Content analysis of 13 dimensions to support student teachers’ PCK in the environmental chemistry textbooks

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Abstract. Environmental chemistry courses in the undergraduate program is an important subject to link many concepts of chemistry and environmental sciences. Content analysis was used by the researchers to determine textbooks compatibility using 13 dimensions of content knowledge. We examined three textbooks often used as references to discuss environmental chemistry issues in the courses. We specify the analysis in the chapter on wastewater. This chapter is a very important chapter to develop trainee teachers’ competencies either as teacher or scientist. We labeled each book with codes of R, S, or T with Kappa coefficient of 82.7, which means no significant differences in perception about observed aspect among researchers. The textbooks only present material-related subjects. Not all dimensions in the content knowledge contained in the textbooks, only dimensions related to basic knowledge.

1. Introduction

Environmental chemistry is the scientific study of chemical and biochemical phenomena occurring in nature. It can be defined as the study of the sources, reactions, transports, effects, and the fate of chemicals in the air, soil, and water environment and effect of human influences on them. It is an interdisciplinary science includes the atmospheric, aquatic and earth chemistry, and relies heavily on analytical chemistry, and other fields of science [1]. Environmental chemistry is important to be studied by pre-service chemistry teachers to study issues related to global environmental issues, and hopefully, they can explain the issue of environmental issues with the concept of chemistry [2].

Wastewater discharged from the households, industries, and various places generally contain harmful substances to human health and environment. Characteristics of wastewater vary depending on the locations, populations, industries, land usages, groundwater level, and level of separation between storm water and sanitary water. Liquid waste is divided into three categories: domestic wastewater include: liquid waste from the kitchen, bathroom, laundry and others; sanitary wastewater includes: domestic wastewater, commercial, office, and similar facilities; and industrial wastewater comes from industry. The properties of industrial wastewater vary depending on the raw materials used, the use of water in the process, and the additives used during the production process[3]. Environmental pollution, especially wastewater, currently is not just a national problem but also a global issue. The problems caused by environmental pollution cannot be separated with toxicology (the understanding of the adverse chemical effects of living organisms). In the last decades, heavy metal toxicology, become the great concern in terms of the health effects [4]. From a toxicological
point of view, heavy metals can be divided into two types. The first is the essential heavy metal, where their presence in a certain amount is needed by living organisms, but excessive amounts can cause intoxication. Examples of these heavy metals are Zn, Cu, Fe, Co, Mn, and so forth. The second is the unimportant or toxic heavy metal, where their presence in the body is unimportant or may even be toxic, such as Hg, Cd, Pb, Cr, As, and others [3].

The chemistry teachers should try to explain the environmental issues using chemical approach. The 21st-century learning requires the teachers to connect their knowledge with the actual phenomena or issues, so students can understand and apply it. The environmental issue became the world’s discussion on the next 10 or even 50 years as humanity progresses [5]. The teachers should have the good content knowledge to explain to their students according to the demands of 21st-century learning [6]. The chemistry teachers should help students to understand the content of scientific knowledge. In line with this, the chemistry teachers must have sufficient academic competence, such as the mastery and understanding of the content as well as the pedagogical skills. Content and pedagogical knowledge should be integrated into learning to create new knowledge [7]. It is defined as Pedagogical Content Knowledge (PCK). Shulman (1986, 1987) stated the PCK is a special knowledge possessed by teachers on how to teach certain content to specific learners with the strategies to achieve understanding [8]. PCK can also be described how the teachers teach the certain subject by accessing what they know about the subject matter, what they know about the learner, what they know about the curriculum related to the subject, and what they believe as the good way of teaching for certain context. Thus, PCK is very important in the learning process and should be owned by the chemistry teachers.

Textbooks used in higher education chemistry lectures should be evaluated if there any content that can improve the ability of pre-service teachers’ PCK. Textbooks used in lectures, especially environmental chemistry, discuss the concepts of chemistry related to global environmental issues should be analysed how much the contents can improve the pre-service chemistry teachers’ PCK [9]. The content analysis was used to assess the content of the textbooks. Content analysis is a technique to analyse and understand textbooks. It is the investigative technique attempts to describe the textbooks objectively, systematically and quantitatively [10]. According to H.D. Laswells, this analysis is as called the quantitative semantics. Researchers can learn a lot about the community by analysing newspapers, magazines, television programs, or music. The researchers who use content analysis does not study people, but their communication. Content analysis of the textbooks is important because the textbook is one of the main components in learning, and very influential in the development of pre-service teachers’ knowledge. In this research, the content in the textbooks refers to the 13 dimensions of PCK [11].

2. Method
The content analysis was used in this research, data were analyzed using qualitative and quantitative analysis. Three books were used as the samples, those were most widely used references to study the environmental chemistry[12]. The chapter on wastewater was the focus of the analysis. This chapter was very important to develop pre-service teachers’ competencies either as teacher or scientist. Those books were issued by publishers from Yogyakarta, Jakarta, and New York. Those books then labeled with R, S, and T to simplify the analysis process. Content analysis was conducted based on the 13 PCK dimensions proposed by Bucat: (1) Knowing more “facts”; (2) Understanding the role of models and theories in chemistry; (3) Alternate between the macro world and related submicroscopic models; (4) Quality of images at the sub-micro level; (5) Understanding the language of chemistry; (6) Operate at multiple levels of explanation, rationalization and prediction; (7) Memory banks of episodes; (8) Ability to distinguish between demonstrable knowledge and arbitrary knowledge; (9) Appreciation of the sources of our knowledge; (10) Recognition of the place and role of chemistry in society; (11) Understanding what chemists do; (12) Knowing what we do not know; and (13) Interlinking learning[11]. The contents from those books were analyzed to find out what extent the 13 PCK dimensions were supported. Content
analysis was performed by researchers and researchers’ assistants, where reliability and validity were concluded from the Kappa coefficient. The researchers divide the 13 dimensions of PCK and then looked out what the extent the contents of the books can improve the pre-service chemistry teachers’ PCK. The results of the analysis from the researchers then compared to find out the interpreter reliability [13]. The reliability was determined by using following formula:

\[
k = \frac{Pr(a) - Pr(e)}{1 - Pr(e)}
\]

\[Pr(a) = \text{The percentage of consistent measurements between readers}\]
\[Pr(e) = \text{The percentage of consistent measurement changes between readers}\]
\[k = \text{The Kappa Coefficient} [14]\]

**Table 1. Interpretation of the Kappa Coefficient.**

| Kappa.       | Interpretation     |
|--------------|--------------------|
| <0           | Poor agreement     |
| 0.00-0.20    | Slight agreement   |
| 0.21-0.40    | Fair agreement     |
| 0.41-0.60    | Moderate agreement |
| 0.61-0.80    | Substantial agreement |
| 0.81-1.00    | Almost perfect agreement |

3. Result and Discussion

**Table 2. 13 dimensions of content knowledge in environmental chemistry text books.**

| No | Content Knowledge Dimension                                      | R   | S   | T   |
|----|------------------------------------------------------------------|-----|-----|-----|
| 1  | Knowing more “facts”                                            | (32)| (20)| (29)|
| 2  | Understanding the role of models and theories in chemistry;      | (60)| (43)| (48)|
| 3  | Alternate between the macro world and related submicroscopic models | (1) | (1) | (2) |
| 4  | Quality of images at the sub-micro level                         | (37)| (19)| (28)|
| 5  | Understanding the language of chemistry                          | (1) | (1) | (2) |
| 6  | Operate at multiple levels of explanation, rationalization, and prediction | -   | -   | -   |
| 7  | Memory banks of episodes                                         | (9) | (3) | (3) |
| 8  | Distinguish between demonstrable knowledge and arbitrary knowledge | -   | -   | -   |
| 9  | Appreciation of the sources of our knowledge                     | -   | -   | -   |
| 10 | Recognition of the place and role of chemistry in society        | (8) |     | (9) |
| 11 | Understanding what chemists do                                   | -   | -   | (8) |
| 12 | Knowing what we do not know;                                     | (34)| (23)| (29)|
| 13 | Interlinking learning                                            | (10)| (5) | (7) |

We found differences in content knowledge in the three books. In table 2, in the R, S, and T books have differences in content knowledge. The R and T books have the same qualities of content knowledge which was almost good, while the S book has the lowest content knowledge. There were differences in the dimensions contained in the R, S, and T books. There were dimensions existed only on the T, or only on the R alone. For the alternate between macroscopic world and related submicroscopic models were found in all books. The heart of chemistry is our use of models/theories at the level of atom molecules to make sense of observable phenomena.
Alternate Between the Macroscopic World and Related Submicroscopic Models

One of the PCK dimensions became the point needed to be described was the relationship between macroscopic and submicroscopic levels. In the R and S there was the explanation as follows:

![Figure 1](image1.png)

**Figure 1.** Interaction between soap with oils, fats, and other water-insoluble organic materials. (a) Illustration in the R and S books. (b) Illustration in the T book.

At the macroscopic level, the soaps and detergents ability to remove fats and oils were well known. At the sub-microscopic level, soaps were the salt of high fatty acids, such as sodium stearate, C$_{17}$H$_{35}$COO-Na$^+$. Soap washing actions were generated from its emulsifying power and the ability to reduce water surface tension. This concept can be explained using the dual nature of soap anions. The stearate consisted of carboxyl ions as the heads, with long hydrocarbons as the tail. In the presence of oil, fat, and other insoluble organic matter, the “tails” dissolve in organic matter, while the “heads” remain in the aqueous solution. Soap emulsifies or suspends organic matter in water. Soap anions form particles of micelle colloid particles, which the hydrocarbon “tails” anions are clustered within small colloidal particles and the “heads” of the carboxylic anions are located on the surface of colloidal particles. In the T book—which uses alkyl benzene sulfonate—, and in the R and S—which use sodium stearate (C$_{17}$H$_{35}$COO-Na$^+$)—, the process of interactions were described in Fig. 1a and 1b. Both useful to explain macroscopic phenomena and illustrate them in sub-microscopic levels.

**What chemists do?**

![Figure 2](image2.png)

**Figure 2.** Chemotherapy Agents to Treat Mercury Poisoning

Dimensions of “What chemist do” only existed in the T book, which explains how a chemist should do if faced with certain phenomena. The T book provided illustration about mercury poisoning. Chemists were expected to know the right treatment for each case. Some of the chemotherapy agents used to treat mercury poisoning, such as N-acetyl-DL-penicillamine, or British Anti-Lewisite (BAL) were shown in Figure 2. These agents enter the cells, convert the intracellular methyl mercury into a mobile complex that ready to diffuse out of the cells, and excreted through urine and feces. The British Anti-Lewisite (BAL) was very effective to deal with inorganic mercury poisoning but cannot be used to treat methyl mercury poisoning. The T was the
only book gave the dimension “what chemists do” by providing information on how the chemists deal with pollutants. The other books presented only the dangers without describing how the chemist’s act. The R book described the treatment of mercury poisoning, as the chemists’ way to act when the same events occur.

The result of the reliability analysis obtained the Kappa coefficient of .827 and p-value of 0.000. This result means p-value <alpha. The alpha of .05 was used in this research. This result means significant Kappa test result, so there were no perception differences of observed aspects among researchers [13] [14].

Some concern regarding the teachers’ PCK was obtained from our analysis. The 13 dimensions of PCK were the basic things to be mastered by teachers to cope with the challenges of the 21st-century learning and as the basis to become teachers who teach their students well. The analyzed textbooks have supported the majority of the PCK's dimensions, but there were several PCK not yet covered in the textbooks. The operating at multiple levels of explanation, rationalisation, and prediction; distinguish between demonstrable knowledge and arbitrary knowledge; recognition of the place and role of chemistry in society; and understanding what chemists do by lecturers during the learning process needs to be added to the S book [11] [16]. Those dimensions are rarely found in chemistry textbooks, especially on the topic of environmental chemistry [17].

Addition of the operate at multiple levels of explanation, rationalisation, and prediction help the students to understand multiple representations and can connect as macroscopic, symbolic, and submicroscopic levels. Distinguish between demonstrable knowledge and arbitrary knowledge have relationships with the bank of memories to determine the provable knowledge or unnecessary results of research implied with phenomena in the chemistry [11]. Recognition of the place and role of chemistry in society requires teachers’ knowledge to relate events in social context and their relation to the chemistry[18]. Appreciation of the sources of our knowledge helps the teachers to recall what is known and try to discuss more deeply, this dimension give students more cognitive conflict [15]. And “what chemist do” provide education about what we should do in facing cases or events as the chemist [12, 19].

Overall, the R and T books have almost the same quality of contained PCK while the S book contained very little PCK. The R book has more characteristics on the understanding of symbolic and chemical reactions while the T book has the power to gain a chemical context in society.

**Conclusion**

The textbooks only present material-related subjects. Not all dimensions of PCK contained in the textbooks. There were only dimensions related to basic knowledge such as: knowing more “facts”; understanding the role of models and theories in chemistry; understanding the language of chemistry but lacking in additional knowledge; understanding and chemistry in context. While the useful dimensions to enhance thinking and understanding skills, such as: operating at multiple levels of explanation, rationalisation, and prediction; distinguish between demonstrable knowledge and arbitrary knowledge; appreciation of the sources of our knowledge; and understanding what chemists do was not contained in the textbooks. Thus, while they can be used as the reference to studying environmental chemistry, the students are expected to use additional sources for dimensions not yet contained in the textbooks. There were no differences in perception about observed aspects among the researchers.
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