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Remediation of chemistry teachers' misconceptions about covalent bonding using cognitive conflict interviews: A case study

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Abstract: Research has shown that most chemistry teachers have misconceptions about covalent bonding. This study investigates whether the cognitive conflict interview technique could persuade teachers to revise their possible misconceptions of covalent bonding. Eight chemistry teachers from different schools participated in this study. Two validated instruments, cognitive conflict technique interview guidelines and the open-ended covalent bonding test, were employed for the data collection. The results showed that the cognitive conflict interviews could facilitate respondents to overcome their misconceptions about covalent bonding. Five of the eight respondents experienced a conceptual change from misconceptions to scientific conceptions, and three others experienced a partial conceptual change. Six concepts which previously caused misconceptions were eliminated and turned into a scientific concept instead. Of the 46 cases of misconceptions, 41 cases turned into scientific conceptions. The result of this study serves as an initial perspective for exploring the effectiveness of cognitive conflict interviews more broadly.

Keywords: chemistry teacher; conceptual changes; contradicts phenomena.

INTRODUCTION

The concepts of covalent bonding underlie other chemistry concepts[1] such as molecular structure and chemical and physical properties of compounds.[2] However, various studies have shown that this subject generates many misconceptions.[3–6] Misconception refers to an individual concept different from the concept accepted by the scientific community,[7] that must be adequately addressed because it can cause learning problems.[8]

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Various studies revealed that secondary school,[2] university students[9] and chemistry teachers demonstrated the misconception of covalent bonding.[10,11] Regardless of those results, limited evidence has been found regarding how to consider these misconceptions. How teachers explain chemical bonding may lead to students' difficulties with comprehending and learning.[12] Therefore, teachers' misconceptions must be corrected to avoid transferring their misconceptions to students. The effort to solve students' misconceptions must be initiated by ensuring that teachers hold clear scientific conceptions.

Cognitive conflict strategies emphasize the instability of people's beliefs in their existing conceptions through contradictory experiences. It then allows them to replace their misconception with scientifically accepted concepts.[13] This teaching strategy involves demonstrating phenomena in which students' observations contradict what they expected.[14] The contradiction causes a mental imbalance that encourages students to change their conceptions to fit the new facts they observe.[15] In other words, the cognitive conflict strategies facilitate the elimination of students' misconceptions after experiencing the counter-scientific conceptions.

The cognitive conflict strategies can be carried out in various ways or methods,[16] including cognitive conflict interviews.[17,18] The strategy of cognitive conflict interview allows researchers to ask in-depth questions to obtain broader and more profound answers.[19,20] The cognitive conflict interviews can also elaborate on students' cognitive structures[18] to uncover their misconceptions.[21] Studies have shown that the cognitive conflict interviews effectively revised students' misconceptions.[19,22] Various chemical phenomena of covalent bonding can be used to challenge the existing teachers' misconceptions, leading them to replace those with scientifically accepted conceptions.[13–15] For example, some respondents consider the electron configuration of an element in a molecule is simply the same as its configuration in a free atom. Presenting a configuration of Cl as a single atom and its configuration in HCl will challenge them to rethink of their initial conception.

EXPERIMENTAL

This study applied a case study and followed the interpretive paradigm[23] concerning the remediation of eight chemistry teachers' misconceptions about chemical bonding. This study was intended to explain the conceptual change phenomena occurring in chemistry teachers who held misconceptions about chemical bonding.[24] The uncovered misconceptions were corrected using the cognitive conflict interview technique.

Respondents

The respondents for this research were eight chemistry teachers from several schools in Banten Province, Indonesia. All respondents hold bachelor's degrees in chemical education with more than three years of teaching experience and offered their consent to participate.

Instruments

Two instruments, given in Supplementary material to this paper, cognitive conflict interview guidelines (Supplement 1) and an open-ended covalent bonding test (Supplement 2), were used for data collection. The cognitive conflict interview guidelines were used to correct the teachers' misconceptions. The open-ended test on covalent bonding consisting of 18 items was used to assess the changes in the teachers' conceptions.

The content validity and reliability of the instruments were assessed based on feedback from two experienced chemistry lecturers. Content validity describes how an instrument has an appropriate sample of items for the construct being measured,[25] whereas the reliability of the measurement result is its consistency and reproducibility.[26] The content validity was analyzed based on its content validity index (*CVI*), while the reliability was analyzed based on their inter-rater agreement (*IRA*).[25,27,28] The *CVI* was calculated by dividing the number of experts who gave a positive rating (*i.e.*, 3 or 4) and the total number of experts. The *IRA* was calculated by dividing the number of items with *IRA* items greater than 0.80 and the number of total items. The acceptable cut-off value for the *CVI* and the *IRA* was 0.80.[27-30] However, Landis and Koch[31] and Regier *et al.*[32] set *CVI* and *IRA* with different criteria, *i.e.*, poor if <0.00, low or unacceptable if 0.00–0.20, fair or questionable if 0.21–0.40, moderate or good if 0.41–0.60, substantial or very good if 0.61–0.80, and almost perfect or excellent if 0.81–1.00. The validity and the reliability of each secondary instrument are shown in Table I.

TABLE I. The CVI and IRA of secondary instruments used in this research

Secondary instrument	*CVI*		*IRA*	
	Value	Agreement strength	Value	Agreement strength
The cognitive conflict interview guide	1.0	Excellent	0.75	Very good
Open-ended test on covalent bonding	1.0	Excellent	0.69	Very good

Table I shows that all secondary instruments are feasible and can be used in data collection. In addition, this study also employed a tape recorder to record the interviews.

Procedure

The respondents were separately interviewed without a time limit. Respondents were free to use pictures or other schematic representations to express their opinions. The open-ended test on covalent bonding was carried out one week after the interview. This test was intended to identify teachers' understanding changes after interviews.

A cognitive conflict interview consists of 4 steps: 1) confirming the pre-conception, 2) creating cognitive conflicts by providing evidence, anomalies, and contradictions to promote mental imbalance that encourages teachers to change their conceptions,[15] 3) stimulating the equilibration process using the relevant questions to help them understand the new concept and 4) confirming the scientific concept.

Data analysis

The responses to the covalent bonding test were analyzed using descriptive analysis and categorized into six degrees of understanding. The degrees are sound understanding, partial understanding, partial understanding with misconceptions, misconceptions, lack of knowledge and no response.[33] This study simplified these six degrees of understanding into three categories (Table II).

TABLE II. The scoring criteria of teachers' responses (modified from Abraham *et al.*[33])

Scoring criteria	The degree of understanding	Category	Example from interviews
The response includes all components of the valid responses	Sound understanding	Sound understanding	Atoms bond to achieve a stable state or lower energy levels
The response includes at least one of the components of valid response, but not all components	Partial understanding		The atoms bond together to be stable, *i.e.*, obey the octet or duplet rule
The response shows understanding and consists of a statement that demonstrates a misconception	Partial understanding with misconception	Misconception	The bond polarity of HF > HCl > HBr is due to the atomic size of F < Cl < Br
The response includes illogical or incorrect information	Misconception		HF, HCl, and HBr have the same bond polarity
The response repeats questions only or is irrelevant or unclear	Lack of knowledge	Lack of knowledge	I don't know how the formal charge relates to stability
No responses or just stated "I have no idea"	No response		–

Partial understanding is an incomplete description of chemical phenomena. Example: They correctly explained that atoms bond each other to achieve stability. However, they explained, "obeying the octet or duplet rule is the root of stability." Partial understanding with misconceptions is a correct understanding but contains misconceptions. Example: bond polarity of HF > HCl > HBr. However, the respondents explained that the difference in the atomic size caused the difference in the bond polarity, where the atomic size of F < Cl < Br. The misconception implied by this statement is the difference in the bond polarity of HF > HCl > HBr is caused by the variability in the atomic size of F < Cl < Br only. The difference in atomic electronegativity causes the difference, F > Cl > Br, rather than the difference in atomic size, F < Cl < Br.

Each response was carefully read, compared, and tentatively assigned to one of the scoring criteria. The responses that were difficult to classify were separated and discussed in focus groups involving all research members until a consensus occurred.

RESULTS AND DISCUSSION

Our previous study showed that all respondents (before receiving cognitive conflict interviews) had misconceptions about the covalent bonding concepts.[11] The cognitive conflict interview guideline (Supplement 1) was developed based on the misconceptions identified through this preliminary research. After the intervention (cognitive conflict interview), only 3 of 8 respondents still demonstrated misconceptions in 2 concepts. The two misconceptions are: 1) the O–H bond of the water molecule resulting from the reaction of acid-base neutralization is a covalent bond and 2) both N–O covalent bonds in the NO_2 molecule are double bonds or single bonds (Table III).

TABLE III. The two misconceptions identified after the intervention

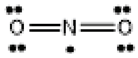
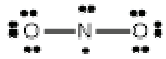
Concept	Misconceptions	Respondent No.
The coordinate covalent bonding	The O–H bond of the H_2O molecule formed by the reaction of H^+ and OH^- are a covalent bonding because the electron pair between the H and O atoms are shared by the H and O atoms	1 3
Lewis structure	The Lewis structure of the NO_2 molecule is:  because both N–O covalent bonds are identical	1
	The Lewis structure of the NO_2 molecule is:  because both N–O covalent bonds are identical	3 7

Table III shows that after the intervention, the respondents who experienced misconceptions were 3, including respondents No. 1, No. 3 and No. 7. In contrast, the other five respondents understood the covalent bonding concepts well. Overall, the misconceptions about the covalent bonding concepts before and after the intervention are shown in Table IV.

TABLE IV. The respondents' misconceptions about the covalent bonding concepts before and after the intervention

No.	Concept	Number of respondents experiencing misconceptions	
		Before intervention	After intervention
1	The purpose of bond-forming atoms	8	0
2	The coordinate covalent bonding	2	2
3	Types of atoms that can form covalent bonds	7	0
4	Polar and nonpolar covalent bonds	4	0
5	The polarity order of covalent bonds	4	0
6	Lewis structure	8	3
7	Octet rule	8	0
8a	The length of C–C bonds in ethane, ethene, ethane	2	0
8b	The length of the covalent bonding in hydrogen halides	3	0
Total cases		46	5

Table IV shows that the cognitive conflict interviews: 1) decrease the number of respondents who experience misconceptions from 8 people to 3 people; 2) reduce the number of concepts in which respondents experience misconceptions from 8 to 2 concepts; 3) reduce the number of misconception cases from 46 to 5 cases.

Previous researchers have also reported the effectiveness of cognitive conflict interviews in correcting misconceptions.[19,22] Cognitive conflict is closely related to conceptual change.[13–15] Cognitive conflict helps a person realize that there is a problem with their conception by showing phenomena, data, or evidence that contradicts their initial conception. This awareness will lead them to replace their initial conception with the scientific one. Several factors could explain the effectiveness of this strategy in correcting misconceptions. Firstly, one-on-one interviews provide a convenient environment leading to a productive discussion between interviewer and respondent. Secondly, confirmation or supporting questions make respondents realize that their initial conception is scientifically incorrect. Confirmatory questions[22] can facilitate and describe the conceptual change process. Thirdly, respondents' prior knowledge was sufficient to recognize the phenomena, data, and/or evidence presented in the interviews. The plenty of experience in teaching covalent bonds leads them to quickly realize their misconceptions when facing the facts, phenomena, data, or evidence that contradicts their conceptions. However, the one-on-one interview approach is time-consuming.[34]

The following interview script illustrates the conceptual change regarding "atoms that form covalent bonds".

1. Researcher: What types of atoms are forming covalent bonds? Metal atoms? Non-metal atoms? Both of them?
2. Respondent: Non-metal atoms.
3. Researcher: Are metal atoms unable to form covalent bonds?
4. Respondent: Yes, right.
5. Researcher: If so, what type of bond is formed between the Be and the Cl in $BeCl_2$ and between the Al and the Br in $AlBr_3$?
6. Respondent: An ionic bond because Be and Al are metals while Cl and Br are non-metals.
7. Researcher: (Indicating a reference that for binary compounds, a covalent bond will be formed when the two atoms forming the bond have an electronegativity difference of <1.7 according to the Pauling scale) Now, pay attention to the following data! (Showing the data on the difference in electronegativity between Be with Cl and Al with Br) Count for a moment! What is the difference in electronegativity between Be and Cl and Al and Br? Smaller or greater than 1.7 on the Pauling scale?
8. Respondent: Smaller than 1.7 on the Pauling scale.
9. Researcher: Well, it is below 1.7 on the Pauling scale. Therefore, what kind of bond is formed between Be and Cl as well as between Al and Br?
10. Respondent: If, based on the data, both of the bonds are covalent.

11. Researcher: Well! Let's go back to the $BeCl_2$ and $AlBr_3$. Are these two compounds composed of non-metallic atoms only?
12. Respondent: No. Be and Al are metals, while Cl and Br are non-metals. Both compounds contain metal and non-metal atoms.
13. Researcher: What does it mean? Is the type of bond in a binary compound determined only by the type of atom that composes it?
14. Respondent: Ermmm ... It means that the kind of bond of binary compounds cannot be seen from the type of atoms composing it. Is it right?
15. Researcher: Yes, that's right. If so, what is your inference regarding the covalent bonding in binary compounds?
16. Respondent: Ummm ... The type of bond in binary compounds can't be seen from the type of atoms forming it, metal or non-metal. However, it can be seen from the difference in electronegativity of the two types of atoms forming it. If the difference in electronegativity of the two types of atoms on the Pauling scale is less than 1.7, the bond is covalent, but if it is greater than 1.7, the bond is ionic.

The interview script above shows that initially, the respondent highly believed that: 1) covalent bonds only formed between non-metal atoms and 2) Be–Cl bond in $BeCl_2$ and Al–Br bond in $AlBr_3$ were ionic bonds (lines 2, 4 and 6). This belief or conception raises a question for the respondent when the interviewer showed the Pauling scale parameter in determining the type of chemical bond, which led to a conclusion different from the respondent's conception (lines 7 and 8). This parameter made the respondent doubt their initial understanding when the interviewer pointed out that the difference in electronegativity between Be and Cl and Al and Br was below 1.7 on the Pauling scale, indicating a covalent bonding, not an ionic bond, as the respondents perceived before. This misconception changed after the interviewer asked the respondent to determine the type of atoms composing the $BeCl_2$ and $AlBr_3$ compounds (lines 11 and 12). At the end of the interview, the respondent believed that the type of bond (covalent or ionic) formed in binary compounds was not dependent on whether the atoms were metal or non-metal but on the difference in electronegativity between the atoms (line 16). This final script indicates a conceptual change from misconception to scientific conception.

Regardless of the positive conceptual change, as shown in the interview script example, three respondents still experienced two misconceptions (Table III). This implies that some misconceptions has persisted, as reported by previous researchers.[35]

The first persistent misconception is the coordinate covalent bonding in the water molecule produced by the acid-base neutralization reaction. The two respondents (No. 1 and 3) only considered the molecular structure of H_2O and ignored how the water molecules were formed. They did not realize that in acid-base neutralization, OH^- acts as an electron-pair donor, and H^+ acts as an electron pair acceptor. Therefore, the bond is a coordinate covalent bonding. The lack of awareness regarding the formation of water molecules,[6,24] leads to the misconception.

The second persistent misconception is related to the Lewis structure of the molecule or polyatomic ion. The three respondents (No. 1, 3 and 7) keep determining the Lewis structure of a molecule according to the following steps: 1) determining the electron configuration of each atom; 2) determining the central atom; 3) drawing Lewis symbols for all atoms; 4) pairing the electrons of each atom until the octet or duplet rule was obeyed. This procedure makes them difficult when dealing with molecules that do not obey the octet rule. The correct steps to write the Lewis structure are identifying the central atom, calculating coordination numbers, bonding and lone pairs, writing a frame of Lewis structure, adding electrons to all the substituents to fulfil the octet or duplet rules, calculating the formal charges of all the atoms, and making the formal charge of all atoms equal to zero.[36]

The Lewis structure and coordinate covalent bonding concepts require a good understanding of the definitions and the rules associated with these definitions.[37] To write the Lewis structure of a species correctly, we need to understand the species well, the rules for writing Lewis structures, and the terms associated with these rules like coordination number, bonding electron pair, lone pair, formal charge, octet, duplet[36] and unpaired electrons.[38] A conventional example of a coordinate covalent bonding is $[Cu(H_2O)_6]^{2+}$, while an example of a coordinate covalent bonding that does not involve a transition element is NH_4^+. The lone pairs of the O atom of the neutral molecule H_2O and the N atom of the neutral molecule NH_3 are critical examples of a coordinate covalent bonding. The source of the electron pair in a coordinate covalent bonding does not always come from the lone pair of an atom of the neutral molecule,[39] for example, OH^- in an acid–base neutralization reaction. Lack of knowledge related to these concepts is a root of misconceptions about the concepts of coordinate covalent bonding and Lewis structure.

The issues of resistant misconceptions have been uncovered in the previous study.[40] According to Piaget, the incomplete conceptual change is caused by the inability to reach the equilibration phase in acquiring new concepts.[1]

CONCLUSION AND IMPLICATION

After applying the cognitive conflict interview, the number of misconception cases held by the teachers decreased. This phenomenon indicates that the cognitive conflict interviews can potentially encourage teachers to overcome misconceptions about the concepts of covalent bonding. Some persistent misconceptions were still found, such as the O–H bond in the water molecule produced by the acid-base neutralization is a covalent bond. We realize that the sample size is insufficient to provide a robust conclusion. Still, the results of this study could be a pilot to implement the cognitive conflict interviews for overcoming misconceptions and establishing a conceptual understanding of chemical bonding and other chemical topics. Therefore, the effectiveness of this method in overcoming misconceptions needs to be proven by further research.

SUPPLEMENTARY MATERIAL

Additional data and information are available electronically at the pages of journal website: https://www.shd-pub.org.rs/index.php/JSCS/article/view/11570, or from the corresponding author on request.

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И З В О Д

ОТКЛАЊАЊЕ ЗАБЛУДА О КОВАЛЕНТНОМ ВЕЗИВАЊУ КОД НАСТАВНИКА ХЕМИЈЕ ПОМОЋУ ИНТЕРВЈУА БАЗИРАНОГ НА КОГНИТИВНОМ КОНФЛИКТУ: СТУДИЈА СЛУЧАЈА

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Истраживања су показала да већина наставника хемије има неке погрешне представе о ковалентном везивању. У оквиру ове студије истражено је да ли техника интервјуа базирана на когнитивном конфликту може да подстакне наставнике да ревидирају те погрешне представе о ковалентном везивању. У истраживању је учествовало осам наставника хемије из различитих школа. За прикупљање података коришћена су два валидирана инструмента, упутство за интервју, технике базиране на когнитивном конфликту и тест с питањима отвореног типа о ковалентном везивању. Резултати су показали да примењени интервју може помоћи испитаницима да превазиђу своје заблуде о ковалентној вези. Пет од осам испитаника направило је концептуалну промену од мисконцепција (заблуда) ка научним појмовима, док је код три испитаника концептуална промена била делимична. Шест концепата који су претходно били извор заблуда елиминисани су и преведени у научне концепте. Од 46 случајева заблуда, 41 случај је преведен у научне концепте. Резултат ове студије служи као почетна перспектива за истраживање ефективности интервјуа базираног на когнитивном конфликту у ширем опсегу.

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