Concept Maps: Theory, Methodology, Technology
Proc. of the Fifth Int. Conference on Concept Mapping
Valletta, Malta 2012

USING CONCEPT MAPS TO ASSESS AND CATEGORIZE ELEMENTARY PRESERVICE TEACHERS MISCONCEPTIONS

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Abstract. This research study reports on the use of concept maps as an assessment tool to investigate elementary pre-service teacher knowledge about dissolving. Propositions from pre/post concept maps were scored using the total proposition accuracy scoring technique (TPA) and were also used to classify concepts as scientific or spontaneous using Vygotsky's theory of concept development. Vygotsky (1986) described spontaneous concepts as un-unified and employing concrete, factual groupings, while scientific concepts are organized hierarchically and have a system. After the instructional intervention, statistically significant improvement was shown on a paired sample t-test ($t = -4.154$, $p<.001$) and many spontaneous concepts which appeared on the pre-concept maps, were either reduced or eliminated (i.e., disappearing and melting). Although medium statistically significant gains were noted for the t-test, these findings suggest that the elementary pre-service teacher science content knowledge about dissolving is weak as the average TPA score was less than two accurate propositions ($n=49$) and many teachers continued to hold the same misconceptions as reported for K-12 students in previous studies (Calik & Ayas, 2005; Kind, 2004; Kikas, 2001; Ebenezer & Erikson, 1996). This research also suggests the teachers have well-developed idiosyncratic conceptions about dissolving that will take considerable time and effort to reduce and/or eliminate. Recommendations to improve the content knowledge for elementary pre-service teachers include: adding a non-majors chemistry course, focusing on the particulate nature of matter during methods course work, and using screening practices to eliminate pre-service teachers who display weak science knowledge about the subjects they will teach to children.

1 Introduction

The use of concept maps for assessing conceptual understanding of students was introduced by Novak in 1972 (Novak & Musonda, 1991). Novak and Canas (2008) have pointed to the advantages of using concept maps for understanding the complex knowledge structure exhibited by students which can include higher order thinking as well as lower order thinking. Concept maps have attracted the attention of other research groups that set out to address the pragmatic use of concept maps by developing design and scoring methods for the use of concept maps for assessment of student conceptual understanding (Ruiz-Primo, 1996, 2000;Yin et al., 2005).

While there have been numerous research studies that address student understanding of important science concepts such as dissolving, there has been only few that address common scientific understandings held by elementary pre-service teachers (Dawkins, 2008). Common student misconceptions reported in the literature include confusing dissolving with melting (Calik, 2007; Ebenezer & Erickson, 1996; Kikas, 2001; Othman et al., 2008; Valandis, 2000) and confusing dissolving with disappearing (Calik & Ayas, 2005; Kikas, 2001; Longden, et al., 1991;). Only a few studies reported misconceptions involving pre-service teachers (Calik & Ayas, 2005; Calik, 2007; Calik, Ayas, & Cool, 2007; Valandis, 2000; Ruiz-Primo, 2000).

This research effort aims to address this gap in the literature by investigating conceptual understanding of dissolving by elementary pre-service teachers enrolled at a large university in the US. The purpose of this study is to assess conceptual understanding and identify the type of concepts held by the pre-service teachers. Specifically, this study investigated elementary pre-service teacher knowledge about dissolving and categorized pre-service teacher knowledge using Vygotsky's (1986) theory of concept development. That is, the scientific concepts and spontaneous concepts held by the pre-teachers were identified according to concept type.

2 Research Study

2.1 Research Design

The research methodology for this study involved a mixed-method approach. The quantitative research design utilized a pre-experimental research design-the one group, pretest-posttest design. The research design was informed by a pilot study completed during the previous year. The qualitative research method used was a thematic analysis approach (Boyatzis, 1998; Braun & Clark, 2006). A forced-consensus model was used to identify and classify propositions as scientific or spontaneous concepts using the pre-service teacher concept maps. Each pre and post concept map was individually examined and marked as either a scientific or spontaneous concept. Spontaneous concepts are described by Vygotsky (1986) as lacking a unified system and employing objective-concrete, perpetual-factual groupings, while scientific concepts are characterized by use of a hierarchical organization system.

2.2 *Sample*

A total of 49 elementary pre-service teachers who were enrolled in a science method courses before the student teaching semester participated in the study. The students were elementary pre-service teachers enrolled in a university professional development school program. Three out of 49 pre-service teachers were male. The ethnicity of the participants in this study included: White (33); Hispanic (11); Asian (4); and African American (1) teachers. Only three pre-services teachers had taken a course in general chemistry. The majority of the elementary pre-service teachers (72%) scored an A or B in their conceptual physics course which was blocked for elementary teacher candidates instead of a general chemistry course taken by non-majors.

2.3 *Procedure*

This research effort used (1) pre/post concept maps; and an (2) instructional intervention. The concept maps were low-level directed concept maps that rely on students providing their own list of key concepts as well as linking phrases for making their own concept maps (Ruiz-Primo, 2000).

The instructional intervention used the 5E Model of constructivism in which the participants is first engaged with the content through a video clip of mercury and gold dissolution. This is followed by the exploration of the concept to be learned. The results from the learning experience were explained by the participants and additional information related to the lesson was added using direct instruction. The experience was elaborated using real-world connections (e.g., bone density, cooking) and the participants were evaluated. The scientific concepts associated with the learning experience included:

1. The process of making a solution takes place as a solute (usually a solid substance or one in a lower quantity) dissolves in a solvent (usually a liquid or the substance in greater quantity) to create a solution.
2. A solution is a special type of mixture which is homogeneous.
3. Solutions display optical clarity.
4. Dissolving is a physical change as opposed to a chemical change (one phase and substances do not react).
5. The process of dissolving begins when enough energy of enthalpy is vested into the system to break solute-solute particle intermolecular forces as well as solvent-solvent particle intramolecular forces (van der Waals forces).
6. The process of dissolving may be facilitated through stirring, heating, pressure, or concentration.
7. A hydration shell forms around the solute.
8. The process of dissolving is reversible using evaporation or distillation.

2.4 *Data Analysis Procedures*

The concept maps were scored by four science education experts using a forced consensus model in an effort to create a cooperative dynamic and make the best possible decisions for the study. That is, concerns were raised and resolved one-by-one. The method for analyzing and scoring of concept maps involved a total count of correct propositions as determined by the consensus of four experts (three science education faculty and one doctoral student). The same procedure was employed to classify concept map propositions as scientific concepts and spontaneous concepts using Vygotsky’s theory of concept development.

Total proposition scores on the pre and post concept maps were used to conduct a two-tailed paired sample t-test. SPSS 20 statistical program package was used to conduct the two-tailed paired sample t-test. Effect size was calculated using Cohen’s d statistic.

2.5 *Pilot Study Results*

Several changes were made as a result of the pilot study. Additional instruction about concept mapping was provided prior to pre-service teacher creation of concept maps and the concept maps were checked for completeness prior to submission (i.e., missing linking words and missing directional arrows). Changes were made to the instructional intervention such as emphasizing the particulate nature of matter and linking this micro-view of dissolving to the concrete learning experience. Finally, a forced-consensus scoring protocol using the *total proposition accuracy scoring (TPA)* method was employed. Prior to the study, pre-service teachers received thirty minutes of instruction for creating concept maps. In addition to instruction, the teachers completed group and individual concept maps to assist in their mastery of how to make a C-map. A C-map is created by the participant without the benefit of word banks, linking phrases, or templates. Each pre-service teacher completed a C-map prior to instruction (pre-concept map). One week following the three-hour instructional intervention, the teacher completed a second C-map (post concept map).

2.6 TPA Results for Paired Sample t-test using SPSS 20

Results for pre- and post-concept maps were analyzed using SPSS 20 statistical package to conduct a paired-sample t-test. The results for the paired t-test for the topic of dissolving are presented in Table 1. Results indicate a statistically significant difference exists between the pre/post concept map scores. The instructional intervention was larger for the post concept map (M=1.54, SD=1.722) compared to pre-concept map scores (M=.61, SD=1.201); t=-4.154, p=<0.001. The results are shown below in Table 1.

T	*P*	df	Mean(pre)	SD(pre)	Mean(post)	SD(post)	Effect size Cohen's *d*	N
-4.154	<0.001	45	0.61	1.201	1.54	1.722	-0.626	46

Table 1: SPSS Dissolving Results of two tailed paired t-test of pre and concept maps scores.

2.7 Results for Identifying Misconceptions about Dissolving Using Pre and Post Concept Maps

Results for the identification of pre-service teacher misconceptions for dissolving are shown in Table 2. Categorization of misconceptions identified in pre-service teacher concept maps with regard to dissolving show that the majority of misconceptions exhibited by pre-service teachers involved the following misconceptions:

- Dissolving involved a change of state (12%)
- Dissolving involved disappearance (12%)
- Dissolving involves the break-down of substances (13%)
- Dissolving involved the mixing or combining of two substances into a mixture (22%)
- Dissolving involved a chemical change (9%)
- Dissolving is affect by variables such as heat, physical agitation and concentration (11%)

After receiving a three-hour instructional intervention, some misconceptions, such as dissolving is melting were abandoned while other misconceptions were significantly reduced. Dissolving is disappearing decreased from 12% to 2%, dissolving is a change of state decreased from 12% to 6%. Other misconceptions proved to be more robust. Dissolving is mixing decreased from 41% to 27% and dissolving is when substances break down decreased from 25% to 18%. Dissolving involves a chemical change increased from 10% to 16%.

A small percentage of students developed scientific conceptions about dissolving including the instructed concept of formation of hydration shells in the process of dissolving (4%) and the concept that dissolving is affect by variables such as heat, physical agitation, and concentration increased from 11% to 28% on the post-concept maps. The scientific terms of solute and solvent as forming a solution was featured in 16% of the pre-service teacher concept maps.

Dissolving is…	Pre concept map	Post concept map
	frequency and percentage of concept or misconception	
when an item sinks to the bottom then dissolves	1 (1%)	0 (0%)
related to density	1 (1%)	0 (0%)
happens through osmosis	3 (3%)	0 (0%)
a substance is cut into small particles or particles are granules	3 (3%)	0 (0%)
when a solid is dissolved in a liquid	5 (5%)	0 (0%)
melting	7 (8%)	0 (0%)
a chemical change	9 (10%)	14 (16%)
combining or blending substances to form a mixture	20 (22%)	13 (15%)
breaking down a substance	13 (12%)	9 (10%)
involves a change of state	11 (12%)	5 (6%)
disintegrating, eroding, deteriorating, disappearing, gone, invisible, absorbed	11 (12%)	2 (2%)
when a solute and solvent come together and form a solution	0 (0%)	14 (16%)
forming a hydration shell	0 (0%)	6 (7%)
affected by stirring, heating, concentration	10 (11%)	24 (28%)
formation of hydrogen shell or is when small particles are surrounded by large particles.	0 (0%)	3 (4%)
Total	93 (99%)*	70 (103%)*

Table 2: Categorization of common misconceptions for dissolving derived from student concept maps (N=44). Percentages do not equal 100 due to rounding error.

2.8 Discussion for Using Instructional Interventions to Target Spontaneous Concepts Interfering with the Development of Scientific Concepts.

Very little content knowledge about the concept of dissolving was displayed on the pre-concept maps. Only the concept of heat or stirring affecting the rate of dissolving was mentioned in 10/93 propositions (11%). The number of correct propositions increased to 49% on the post-concept map where 44/87 propositions were coded as representing an accurate relationship between scientific concepts. The pre-concept map data shows 32 pre-service teachers (65%) created a pre-concept map with no correct propositions. After instruction, the number of post-concept maps with a score of zero was reduced to 14 (28%) which represents a large number of pre-service teachers who are not able to form even one accurate propositional relationship for the concept of dissolving.

As shown on the paired t-test, the mean number of correct propositions on the pre-concept map was less than one correct proposition per pre-service teacher (M=0.61, SD=1.201) and was less than two correct propositions for the post-concept map (M=1.54, SD=1.722). These results suggest the instructional intervention for the topic of dissolving did have a positive effect on pre-service teacher knowledge as measured using the TPA scoring method for concept maps. The effect size, as measured by Cohen's d, was medium for the instructional intervention (-0.626). Although this represents a statistically significant gain (t=-4.154, p=<0.001) given the target learning objectives for the instructional intervention, there remains a good deal to learned by the pre-service teachers about the topic of dissolving. It should not escape our attention that pre-service teachers must be scientifically literate in order to plan lessons which will help students learn about this important topic which is taught in grades 4-6 in the US. Scientific literacy requires the use of language, specifically academic vocabulary and the assignment of word meaning.

Vygotsky (1986) described the importance of language as the process that leads to concept development. First, he described the formation of spontaneous concepts which arise as a result of encounters with everyday concrete experiences (e.g., sugar dissolves in tea). If these experiences establish the lower boundary for instruction, then it is here that the starting point for instruction begins (zone of proximal development). Secondly, the academic vocabulary associated with dissolving (e.g., solute, solvent, solution) must be taught because it is not part of everyday language. Next, the abstract characteristics of the concept are taught as they not evident in the concrete experiences that accompany everyday life and require the help of an instructor in order to be understood. It is within the context of abstract characteristics that we encountered the most challenge with regard to pre-service teacher concept acquisition.

In this study, pre-service teachers lacked knowledge about the micro-level processes associated with dissolving. The pre-service teachers created concept maps that showed everyday concrete spontaneous concepts which sometimes included a few members of the set of knowledge for dissolving which are unified with others, but not all of the concepts were organized into a unified system that is characterized as a scientific concept. Using Vygotsky's concept development theory, a number of spontaneous concepts were identified in this study. Specifically, the pseudo-concept stage, dominated the pre-service teacher understandings about the concept of dissolving. Vygotsky (1986, p. 122) describes the pseudo-concept as the "shadow of a true concept." That is, a student can learn the meaning of a word, such as melting, yet erroneously apply it to a process such as dissolving which is unrelated to melting. Pseudo-concepts often masquerade as scientific concepts, but can be exposed in the attempt to generalize the pseudo-concept to a context for which the student is unfamiliar.

For example, when the pre-service teacher describes salt dissolving in water as melting, the pre-service teacher reveals a pseudo-concept which lacks a unified system associated with melting. That is, because the pre-service teacher does not understand the micro-view of dissolving, they attempt to generalize the meaning of the unrelated word, melting to include the concept of dissolving. Since this concept appears during kindergarten (Driver, 1985; Kikas, 2001) the instructor is challenged with the task of providing the academic language and learning experiences needed to help the pre-service teachers develop scientific understandings about the nature of melting and dissolving and why they are different. In an effort to ameliorate this lack of understanding, one of the learning experiences used in this study involved the investigation of dissolving without the addition of heat or stirring.

A persistent pseudo-concept present in this study was dissolving involves a chemical change. This particular pseudo-concept generally appears during high school (Nusirjan & Fensham, 1987) and proved to be a robust misconception. The incidence of occurrence on the concept maps increased post instruction from 10% to 16%. Interestingly, one scientific concept taught during the instructional intervention included the idea that, unlike a chemical reaction, dissolving is a reversible process. Although the students did not evaporate water from a solution, each of the pre-service teachers handled a beaker filled with salt crystals. The solution had previously been placed on the window sill until all the water had evaporated. Reduction of this particular pseudo-concept will require additional research.

Similarly, the pre-service teachers' understanding of mixtures was more akin to mixing. The teacher concept maps revealed a lack of a unified system for the concept of mixtures. This pseudo-complex was also robust, but did decrease from 22% to 15% after the instructional intervention. The concepts maps show that pre-service teachers do not understand that the superordinate concept of mixture involves homogeneous and heterogeneous mixtures, and that solutions are a special type of homogeneous mixture. Furthermore, the pre-service teachers do not know how colloids or emulsions fit into this system as subordinate concepts to homogenous mixtures. Again, this lack of an organized scheme represents a challenge for the instructor to bridge the gap between the pseudo-complex and scientific conceptual understanding as necessary prior knowledge is needed to understand this process (i.e., mixtures) and absent from the Pre-service teacher schema.

The pseudo-concept of "dissolving is breaking down a substance" decreased slightly from 12% to 10% on the post-concept maps. It was not clear from the concept maps if "breaking down" meant a physical or chemical change, thus we left this meaning open to the interpretation of the reader. Considerable effort was made during the instructional intervention to discuss the particulate nature of matter via technology as a tool showing computer animations of how salt-water and sugar-water solutions are formed. As the abstract understanding of dissolving is the source of many of the pseudo-concept identified in this study, more examples, discussion, and additional time to process information about the particulate nature of matter is warranted if pre-service teachers are to move toward the development of a unified system to understand the process of dissolving.

A pseudo-concept related to melting that generally appears during middle school, is change of state (Prieto et al. 1989; Abell & Deboer, 2008). The concept maps showed little evidence of a unified system for understanding what is meant by change of state. The pre-service teachers inappropriately applied generalized concepts for evaporation and condensation to dissolving. The pre-concept maps show 12% of pre-service teachers associated dissolving with change of state (e.g., evaporation, condensation) and this number was reduced to 6% on the post-concept maps. In an effort to develop scientific conceptual knowledge, discussion questions associated with the learning experience asked the pre-service teachers to describe what was happening to the sugar and salt as they were combined with water and formed a solution. Also, a computer animation was used to address what the pre-service teachers could not see during the laboratory; that is, "What happened to the solute and solvent? and "Did the solute change state?"

The pre-concept maps showed a number of other pseudo-concepts such as disappearing, absorbing, eroding, deteriorating, and disintegrating (12%) which appear as early as kindergarten (Kikas, 2001). These misconceptions were almost eliminated after instruction (2%) with only two pre-service teachers continuing to hold on to this particular misconception. Again, the use of computer animations and discussion were key instructional strategies used to target these misconceptions.

The post concept maps show the most common concept to be derived from the instruction intervention was that of dissolving is affected by stirring, heating, and concentration. Twenty-eight percent of post-concept maps showed propositions related to this idea compared to 11% on the pre-concept map. The instructional intervention did use investigations that specifically addressed how heat, physical agitation, and concentration affected the process of dissolving salt in water and sugar in water.

The use of academic language associated with dissolving such as solute, solvent, and solution is taught during middle school (Calik & Ayas, 2005). Two pre-concept maps attempted to use academic vocabulary, but reversed the terms solute and solvent. This reversal of vocabulary also appeared on the post-concept maps. Fourteen propositions (16%) used the terms, solute, solvent, and solution to describe the process of dissolving. Vygotsky's theory of concept development places a premium on communicating through gestures, language, sign systems, mnemonic techniques, and decision-making systems to help the individual derive meaning and conceptual understanding. For this reason, it is the instructor who plays a central role in the learning process. More attention to the acquisition of academic vocabulary is needed so pre-service teachers can explicate their knowledge about dissolving and in turn, communicate this knowledge to future students.

Although targeted efforts were made to assist the pre-service teacher with the understanding of the micro-processes associated with dissolving, only six teachers used propositions that correctly conveyed information about the concept of a hydration shell (7%). Three teachers incorrectly identified the hydration shell as a hydrogen shell on the post-concept maps (4%). This lack of understanding stems from the absence of knowledge about the particulate nature of matter (Nakhleh, 1992) and/or a lack of understanding about the role of inter-molecular forces involved in the process of dissolving (Kind, 2004). Again, a focus on the particulate nature of matter and mastery of academic vocabulary is needed.

2.9 Conclusion

In general, the 49 pre-service teachers in this study had no prior knowledge about dissolving as demonstrated on the pre-concept maps which showed only 11% of the propositions as representing a relationship between two or more scientific concepts. The instructional intervention was statistically significant and raised the number of propositions representing an accurate relationship between scientific concepts to 51%. However, 51% represents an almost equal number of misconceptions continued to be held by the pre-service teachers. These findings also indicate that pre-service teachers hold on to robust misconceptions. In this study, the concept of dissolving involving a chemical change (16%) and dissolving means combining or blending substances to form a mixture (15%) appear as robust misconceptions.

Using Vygotsky's Theory of Concept Development, the concept maps show that pre-service teachers continue to think in pseudo-complexes about basic science concepts which are taught during elementary school. The results show that students use macro-level descriptions for the processes involved in forming solutions, such as forming a mixture or that substances breakdown upon dissolving. The teachers continue to struggle with the process of dissolving on the micro-level. Moreover, analysis of academic transcripts showed that out of a population of 49 elementary pre-service teachers, only three student teachers enrolled in a college level general chemistry class although all pre-service teachers completed at least 12 semester credit hours of science coursework for elementary majors. For this reason, few students were able to utilize instruction about hydration shells and their role in enabling dissolving of ionic and molecular substances even after receiving instruction.

In summary, the misconceptions held by the pre-service are the same as those held by students in grades K-12 (Calik, 2007; Valandis, 2000; Kind, 2004; Nusirjan & Fensham, 2007; Kikas, 2001). In this study, the average number of total propositions (correct and incorrect) was 6.04 for a pre-concept map and 9.81 for the post-concept map. However, 65% of pre-concept maps received a TPA score of zero and 29% of the post-concept maps were scored as zero. Thus, the teacher knowledge about dissolving is dismally low (Alonzo, 2002, Heller, Daehler, & Shinohara, 2003) and many of the pre-service teachers have well-developed idiosyncratic conceptions about dissolving which will take considerable time and effort to reduce and/or eliminate.

3 Summary

The teachers who participated in this research study were enrolled in a teacher preparation program that is nationally-recognized and certifies approximately 300 teachers each year. The purpose of this study was to use concept maps as an assessment tool to investigate conceptual understanding of pre-service teachers for the concept of dissolving. Pre/post concept maps were used to document changes in teacher knowledge as the result of a three-hour instructional intervention. The intervention was designed to address common misconceptions about dissolving which occur in the research literature and to and create learning experiences that would increase the likelihood of developing an organized and unified system of knowledge about the process of dissolving.

A pilot study was used to improve the design of the study. Concept map training, the instructional intervention, and scoring method were changed as a result of the pilot study. Specifically, a standardized 30-minute training block for concept mapping was implemented, adjustments were made to the instructional intervention, construction of concept maps were checked before submission, and the TPA scoring method using a forced consensus model was used to improve the research study.

The total proposition method for scoring concept maps (TPA) proved to be an adequate method for using pre/post concept maps as assessment tools to document growth in teacher knowledge. The pre-concept maps provided information about the misconceptions held by the pre-service teachers and allowed for instructional adjustments to be made which were specific to the participants in the study.

The results for the instructional intervention were statistically significant (t=-4.154, p=<0.001). However, robust misconceptions identified in this study included: dissolving is a chemical change (16%); dissolving involves making mixtures (15%) or dissolving is the breakdown of substances (10%). These data confirm what has already been reported in the literature for K-12 students and informs future instruction for elementary pre-service teachers enrolled in teacher preparation programs. Acquisition of scientific concepts included propositions that used academic vocabulary (i.e., solute, solvent, and solution), variables that affect the rate of dissolving (i.e., heat, physical agitation, and concentration) and the formation of hydration shells. Propositions that were scientifically accurate increased in frequency from 11% to 49% after the instructional intervention.

The results of this study demonstrate these elementary pre-service teachers' knowledge about dissolving, as measured using pre/post concept maps, is dismally low and that the teachers have developed elaborate, mostly, concrete, unorganized understandings about the process of dissolving. In general, there is a complete lack of understanding about the particulate nature of matter.

Three recommendations are made based on the results of this study: (1) all elementary pre-service teachers should enroll in at least one non-majors chemistry course as a requirement of the degree; (2) an increased focus on science concepts, particularly the particulate nature of science, should be included in science methods course work that leads to teacher certification; and (3) pre-service teacher knowledge routine should be routinely screened and individuals who display weak science knowledge about the subject they will teach should be removed the certification program.

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