Concept Mapping: Renewing Learning and Thinking
Proc. of the Eighth Int. Conference on Concept Mapping
Medellín, Colombia 2018

A NEW VALIDATION METHOD FOR DEFINING CONCEPT MAP CATEGORIES

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Abstract. This paper describes a new method for developing and refining the categories into which the concepts of a collection of concept maps may be classified. The method is used to develop a set of ten categories into which concepts relating to the domain of 'process safety' may be assigned. The categories created were used to analyse 103 concept maps that were generated by second year undergraduate chemical engineering students. The method involved defining ten different categories into which the process safety concepts could be assigned. Each map was then analysed independently by three different assessors who each bring different perspectives on the topic to the analysis. Each assessor assigned every concept of each of the maps to one of the ten categories. The disagreements that inevitably occurred between the three assessors were then analysed using a novel three-way table. A close analysis of the disagreements aided by the new table allowed each of the categories to be more closely defined, removing ambiguities and uncertainties. The results showed that the students generally understood the non-physical preventative measure in the process industries as well as the consequences and potential outcomes. The students appeared not to recognize the importance of education and training in maintaining safety.

Keywords: concept mapping, categories, taxonomy, process safety, validation study

1 Introduction

Imparting a sound understanding of process safety is a crucial element of any chemical engineering program. The study of real past engineering incidents in the classroom is often an efficient way to emphasise the importance of process safety. In the University of Melbourne for example, undergraduate students enrolled in chemical engineering program learn the subject of process safety throughout their course. One challenge that any educator faces is to how to properly assess student learning in the safety domain. A study conducted by Shallcross (2013) suggested the use of concept maps to assess the learning and understanding of cohort and individual around the safety case studies. Concept maps are a graphical technique of presenting information and relationship between different concepts. This method has also been used by others researchers for example, in sustainable development topic by Lourdel *et al*. (2007) and Segalàs *et al*. (2008). In this study, we focus on the use of concept maps as a tool for assessment, in which a new method is proposed to develop the categories, into which concepts may be allocated. This method is applied to the development of a taxonomy for the analysis of concepts relating to process safety.

2 Methods for Concept Map Analysis

Several different techniques have been used in the past to assess concept maps. Different scoring techniques assess different elements of conceptual organisation and understanding. Some of the scoring techniques are based on assigning points for specific characteristics or components of a concept map, which can be grouped under quantitative approach, while others assess concept map qualitatively. Broadly, there are six systems that can be categorised in the former approach which includes; the weighted component scoring system; holistic scoring system; map comparison scoring system; combination method of component scoring and map comparison system; combination method of component scoring and holistic scoring system; as well as categorical scoring system.

In the weighted component scoring system, researchers score concept maps originally based on number of concepts, links, cross-links and hierarchies as suggested by Novak and Gowin (1984). This was further developed later by other researchers (Barenholz and Tamir, 1992; Heinze-Fry and Novak, 1990; Markham *et al.*, 1994; McClure and Bell, 1990; Nakhleh and Krajcik, 1991; Roth and Roychoudhury, 1992; Turns *et al.*, 2000; and Wallace and Mintzes, 1990) by either adding new features to the initial version or modifying it. In the holistic scoring system, researchers aimed at pursuing the possibility of evaluating concept maps as a whole, Besterfield-Sacre *et al.* (2004) analysed comprehensiveness, organisation and correctness of a map based on three point scale rating.

Goldsmith *et al.*, (1991) and Acton *et al.* (1994) compared students' concept maps in terms of the likeness of concepts and their adjacent concept, as well as the links to a criterion map. In regards to the combination method of component scoring and map comparison system, Ruiz-Primo and Shavelson (1996) scored three criteria of the concept maps; total proposition accuracy score, salience score and convergence score. This system was explored earlier by other researchers who applied different variations (Champagne *et al.*, 1978; Beyerbach, 1988; Anderson and Huang, 1989; Hoz *et al.*, 1990; Mahler *et al.*, 1991; and Schreiber and Abegg, 1991).

Some researchers have experimented with the combination method of component and holistic scoring system. For example, Jablokow *et al.* (2015), analysed undergraduates' concept maps using twelve traditional metrics (which among others include total number of concepts, hierarchies and links, map density and complexity, link similarity and closeness index) and four holistic metrics (namely dominant structural pattern, comprehensiveness, organisation and correctness). Nonetheless, in the categorical scoring system, (Lourdel *et al.*, 2007; Segalàs *et al.*, 2008; and Shallcross, 2013) concept maps are analysed by grouping each concept to its relevant categories to present students' appreciation around a study domain.

In the qualitative approach, (Kinchin and Hay, 2000) proposed to extract three types of structure from concept maps; spokes, chains and nets to indicate whether students demonstrated rote learning or meaningful learning in their study domain. Another alternative to that was developed by Liu *et al.* (2005), where a set of algorithms to perform links analysis were developed in order to identify the misconceptions of the students. The study compared links of each concept of students' maps with the links of each concept of a teacher's map.

The current study is aimed at developing a more robust method to define the categories, into which the individual concepts of a concept map might be classified. We do this by having three different assessors to analyse each concept map, and then analysing the extent to which the assessors agree or disagree with one another. Using the novel three-way tables, the concept types which are prone to disagreement can be identified, and then the categories more refined.

3 Methodology

Second year chemical engineering students were given 30 minutes activity to prepare a concept map based around the domain "Process safety". In the previous year, they had received extensive training in the use and creation of concept maps and had be required to prepare several concept maps on topics ranging from "mobile phones" to a high-speed rail accident. The students were not given any concepts or joining words, just the domain. They were expected to prepare maps of at least 25 concepts without knowing the categories that they would be assessed on, as the development of the categories' taxonomy were done by assessors after the activity.

A total of 103 student concept maps with the domain "process safety" were analysed for this present study. The maps were most well-formed with the propositions usually indicated by arrows showing how the joining words linked the adjacent concepts. Here, it is worth noting that the maps were completed in the English language although at least half the class were non-native English-speakers.

In his work looking at analysing the concept maps of students using safety incident case studies Shallcross (2013) proposed the use of six categories into which individual concepts featured in students' maps could be classified (Table 1). Later he proposed the use of eight categories for concepts maps with "Process and personal safety" as the domain (Shallcross, 2015). This was the first work to use concept maps to attempt to assess student and cohort learning of engineering safety concepts. The categories covered the entire range of concepts that might be encountered from potential hazards, and preventative measures that can be put in place to maintain safety, to the potential consequences of any incident. Another category was defined that considered the consequences of any event. Education and training, and actors and stakeholders were two other categories that were included. The final category "environmental" was included in response to the significant number of concepts that could not be assigned into any other category, but which had a definite association with the environment and the specific environmental impacts of any incident. Because of the very large number of concepts that relate to preventative measures that can be taken to reduce hazards and the likelihood of incidents, Shallcross proposed the use of two distinct categories, the first relating to physical preventative measures, and the second relating to non-physical, but more procedural preventative measures.

Categories		
Safety Case study; Shallcross (2013)	Process and Personal Safety; Shallcross (2015)	Process Safety; This study
1. Context 2. Incident Description 3. Causes 4. Consequences and Aftermath 5. Lessons Learned 6. Actors and Stakeholders	1. Preventative measures (physical) 2. Preventative measures (non-physical) 3. Consequences 4. Actors and Stakeholders 5. Education and Training 6. Potential Hazards/Causes 7. Incident Response 8. Environmental	0. Irrelevant/ Unrelated 1. Potential Hazards 2. Preventative - physical 3. Preventative - non-physical, procedural 4. Consequences and Outcomes 5. Incident Response 6. Education and Training 7. Actors and Objects 8. Ideal and Values 9. Others

Table 1: Taxonomy of Safety Categories used in the assessment

In the current work, we have based our categories on the work of Shallcross but have replaced his "Environmental" category with "Ideals and Values". In our first iteration of the taxonomy, we included a ninth category "Others" which was designed to capture all those concepts that are relevant to the domain but do not fit well within any category. After performing an analysis of the concept maps we included another category "Irrelevant /Unrelated" to address the not insignificant number of concepts that were completely irrelevant to the domain. Table 2 provides more details of the categories that are proposed for the present study.

In this work three assessors independently analysed each of the concept maps applying the taxonomy of Table 2 to allocate each concept to one of the ten categories. One of the assessors is a professor of chemical engineering who has experience in industry and expertise in process safety. The second assessor is a PhD student who has degrees in chemical engineering and process safety, while the third assessor has no formal background or experience in engineering, but has experience in using concept maps. An analysis of agreement and disagreement between assessors and validity of newly developed categories' taxonomy was conducted. We interpret agreement as identical responses on the same concept for all assessors under similar assessment conditions (using the similar categories guide and procedures for assessing similar concept maps). Disagreement occurs when the assessors had different responses on the same concept under similar assessment conditions. Whereas, validity is used to ensure that the new developed categories' taxonomy legitimately measures students' understanding.

The assessment steps started with the development of ten categories' taxonomy as a first draft for process safety domain. As shown in Figure 1, the assessment process involves two main phases. In the first phase, all three assessors used the first draft to assessing 51 students' concept maps (set 1). Then, the assessors' responses were analysed, where all agreement and disagreement were identified and analysed. Based on the disagreements in the responses, discussions were carried out between all assessors to revise the categories' taxonomy. Another assessment was conducted (second phase) to validate the results obtained from the first phase. In phase two, the assessors used the revised categories' taxonomy to analyse 52 students' concept maps (set 2), after which, the assessors' responses were analysed.

	Category	Meaning	Example of concepts
0	Irrelevant/ Unrelated	Concepts which are not precise/unclear or are insignificant and require further explanation. Usage of terms which are not appropriate to describe the concepts in the domain.	chronology, results, non-often, low, high, fuses, electric circuit, form, purpose
1	Potential Hazards	A source or a situation with potential for harm, damage or adverse effects (health effects to people, losses to property/equipment, or to environment). Potential hazards include dangerous objects, harmful substances and materials, sources of energy, unsafe conditions, processes, unsafe practices/ actions, human factors and behaviours.	wet floor, working from heights, malfunction equipment, welding, electrical hazards (frayed cords, missing ground pins), confined spaces, vapour and fumes from welding, flammable materials (solvents), extreme temperatures, ergonomic hazards (vibration, frequent lifting), unguarded machinery, human error (negligence, ignorance)
2	Preventative – physical	Physical equipment that protects personnel or process from workplace hazards, or during non-routine operations and emergencies, help avoid injuries, illnesses and incidents.	alarm (to indicate things getting out of control), barrier, PPE (safety harnesses, anchor points, lanyards), horizontal lifelines, flare, fire sprinkler
3	Preventative – non-physical, procedural	Policies, procedures and practices/actions that protect personnel or process from workplace hazards, or during non-routine operations and emergencies, help avoid injuries, illnesses and incidents.	SOP, maintenance, design, communicating with supervisors, reporting near misses or incidents, no smoking, hazard control plan, redundancy
4	Consequences and Outcomes	The effects of an unplanned event (occurrence or change of particular set of circumstances)/incidents resulting in or having a potential for injury, damage or other loss to people, property, infrastructure and processes The outcomes/ results of action/materials occurring earlier (positive/negative)	gas leak, fire, costs and liability, blemished reputation, death, punishment of breaking rules, safe operation, cost, minimise loss, bonus, profit
5	Incident response	The action or involving the usage of equipment/procedure of responding, organising, coordinating and managing of available resources after an imminent event to mitigate or minimise the impact of the event or damage to people, property, infrastructure and processes	evacuation, first aid, emergency assembly point, fire water system, emergency shut down procedures/equipment, medical treatment, containment/dikes, fire extinguisher
6	Education and Training	Process to equip/maintaining personnel with knowledge and skills, awareness, understanding and know-how required to work safely, identify hazards, report, respond and mitigate the impact of incidents	evacuation drill, awareness training, worksite demonstrations, promoting good work practices, case studies
7	Actors and Objects	People, institutions including companies, government and government agencies, stakeholders that have influence in the domain Objects - general description of equipment, machineries, materials which are not belong to the other categories	workers, society, management, equipment, methanol tanks, computers
8	Ideal and Values	Principles or standards of behaviour/ attributes that are important to the domain	responsibility, commitment, ethics, sustainability, reputation, safety culture, reliability, honesty

Category		Meaning	Example of concepts
9	Others	Relevant/significant but inapplicable to any of the category of 1 to 8	location

Table 2: Categories' Taxonomy for concepts related to process safety

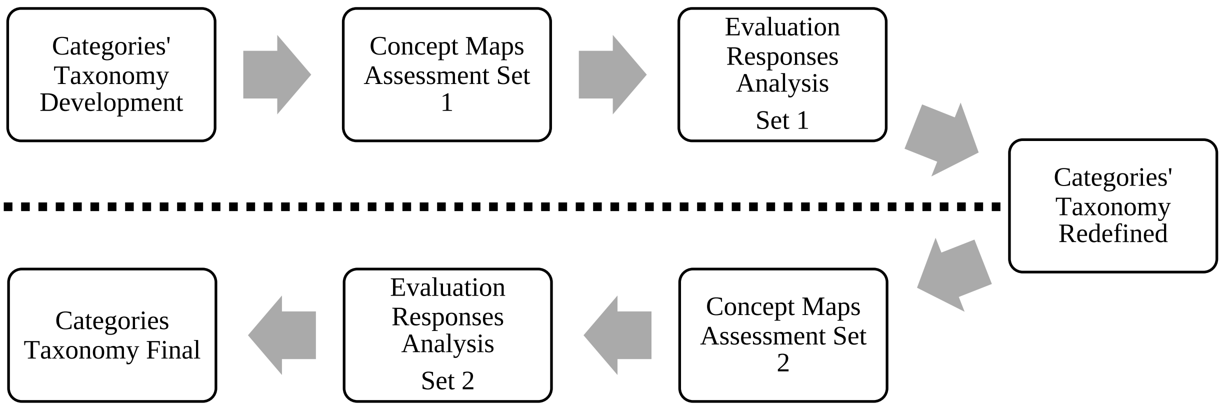


Figure 1: Assessment flow

4 Study Results

Results of this study provide a new method to validate the definition of proposed concept category as well as a new procedure for presenting the information. After the completion of the assessment, the assessors sat together to discuss, evaluate, and provide feedback on the concept categories' taxonomy. The focus of the discussion was on the evaluation of the concept categories' taxonomy. Assessors shared their opinions regarding the strengths and weaknesses of the concept categories' taxonomy. It was concluded that that categorising concepts into the proposed concept categories depends to a certain extent, on the level of subjectivity among assessors.

Based on the observation of assessors' responses and the discussion, some concepts could be further categorised into several categories depending on the context of the proposition. For example, the concept of 'equipment' can be classified into the categories 'Potential Hazards' (Category 1); or 'Preventative-Physical' (Category 2); 'Consequences and Outcomes' (Category 4); or 'Actors and Objects' (Category 7). As illustrated in Figure 2, concept 'equipment' in the left box was classified in category 'Preventative-Physical' (Category 2) while in the right box, the concept was assigned into category 'Consequences and Outcomes' (Category 4). Thus, assessors agreed that interpretation is crucial to determine the most appropriate category for particular concepts that have several different meanings, as shown in the example above. Moreover, the assessors were trained to analyse this type of concepts according to the context to understand the intended meaning, in order to correctly categorise it. Category 9, "Others" was used by the assessors when it became very difficult to readily assigned into one of the more defined categories of 1 to 8. The concept "location" is an example of a concept with a valid place in a concept map on "process safety" but which is difficult to assign into one of the eight main categories. This would be assigned to Category 9.

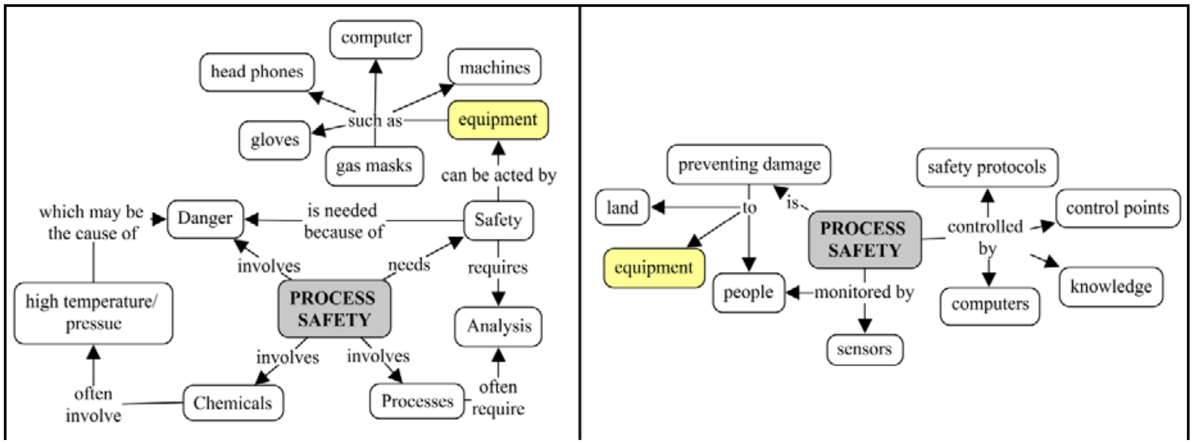


Figure 2: Samples from students' concept maps showing example of concept 'equipment'

Next, responses collected from the assessors were presented in a newly developed three-way table (Figure 3). The three-way table exhibits regions in which the assessors' responses were compared against each other. One of the advantages of presenting assessors' responses in a three-way table, is that it clearly shows the number of agreements and its total, as well as the number of disagreements between the assessors. This is a crucial observation in validating the concept categories' taxonomy. Figure 3 is used to introduce the reader to the new method of presenting data using just three categories. The table is designed around three interlinked tables, the one table showing how the responses from Assessor A compare with those of Assessor B, another table showing the comparison between Assessors B and C, and the third (and highlighted) table comparing the responses of Assessors A and C. In the upper example, we see that on 16 occasions, both Assessors B and C agreed that a concept should be assigned to Category 2, but on 8 occasions, Assessor A recommended that a concept be assigned to Category 1 while Assessor B concluded that the same concept would better be categorised into category 3. Considering now the lower part of Figure 3, some of the highlighted features include that Assessor B assigned 22 concepts in total to Category 1, while Assessors A and C agreed on 79 occasions with one another.

Now consider Figure 4 which presents the full set of data for 103 concept maps, independently analysed by the three assessors. We note that the number of the distributions in the agreement boxes were almost comparable across all categories for all assessors. This suggests that the techniques used to evaluate the concept maps was appropriate and reproducible. Although the agreement responses between assessors were remarkably similar, especially on Category 3 (Preventative –non-physical, procedural), Category 4 (Consequences and Outcomes) and Category 7 (Actors and Objects), this study also explores the categories in which assessors had many disagreements. For example, the concepts of 'fire-sprinkler" and 'flare' are planned equipment which function to protect personnel or process from incidents as prevention (Category 2) rather than as a response (Category 5) to incidents. As a result of this confusion, assessors had disagreement in these two categories in both phase 1 and phase 2 evaluation. This confusion however was solved during the discussion and knowledge sharing session among assessors.

In addition, three-way table also presents the total number of responses for every category by the assessors. This was important in this study as one might predict that ideally every assessor must have similar total number of responses for every category if they have 100% agreement on the categorisation. However, the results show a different trend. For example, the total responses of Assessor A for Category 1 is 338, while for Assessor B and Assessor C it is 197 and 252, respectively. Also, it is worth noting that, for summation agreement score between Assessors A and C is higher (1824 responses) compared to summation agreement between Assessors A and B (1549 responses) and Assessors B and C (1658 responses). We assume that this is because Assessor B has no formal education on process safety domain. Although this study expected assessors to have high agreement and responses, assessors might have their own understanding and interpretation on certain concepts. Hence, this explains the disagreement between assessors and also variation observed in the results. Another contributing reason could be that the students' concept maps were fragmented and scattered structurally, with incomplete proposition (without linking words) thus, making the marking process more challenging.

Although we do not directly measure student understanding in this study, we can see from the summation box (indicated by dark grey) that assessors have classified significant numbers, about one fifth of students' concepts in category preventative – non-physical, procedural (Category 3), followed by category consequences and outcomes (Category 4) for more than 14%. It shows here that students understood the non-physical preventative measure in the process industries as well as the consequences and potential outcomes. However, the students appeared not able to correlate strongly on the importance of education and training in maintaining safety, as shown only 5% of students' concepts were classified in Category 6.

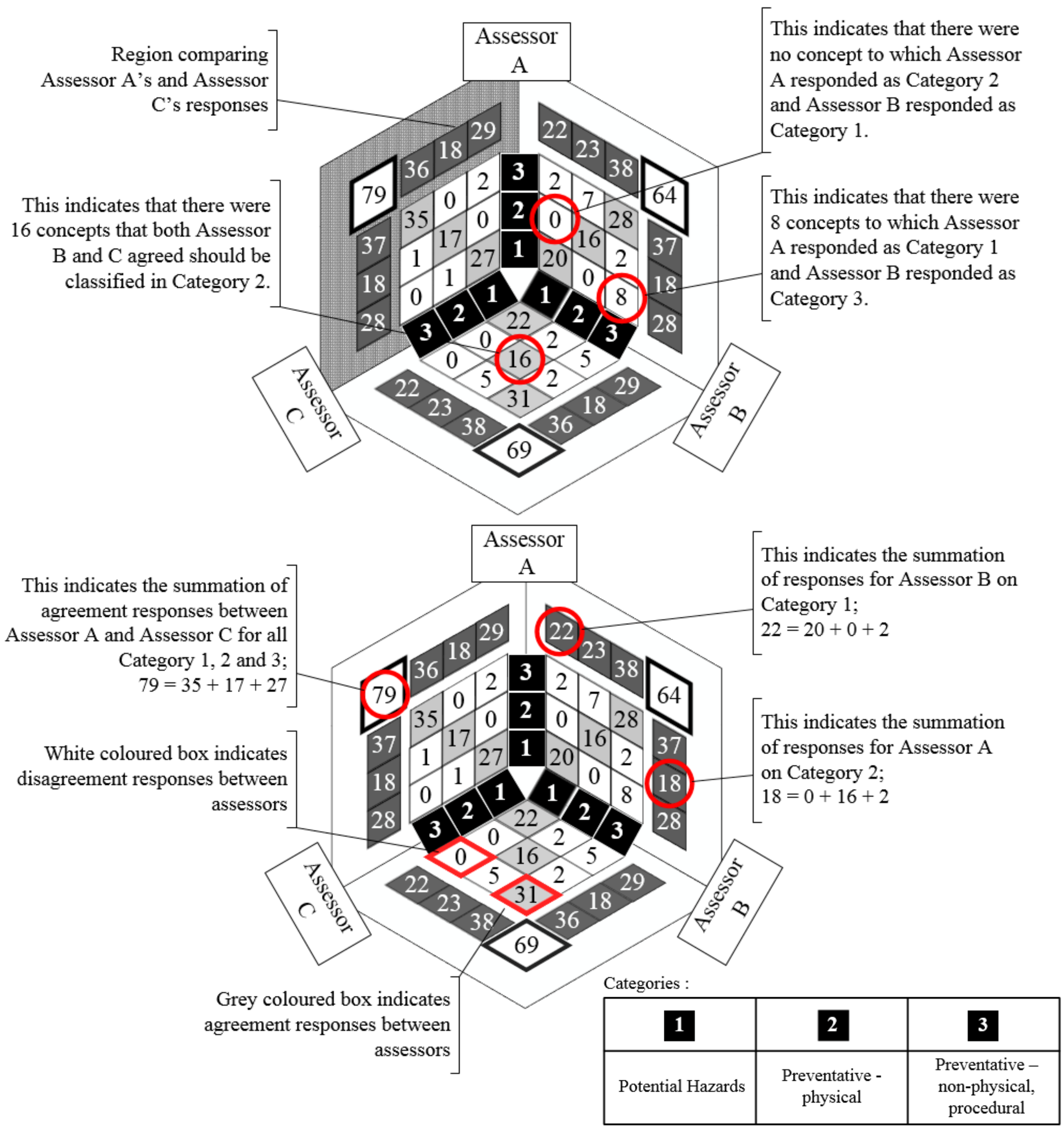
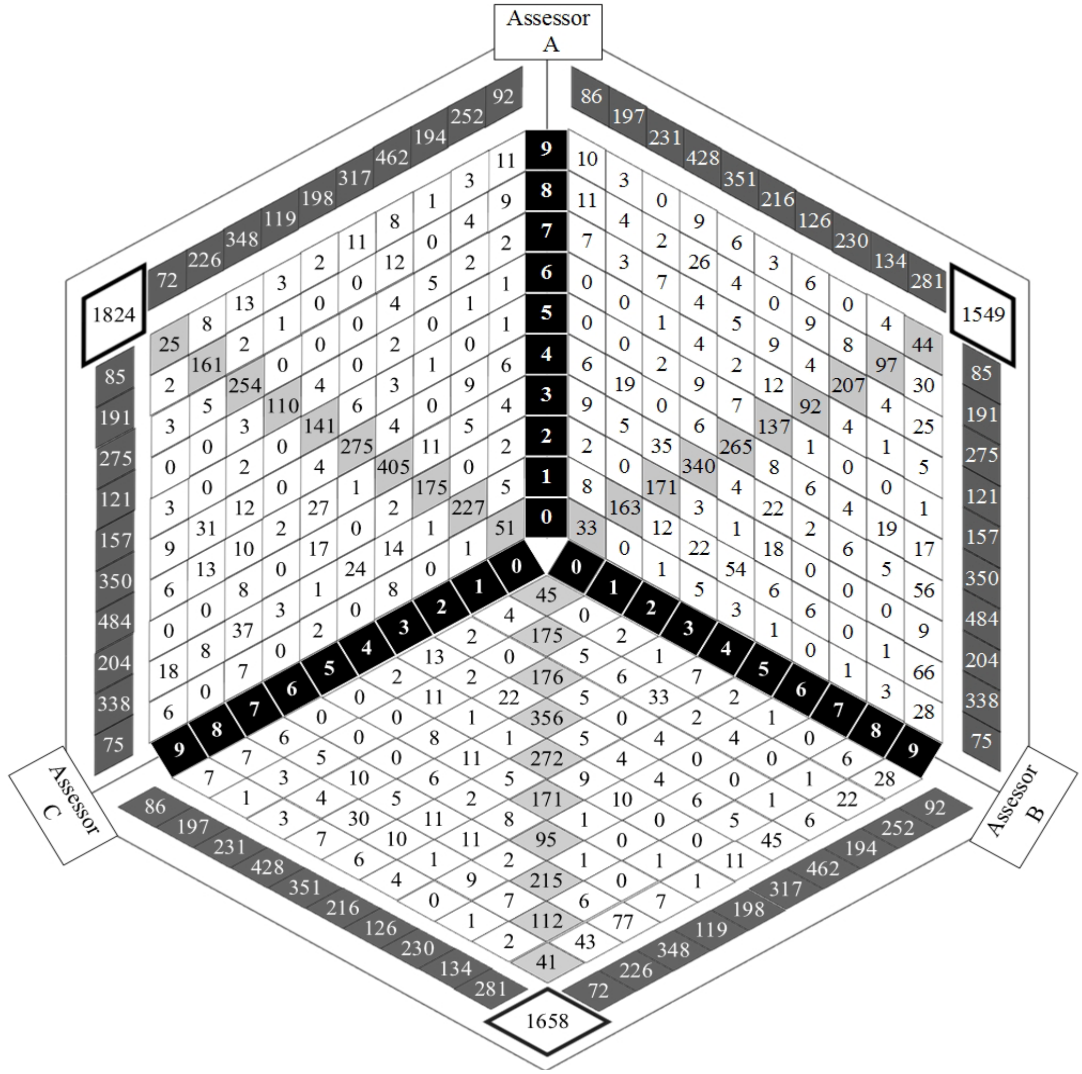


Figure 3: Three-way table of responses between the three assessors



Categories:

0	1	2	3	4	5	6	7	8	9
Irrelevant/ Unrelated	Potential Hazards	Preventative - physical	Preventative – non-physical, procedural	Conseque-nces and Outcomes	Incident Response	Education and Training	Actors and Objects	Ideal and Values	Others

Figure 4: Three-way table of overall responses of students' concept maps (n=103)

5 Concluding Remarks

Ensuring that chemical engineering students graduate with a sound understand of the importance of process safety is vitally important. Assessing student knowledge around important concepts in process safety can be difficult if the topic is integrated throughout the curriculum without one single subject or unit being a focus. We believe that the use of concept maps is a valuable tool in assessing student and cohort knowledge of process safety. Hence, this would be beneficial to guide instructors in teaching process safety in the future as it able to identify attributes that students may have struggled with in the class.

In developing a method to assess student concept maps for process safety we have developed a new tool. This tool, the three-way table, allows concept map categories and definitions to be better defined by identifying the particular situations when three assessors disagree with how particular concepts should be classified. The tool is an excellent way to focus discussions between the three assessors in order to better define the categories. This novel approach leads to a more robust and reliable taxonomy, and has been successfully applied to the developed a taxonomy for the domain of "process safety".

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