Dev. 36 7 p 1401-1417
[22] Holley K A 2018 The role of threshold concepts in an interdisciplinary curriculum: a case study in neuroscience Innov. High. Educ. 43 1 p 17-30
[23] Ryan A M and Gass S E 2017 Quantitative reasoning: Exploring troublesome thresholds Discussions on Univ. Sci. Teach.: Proc. West. Conf. Sci. Educ. 1 1 p 1-15
[24] Park E J, Light G and Mason T 2008 Identifying Threshold concepts in learning nanoscience by using concept maps and students’ responses to an open-ended interview.
[25] Chen T L, Liu Y L, Yueh H P and Sheen H J 2010 Identifying the threshold concept of learning nano-science and nano-technology in material engineering by curriculum map Int. J. Technol. Eng Educ. 7 3 p 25-32
[26] Davies P and Mangan J 2007 Threshold concepts and the integration of understanding in economics Stud. High. Educ. 32 6 p 711–726
[27] Hill S 2019 The difference between troublesome knowledge and threshold concepts Stud. High. Educ. p 1–12
[28] Scott J B, Harlow A, Peter M and Cowie B 2010 Threshold concepts and introductory electronics Proc. of the 2010 AaeE Conf. (Sydney: AaeE) p 409-416
[29] Hesterman D C, Male S A and Baillie C A 2011 Some potential underlying threshold concepts in engineering dynamics Proc. of 22nd Annual Conf. for the Australasian Assoc. for Eng. Educ. (Fremantle: AAAE) p 619-625
[30] Male S and Baillie C 2011 Engineering threshold concepts SEFI-Annual Conf. of Eur. Soc. for Eng. Educ. (Lisbon: World Engineering Education Flash Week) p 251-257
[31] Clouder L 2005 Caring as a ‘threshold concept’: transforming students in higher education into health (care) professionals Teach. High. Educ. 10 4 p 505-517
[32] Cope C and Staehr L 2008 Improving student learning about a threshold concept in the IS discipline Inform. Sci. Int. J. Emerg. Transdiscipl. 11 p 349-364
[33] Barber P Y, Atkinson L, Possin G and Woodall L 2008 Light bulb moments: Identifying information research threshold concepts for fourth year engineering students 19th Annual Conf. of the Australasian Assoc. for Eng. Educ.; Proc. of the Institution of Eng. (Australia: Institution of Engineers) p 349