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Exploring teachers' meta-strategic knowledge of science argumentation teaching with the repertory grid technique

Yu-Ren Lin[a], Cheng-Yu Hung [b] and Jeng-Fung Hung[c]

[a]Institute of Science Education and Communication, Central China Normal University, Wuhan, People's Republic of China; [b]Institute of Education, National Chiao-Tung University, Hsinchu, Taiwan; [c]Institute of Science Education, National Kaohsiung Normal University, Kaohsiung, Taiwan

ABSTRACT

This study investigated two science teachers' meta-strategic knowledge (MSK) of argumentation teaching by applying the repertory grid technique (RGT). One teacher was a novice, while the other was experienced in teaching argumentation. Using the RGT, we elicited the objectives and strategies of the two teachers regarding their argumentation teaching involving two social scientific issue (SSI) scenarios. The results showed that the experienced teacher had more varied and organised MSK for teaching argumentation than the novice teacher. Meanwhile, the novice teacher indicated a belief that the learning of argumentation should occur in a more student-centred manner, rather than relying on a traditional lecture-based environment. Consequently, she spent a considerable amount of time engaging students with their peers' ideas through discussion and collaboration. On the other hand, the experienced teacher noticed that most of students had the ability to generate arguments, but that few knew how to argue based on evidence. Therefore, she helped students to collect data from various resources and suggested that they construct their own knowledge framework in order to improve students' ability to incorporate their understanding of scientific knowledge into scientific argumentation.

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Argumentation; meta-strategic knowledge; repertory grid technique

Introduction

The importance of developing scientific literacy has been highlighted in various studies and texts regarding science education (Millar & Osborne, 1998; Norris & Phillips, 2003). Scholars in science education have reported that the ability to engage in scientific argumentation is an important component in building students' scientific literacy (Abell, Anderson, & Chezem, 2000; Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002; Erduran, Osborne, & Simon, 2004; Kuhn, 1993). For most science teachers, however, it may not be easy to integrate the teaching of scientific argumentation into their science instruction (Berland & Hammer, 2012; McNeill & Knight, 2013; Sadler, 2006).

CONTACT Cheng-Yu Hung hcy98p@cs.ccu.edu.tw
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The reasons for this difficulty are that, first, due to the fact that argumentation learning is basically an activity which emphasises students' reasoning and communicative skills, it is hard for teachers to apply traditional lecture-based approaches, which are regarded as more simple and straightforward than student-centred approaches, when attempting argumentation instruction (Jiménez-Aleixandre & Erduran, 2008; Sadler, 2006; Simon, Erduran, & Osborne, 2006). Second, it has been suggested that science teachers must know the components of a sound argument before they can know how to teach argumentation using the explicit approaches that have previously been proven to be more effective than implicit approaches (McDonald, 2010; McNeill, 2009; Oliveira, Akerson, & Oldfield, 2012; Sampson, Grooms, & Walker, 2011; Schwarz, Neumann, Gil, & Ilya, 2003). Third, the teaching of argumentation involves the management of students' dialogue interactions, including their motivations, emotions, knowledge, and possible dialogue conflicts (Albe, 2008). Given these challenges, it has been reported that teachers typically need substantial training in order to teach argumentation effectively (Duschl & Osborne, 2002; McNeill & Knight, 2013; Simon et al., 2006).

In order to improve the professional development of science teachers with respect to teaching argumentation, a number of studies have emphasised the importance of pedagogical content knowledge (PCK) (Berland & McNeill, 2010; McNeill, González-Howard, Katsh-Singer, & Loper, 2016), as well as metacognitive knowledge (Anastasiadou & Dimitriadou, 2011; Keller, 2008; Zohar, 2008; Zohar & Ben-David, 2008; Zohar & Peled, 2007). Zohar (2008) merged these two kinds of knowledge into a single type of knowledge termed 'meta-strategic knowledge' (MSK). Zohar defined MSK as 'general knowledge about the cognitive procedures that are being manipulated' (Zohar, 2008, p. 254). With regard to teaching argumentation, MSK may consist of the following abilities: naming the strategies being used to enhance students' high-level thinking skills; explaining when, why, and how a given strategy should be used; what the risks could be if the strategy is not used appropriately; and which tasks might call for the use of it (Zohar & Ben-David, 2008).

The purpose of the present study was to explain teachers' MSK of argumentation teaching. As with metacognitive knowledge, MSK is regarded as a kind of tacit knowledge that is not easy to be either observed or described (Eraut, 2000; Kuhn, 1999; Kuhn, Katz, & Dean, 2004; Zohar & Ben-David, 2008). To overcome this challenge, we applied the comparative research method and the repertory grid technique (RGT) in this investigation. Two science teachers with different levels of experience in argumentation teaching (one a novice teacher and the other, an experienced teacher) were selected for the study, during which the designs of their argumentation teaching were elicited, including their planning of instructional objectives, their uses of appropriate strategies for achieving these objectives, and their evaluations of the relationships between the arranged objectives and strategies. The application of the RGT enabled us to elicit and reveal the specific features of the two teachers' MSK of argumentation teaching, while a comparative analysis helped us to make related descriptions and explanations. Specifically, the following two questions were posed:

(1) What were the features of the novice teacher's MSK and of the experienced teacher's MSK for argumentation teaching that were revealed by the RGT analysis?

(2) Based on the analyses and comparisons of the two teachers' MSK, what suggestions can be provided for the professional development of other teachers with regard to teaching argumentation?

Literature review

Teachers' PCK and MSK for teaching argumentation

Argumentation is a verbal and social activity aimed at resolving differences in two or more points of view by justifying or refuting the propositions expressed in a given viewpoint (van Eemeren et al., 1996). It has been suggested that knowledge and skills relating to argumentation should be integrated into science education because they help students to better understand any scientific knowledge a teacher intends to teach, in addition to improving students' views regarding the nature of science and helping them to develop communicative competences (Duschl, Schweingruber, & Shouse, 2007; Jiménez-Aleixandre & Erduran, 2008). However, previous studies have found that the major obstacle in teaching argumentation is that students are unable to discern what data are relevant or what counts as evidence (Kelly & Bazerman, 2003; Kelly & Takao, 2002; Zeidler, 1997). Relatedly, Zohar and Nemet (2002) found that a typical problem in students' science reasoning was that they tend to form unwarranted opinions and ignore alternative points of view. When students try to justify their assertions, they tend to avoid cardinal rebuttals from the opposition and attempt to circumvent the focus of the given dilemma. Previous researches on argumentation teaching have also found that in-service and pre-service teachers rarely integrate argumentation into science classroom instruction (Berland & Reiser, 2009; McNeill & Krajcik, 2007; Simon et al., 2006). One reason for this is that argumentation in science classrooms involves complex dialogue interactions, as opposed to dialogues that could be described as linear in nature (Coffin & O'Halloran, 2009; Jiménez-Aleixandre, Rodríguez, & Duschl, 2000; Koschmann, 2003; Noroozi, Weinberger, Biemans, Mulder, & Chizari, 2012; Nussbaum, 2002). These issues make it difficult for science teachers to propose appropriate strategies for improving students' argumentation abilities (Zembal-Sual, Munford, Cawford, Friedrichsen, & Land, 2002).

To provide support for teachers seeking to integrate science argumentation into their classrooms, studies have emphasised the importance of teachers' PCK (Alozie, Moje, & Krajcik, 2010; McNeill & Knight, 2013; Sadler, 2006). Magnusson, Krajcik, and Borko (1999) reported five discrete components that can be used to conceptualise PCK: (1) orientation towards science teaching; (2) knowledge and beliefs about science curricula; (3) knowledge of students' understanding of science; (4) knowledge of assessment in science; and (5) knowledge of instructional strategies. It is generally agreed that effective teaching requires the integration of these components of PCK. This integrated and differentiated knowledge supports a teacher's instruction of high-level thinking skills and also allows for deep and integrated understanding on the part of students. Simon et al. (2006) categorised a number of teacher utterances that reflect the goals of argumentation learning, such as encouraging discussion, listening, positioning, prompting justifications, constructing arguments, and encouraging evaluation. These utterances not only identify the important phases of student argumentation learning, but also provide science teachers with a framework for developing appropriate objectives and strategies to teach argumentation. McNeill and Knight (2013) explored 70 teachers' PCK relating to teaching argumentation in grades K–12 as they engaged in professional development relating to argumentation teaching. Their study found that teachers exhibited increased comfort in using the components of claims, evidence, and reasoning during instruction, but that the integration of argumentation into students' learning continued to be a challenge. The authors also indicated a number of considerations in teaching argumentation. For example, they indicated that most of the teachers exhibited a limited understanding of argumentation with regard to both structural components and dialogic interactions, and that this lack of knowledge affected their strategies and questions designed for improving argumentation. These considerations for teaching argumentation were then elaborated on and revised in a recent study by the same authors (McNeill et al., 2016). The revised content regarding PCK relating to teaching argumentation placed a greater emphasis on facilitating the processes of argument generation and justification, as well as greater emphasis on encouraging students' dialogic interactions. These suggestions provided science teachers with scaffolds to develop appropriate instructional objectives, strategies, and assessments for teaching argumentation.

In addition to investigating teachers' PCK, previous studies have also highlighted the importance of teachers' MSK in teaching argumentation (Zohar, 2006, 2008; Zohar & Peled, 2007). The MSK of teachers is associated with the teachers' perceptions of how their students learn, what strategies should be utilised, and what kinds of objectives are appropriate for students (Zeidler, 1997; Zeidler, Sadler, Simmons, & Howes, 2005; Zohar, 2008). To apply MSK in argumentation teaching, it is suggested that science teachers should: (1) believe that their students (including students at all academic levels) have the necessary abilities to engage in argumentation (Resnick, Salmon, Zeitz, Wathen, & Holowchak, 1993; Zohar, 2008; Zohar & Dori, 2003; Zohar, Vaaknin, & Degani, 2001); (2) provide scaffolds and guidance based on students' knowledge backgrounds (Weinberger, Stegmann, & Fischer, 2010; Zohar & Nemet, 2002); and (3) explain to students the basic components of a sound argument (Hogan & Maglienti, 2001; Kuhn, 1991; Simon et al., 2006). Zohar (2008) emphasised that MSK enables teachers to reflect on and evaluate both the cognitive level and the meta-strategic level of their teaching. The former refers to the issues, statements, and dialogue interactions being discussed, while the latter addresses the rules, principles, and components of the interactions. Teachers need to be aware of their own MSK, in addition to applying it to their pedagogical knowledge.

Application of the RGT in science education

The RGT was developed by Kelly (1955), a psychologist and educator best known for his personal construct psychology (PCP), a theory of constructivism. To explain the process of learning, Kelly argued that an individual constructs his/her personal experiences through a continuous series of hypothesising and testing (Bradshaw, Ford, Adams-Webber, & Boose, 1993). Based on feedback from testing, the individual decides which experiences should be preserved, revised, or abandoned (Edwards, McDonald, & Young, 2009). The RGT was developed based on the theory of PCP. To apply the RGT in educational research, it is necessary to collect both qualitative and quantitative data. Thus, the RGT is regarded as a kind of mixed research method (Kington, Sammons, Day, & Regan, 2011). The standard

RGT procedure provides an effective way of eliciting personal constructs and beliefs regarding a given topic from a subject. The elicited constructs will then be organised and given back to the subject for further evaluation. That is, the application of the RGT enables the subject to engage in reflection, evaluation, explanation, and justification (Boyle, 2005; Mayo, 2004; Tobacyk, 1987). These thinking skills are related to metacognitive knowledge. Bencze, Bowen, and Alsop (2006) applied the RGT to explore science teachers' cognitive structures regarding science teaching. All of the teachers' personal constructs, including their instructional strategies, as well as comments on the strategies were elicited through the standard RGT procedure. These constructs were then handed back to the original subject for further evaluation. Hence, the investigators could explore the teachers' pedagogical tendencies, their knowledge of science teaching, and their views on the nature of science. Mayo (2004) investigated the effect of the RGT on students' learning of the history of psychology. In that study, all of the students' constructs/comments about the psychologists most relevant to the intellectual history of psychology (e.g. Piaget and Skinner) were elicited after an introductory course. Only students in the experimental group were then allowed to review and discuss their own and others' constructs about the psychologists. As Mayo reported, 'the observed outcomes of the end-of-semester, whole-class discussion in the RG condition (experimental group) lend additional support to students' perceptions that RGT encouraged conceptual understanding and active involvement in learning' (p. 180). The study indicated that the grid rating and discussion activity promoted students' conceptual understanding. Wu, Hwang, Tsai, Chen, and Huang (2011) applied the RGT to develop a learning system for the training of advanced practice nurses. The RGT learning system was applied in mobile devices as a personal digital assistant to help the users to reflect on what they had observed during a clinical observation. Wu reported that 'via the mobile learning system, the learning achievements of the students in identifying diseases of the respiratory system can be promoted' (p. 13). Through the integration of the RGT, the learning would be more student-centred and reflective. Bezzi (1996) investigated students' cognitive systems and learning improvement in geology with the application of the RGT. The design of the intervention in that study consisted of supplying the students with the results of the RGT analyses of their own cognitions. The strategy enabled them to review their own cognitive structures and to reflect on what they had learnt during the instruction. Moreover, the study also supplied the students with the instructor's RGT results, allowing them to engage in evaluation discussion and reflection as well as to compare their own results with those of the instructor. The results showed that the RGT can be used to reveal subjects' cognitive structures and also to improve their metacognitive skills. These reported advantages of RGT indicated to us that it could provide us with a systematic method for analysing the MSK of teachers with regard to teaching argumentation.

The application of the RGT allows investigators to make comparisons across both individuals and times (Ben-Zvi Assaraf, Dodick, & Tripto, 2012; Gupta, Fischer, van der Lans, & Frewer, 2012; Henze, Van Driel, & Verloop, 2007; Keynan, Ben-Zvi Assaraf, & Goldman, 2014; McGregor, 2014; Touw, Meijer, & Wubbels, 2015). Henze et al. (2007) used the RGT to investigate science teachers' personal knowledge about teaching models and modelling. They selected 12 activities from a new education reform (e.g. 'generate a model,' 'discuss the function of a model,' and 'make predictions based upon a model') to elicit personal constructs from the teachers. These constructs were then used as components to develop a grid test for evaluating the teachers' knowledge of teaching models. Based on the grid test, a pretest–posttest design was applied to investigate the changes in the teachers' knowledge as they became more experienced in teaching models. In addition to developing a grid test, applying content analysis to explore changes in personal constructs is another means of making comparisons. Keynan et al. (2014) used the RGT to assess the impact of a constructive-based learning unit on the development of students' ecological system thinking abilities. In that study, 15 terms related to the ecosystem (e.g. 'geosphere,' 'hydrosphere,' 'human influence,' and so on) were selected as elements that were then used to elicit students' personal constructs. Next, the elicited constructs were sorted into three sequential categories according to a theoretical framework developed in earlier pilot studies: analysis, synthesis, and implementation. Thus, the study was able to trace the changes in students' thinking abilities before and after the learning unit. Gupta et al. (2012) applied the RGT to investigate and compare expert opinions on factors influencing societal responses to the application of nanotechnology. The RGT helped to collect and organise data from experts in various professional fields, such as cosmetics, material science, polymer technology, food science, and so on. It also provided a systematic approach through which the investigators could interpret and compare these experts' thinking and ideas.

Enhancing teachers' argumentation teaching knowledge and skills

Due to the fact that one of the teachers invited to participate in the present study had less experience teaching argumentation, we were aware of the need to advise her on the meaning of scientific argumentation and the principles of teaching argumentation (Clark & Sampson, 2007; Simon et al., 2006). Specifically, we explained to this novice teacher five potential contributions of integrating argumentation in science classrooms (Jiménez-Aleixandre & Erduran, 2008): (1) supporting the development of communicative competences and, in particular, critical thinking; (2) empowering students to talk and write in the language of science; (3) supporting the enculturation of practices from scientific culture; (4) supporting the development of the ability of scientific reasoning; and (5) supporting access to cognitive and metacognitive processes of thinking. Additionally, the two forms of argumentation process, monological and dialectical argumentation, were also introduced. The former concerns how a single person constructs an argument in her/his mind through a reflective and personal internal reasoning process (Goldman, 1999), while the latter emphasises the dialogue interactions between individuals (Asterhan & Schwarz, 2007; Duschl & Osborne, 2002). Based on previous studies, the form of dialectical argumentation is generally considered more appropriate for integration into science classrooms because it provides more opportunities for students to learn how to argue collaboratively (Asterhan & Schwarz, 2007; Clark & Sampson, 2008; Nielsen, 2013).

The second form of support provided to the novice teacher consisted of encouraging her to apply the explicit approach in designing her argumentation instruction (McDonald, 2010; Yerrick, 2000; Zohar & Nemet, 2002). The explicit approach emphasises the instruction of what constitutes a sound argument. Hence, Toulmin's argument pattern (TAP) was introduced, and the structure of a sound argument was also explained (Toulmin, 1958). Furthermore, suggestions from studies regarding the application of TAP were also outlined for the novice teacher before the instruction (Chang & Chiu, 2008; Kelly, Druker, & Chen, 1998). For example, the teaching of argumentation should generally be conducted in a more constructive way. A science teacher must manage student dialogue interactions in the classroom, which includes managing student positions regarding a given issue, managing student emotions when they generate arguments, managing the students' attitudes as they provide responses, and managing possible dialogue conflicts (Jiménez-Aleixandre, 2008; Kolstø & Ratcliffe, 2008; McNeill & Pimentel, 2010).

Researchers in science education have reported that the integration of social scientific issue (SSI) into science learning is an effective method of teaching argumentation (Sadler, 2004; Zeidler et al., 2005; Zeidler, Sadler, Applebaum, & Callahan, 2009). Sadler (2004) indicated that the application of SSI in science learning aids in the development of argumentation skills and increases students' abilities in terms of knowledge evaluation, communication, and justification. Lewis and Leach (2006) reported that the capacity to engage in discussions regarding the application of a gene technology (the SSI discussed in the study) is influenced by the ability to understand the relevant scientific knowledge. An SSI scenario usually involves frontier forms of scientific activity in which students need to rely on multiple sources when forming arguments and explanations, and when making decisions. In contrast to cases in which problems can be solved with well-structured logic, an SSI is always regarded as ill-structured, multi-logical, and controversial. Kolstø (2005) argued that students should be taught that science is closely related to epistemic and social values. Arguments regarding an SSI must therefore be considered from multiple perspectives. As such, the teaching of argumentation is not simply a matter of instruction regarding right or wrong answers; rather, it involves contrasts between environmental issues, economic values, affective issues, political stances, and even broader global issues (Simonneaux, 2008). The purpose of applying an SSI in teaching argumentation is to promote students' ability to identify bias, to engage in critical reflection, to develop open-mindedness, and to understand controversial issues (Oulton, Dillon, & Grace, 2004). In the present study, these suggestions regarding the teaching of argumentation with SSIs were carefully evaluated for both teachers to enhance their knowledge and skills for teaching argumentation with SSI scenarios.

Methodology

Participants

The present study was conducted at a nursing high school in southwestern Taiwan. There were a total of seven science teachers teaching at the high school, and five of them expressed their interest in teaching argumentation. We invited them to join our research project, and arranged an eight-hour workshop to improve their basic knowledge of argumentation. After the workshop, they were asked to participate in a one-hour, semi-structured interview to probe their knowledge of argumentation and teaching argumentation. After the interview, two of the teachers, Sue and Evonne, were selected to represent a novice teacher and an experienced teacher, respectively, in the present study.

Sue held a master's degree in teaching biology and had already had eight years of experience in teaching science and biology when we invited her to participate in the study. On the other hand, Evonne was a Ph.D. candidate who had also had eight years of experience in teaching science when she was invited to participate. In addition, she had been trying to integrate argumentation into her science classroom over the past two years due to the fact that the topic of her Ph.D. thesis was related to argumentation teaching.

Although Sue and Evonne were almost the same age and had similar seniority in terms of teaching, they had different perspectives on classroom instruction. Evonne enjoyed a less formal learning environment. She believed that students' participation in scientific argumentation would improve their understanding of what science is about, the processes involved in scientific investigations, and the limitations of science. Consequently, students in Evonne's science classroom had more opportunities to conduct scientific experiments, communicate, and share their ideas collaboratively. In contrast, Sue emphasised discipline and organisation in her classroom. She usually used a traditional lecture-based approach to teach science. However, she expressed a desire to change from this traditional approach when teaching argumentation. This was one of the reasons she was willing to join our research project. Both Evonne and Sue were responsible for teaching one science course and two classes each in the high school. In total, four 10th grade classes totalling 182 students (178 female, 4 male) majoring in nursing, participated in our project.

Instructions and learning units

At the beginning of the research semester, both teachers were asked to integrate argumentation into their science course for the first two learning units of the school curriculum. Each unit encompassed four class periods lasting 45 minutes each and occurring over the course of two weeks. The scenarios featured in the argumentation learning units were each related to an SSI which has been regarded as being beneficial for students in terms of their understanding of the related scientific knowledge and in terms of allowing them to practise how to argue scientifically (Dawson & Schibeci, 2003; King & Kitchener, 2002; Patronis, Potari, & Spiliotopoulou, 1999; Yang & Anderson, 2003). A total of three topics of SSIs were created through discussions with the two teachers based on the high school students' prior knowledge and motivations, and on the content of the science curriculum. Next, the two teachers chose two topics of SSIs from the three to develop instructions and tried to integrate argumentation into these instructions. The first SSI for the experienced teacher's instruction was called 'the Su-Hua highway.' The main questions for argumentation in the SSI were 'Should our government decide to construct the Su-Hua highway in the near future (the highway connects Suau to Hualien county along the east coast of Taiwan)? What suggestions can you provide before the decision has been made?' The novice teacher, meanwhile, also chose an environmental SSI called 'green or nuclear energy' to be used in her first SSI instruction. The prompt for student argumentation in this case was 'Is it necessary to build one more nuclear power plant on the island of Taiwan? Please provide suggestions to our government officials.' In order to allow for a more equitable comparison between the two teachers, they agreed to apply a third SSI, which was called 'chemical cosmetics,' for their second unit of argumentation teaching. After some discussion, the two teachers decided to use the question 'Do you agree that people should use chemical cosmetics in daily life, and if so why?' to engage their students in argumentation.

Data collection

According to the standard RGT procedure, the process of data collection in the present study included three phases: eliciting instructional objectives and strategies, constructing a repertory grid (RG), and rating the RG.

Eliciting the instructional objectives and strategies

We carried out two semi-structured interviews for each teacher to obtain the two teachers' respective instructional objectives and strategies for argumentation teaching. The first interview was conducted before the instruction to elicit their instructional objectives, while the second interview was conducted after the instruction to allow them to reflect on the strategies they used to achieve these objectives. We transcribed all of the statements made by the teachers during the interviews and then applied the method of content analysis to summarise them more briefly and precisely (Haney, Russell, Gulek, & Fierros, 1998; Miles & Huberman, 1994). First, we reviewed all the transcripts and used underlining to highlight the key points of every statement in the transcript. Second, these key points were reorganised to make them more coherent by reducing their complexity but maintaining their original meanings. The process of summarisation enabled us to clarify the instructional objectives and strategies applied in the teaching (Table 1). These data were then submitted to the two teachers for further confirmation and modification. Appendix 1 shows the results of our summarisation.

Constructing and rating the RG test

The summarised objectives and strategies were treated as constructs and elements, respectively, for constructing an RG test. Based on Kelly's theory, the constructs and elements should be arranged into the bottom and right sides, respectively, of a two-dimensional grid matrix (Figure 1). A total of four RG matrixes were established because both the experienced teacher and the novice teacher each had two SSI argumentation instructions. The RG matrix is regarded as an effective instrument for exploring hidden patterns among relevant items (Easterby-Smith, 1980). Specifically, the structure of an RG matrix enables a subject to rate how well the items on the bottom and right sides of the matrix match with one another (Bezzi, 1996). To complete the RG rating, the two teachers were asked to assign each strategy to a position (e.g. '3') along the 5-point continuum of each objective in the given RG matrix. The scores in the RG testing were collected through the teachers' own evaluations of their argumentation teaching. During the rating, the two teachers reviewed the instructional objectives they had arranged and the strategies they had adopted, and then evaluated each of their relationships. Such reflection

Table 1. The summarisation of an instructional strategy from the transcript of an interview with Sue.

Elicitation
Interviewer: Can you recall how you taught argumentation with regard to your first argumentation topic 'green or nuclear energy'? That is, what strategies did you use in your argumentation instruction when teaching the SSI? Please tell us.
Sue: At the beginning of the lesson, *I asked them to share their ideas about what energy is, why it is important in our daily lives, and what will happen if our energy resources are depleted.*
Interviewer: OK, your first strategy was to provide and encourage them to discuss related issues about the topic.
Sue: Yes, *I gave them time and opportunities to share their ideas about energy, and to discuss related issues in the classroom.*
Summarisation
Provide opportunities for students to share their ideas and discuss other issues related to the SSI.

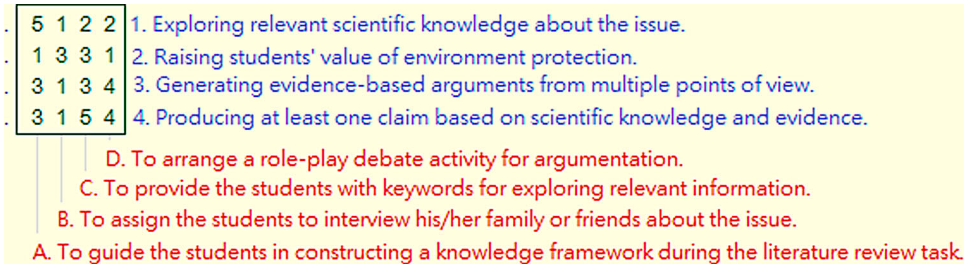

Figure 1. An example of a repertory grid matrix.

processes enabled the two teachers to project their metacognitive knowledge of argumentation teaching on their own RG matrix.

Data analysis

Principal component analysis

The present study applied principal component analysis (PCA) to the RGT to explore the features of the two teachers' MSK. The main data for the PCA included both qualitative and quantitative data. Specifically, the data consisted of the instructional objectives and strategies, as well as the scores in the RG testing. These data were entered into the RepGrid V program so that we could apply the PCA function of the program to reduce the complexity of the data, and then explore the features of the teacher's MSK. We believe that there is some redundancy for an RG in terms of those variables (i.e. the instructional strategies and objectives). That is, for these variables, if the rating scores are the same or similar in an RG matrix, they should be compressed because they may be measuring aspects of the teacher's knowledge redundantly. The PCA converts these correlated variables into a small number of uncorrelated and artificial variables, which are called 'principal components.' These principal components account for a maximal amount of variance in the data set. Specifically, by analysing the variances of every variable of an RG matrix, the PCA defined a smaller number of variables, which helped us to clarify the internal structure of the RG matrix (Slater, 1977). For our study, this variable reduction procedure revealed the features of each teacher's MSK of argumentation teaching.

The RepGrid program graphically maps both elements and constructs in a 2-dimensional space. The horizontal and vertical axes of this 2-dimensional space represent the first and second principal components, respectively. As it was described in a previous study by Bezzi (1999)

> The PCA layout can be considered a 'simplified' expression of the geometry of an n-dimensional space in which the major dimensions are 'compressed' into a restricted number of components. They, in a sense, condense the larger variance expressed by the element and construct matrices of the raw data, enabling an easier analysis of the relationships between elements and constructs. (p. 682)

Elements and constructs are plotted within the 2-dimensional space according to their loadings on the two principal components. The more similar any of the two objects (elements, constructs, or element and construct) are in terms of the loading of the two principal components, the closer the positions of the two objects will be in the 2-dimensional space. To be significant, the two principal components must explain a high percentage of variance, and if they do not, then these objects, in spite of appearing close in the 2-dimensional space, could actually be far away when a third component is considered. It is normally assumed that the first two principal components must account for over 60% of the overall variation in order to provide meaningful indications (Bezzi, 1999; Tan, Chen, & Lee, 2013). A simple introduction to the PCA of RGT and interpretation can be found in Fetherston (1995); more mathematically oriented readers can find a detailed description of PCA in Chapter 6 of Pope and Keen (1981).

Explainable cluster and the content analysis

The 2-dimensional space of a given PCA is regarded as a symbolic representation of a given subject's cognitive structure (Bezzi, 1999; Borell, Espwall, Pryce, & Brenner, 2003; Easterby-Smith, 1980). In turn, the positions of the individual objects within the 2-dimensional space are thought to provide good representations of their correlations – that is, the closer two objects are, the greater the degree to which they can explain each other (Ralley, Allott, Hare, & Wittkowski, 2009; Tan et al., 2013; Wickelmaier, 2003). For example, objects mapped on the same quadrant of a 2-dimensional space (25% of the total area of PCA layout) could be seen as one group, such that they explain each other, or they could all be explained with a single reason (Blundell, Wittkowski, Wieck, & Hare, 2012; Gupta et al., 2012; Vanfretti & Farrokhabadi, 2013). These groups in the PCA layout were defined as 'explainable clusters' in the present study, a concept which helped us to clarify which objectives and strategies were capable of explaining one another. The process of identifying explainable clusters consists of manual data processing that utilises non-technological tools. Two rules guide this identification process. First, these objects' positions must be close to each other. The standard used in our study for defining an explainable cluster was stricter than those used in previous studies. The reasons for this greater strictness were as follows. First, we held the view that an instructional strategy used in instruction for argumentation must be highly related to an objective that the teacher is seeking to teach before we can claim that they are explainable for each other. Second, all the instructional objectives and strategies developed by the teachers were based on the SSI scenarios and a student-centred approach, and these conditions might have made the objects closer in the layout of the PCA than objects typically are in other cases. Consequently, we defined an explainable cluster as consisting only of the objects grouped within less than 10–15% of the total area of the PCA layout. The second rule was that each explainable cluster must include at least one instructional objective and one strategy. This rule enabled us to claim that the given objective is meaningful to the given strategy in the given teacher's knowledge of argumentation teaching, which implies, in turn, that the teacher's MSK is well-organised. In this regard, the greater the number of explainable clusters that can be identified in the PCA layout, the more structured the teacher's MSK. Each of the explainable clusters was manually marked by a dotted circle, which made it more convenient for us to examine the components. The explainable clusters may be different from one another in terms of their number of components, that is, the number of instructional objectives and strategies. These differences in components can reveal, in turn, a feature of the teacher's MSK. That is, whether the teacher tends to use more instructional strategies in order to achieve fewer instructional objectives or vice versa. We calculated how many explainable clusters could be found in each PCA layout. Then, we applied the method of content analysis for every explainable cluster to provide further explanations of how these components were important for each teacher's argumentation teaching. Finally, we explored relevant evidence from the transcripts of the interviews and from the transcripts of the student argumentation during the four SSI activities to support our explanations.

Results

The PCA of Evonne's instruction

Figure 2 displays the PCA layout of Evonne's first argumentation activity (Su-Hua highway). Three explainable clusters were found in the layout (Figure 2). The first two principal components in the layout accounted for 77% (56% + 21%) of the variance, indicating that the layout met the standard for the PCA, which meant, in turn, that the objects in the clusters were truly related to each other.

There were three clusters identified in Figure 2. The first one (Cluster I) was composed of one instructional objective and one strategy. The content of the objective was that the students 'producing at least one claim based on scientific knowledge and evidence.' The related strategy was to 'guide the students to explore related literatures about the issue.' This cluster indicates a feature of Evonne's MSK. That is, the strategy of providing guidance for students to explore relevant literatures is important to their ability to generate evidence-based arguments. The following transcript from an interview with Evonne supports our explanation above. Evonne expected that the students could improve their ability to generate evidence-based claims after learning how to collect and explore relevant literatures.

The reason why students always use personal opinions as backing in argumentation could be that they don't know or they haven't collected any related evidence or information about the issue. Thus, I gave them some opportunities to collect related literatures. I asked them to come up with some keywords and then requested that they use the internet and our library to explore the relevant literature.

Cluster II was also composed of one objective and one strategy. The objective was 'generating evidence-based arguments from multiple points of view,' while the related strategy was to 'guide students to make claims according to their character in the role-playing debate activity.' During the role-playing debate, students were asked to make statements according to the career they had chosen (e.g. economist, politician, ecologist, or doctor). Evonne expected that the students would have more opportunities to generate arguments from various points of view when engaging in this activity. The following transcript from an interview with Evonne reveals her expectations.

The role-playing debate activity provides them with opportunities to communicate their ideas about the issue from multiple points of view because they must explore related literature based on the career that they each chose before, and then make statements by using the evidence in the field. I expected that they would thus be able to interpret the issue from multiple perspectives.

Cluster III was also composed of one objective and one strategy. The content of the objective was 'exploring relevant scientific knowledge about the issue.' The related strategy

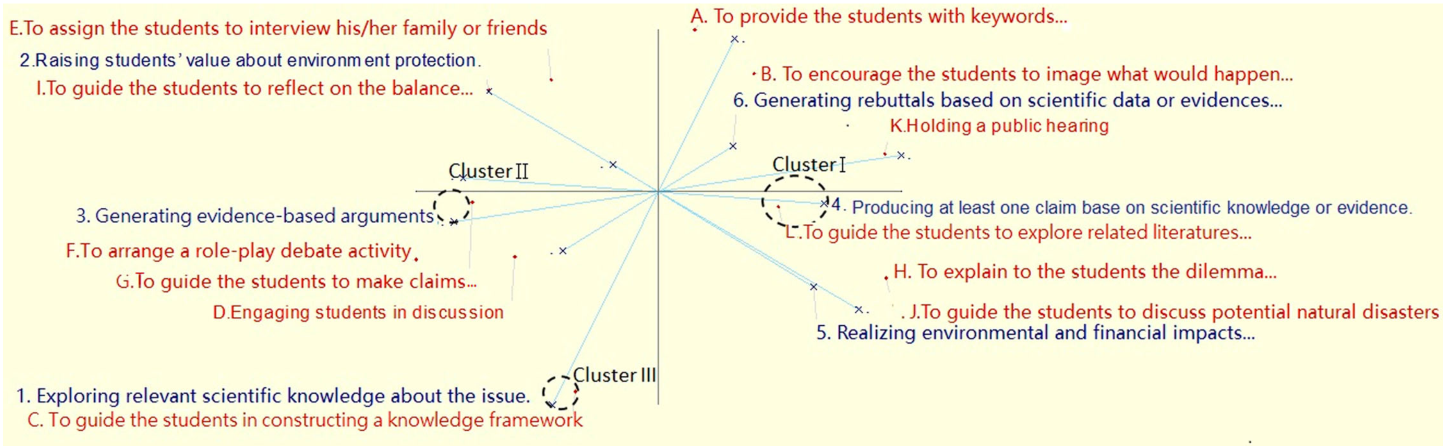

Figure 2. The PCA layout of Evonne's first argumentation activity.

was to 'guide the students in constructing a knowledge framework during the literature review task.' We found that the content in Cluster III was similar to that in Cluster I because both clusters focused on the process of literature exploration. The difference was that the strategy in Cluster I emphasised guiding students on how to collect literature, while the strategy in Cluster III emphasised how to review the collected literatures. Evonne believed that the students might have problems during the literature review process, especially during the process of selecting and reading the literature. As she stated in the interview:

> I cannot expect students to have the ability to know which literature or study is worth reading. Some of the studies are abstract and hard to read … I guided them on how to take notes while reading, and gave them advice on how to organize the ideas they noted into a knowledge framework. For example, I suggested that they develop a framework with two factors; the first factor, position, included two subcategories: affirmative and negative. The second factor consisted of the relevant empirical evidence and also included two subcategories: empirical evidence and theoretical explanations. With this guidance, I felt that they would be able to construct their own knowledge framework and use it when generating an argument.

Evonne provided guidance to help the students to organise the information they collected and expected that they would then be able to develop a knowledge framework that they could then apply conveniently and precisely in argumentation.

Figure 3 shows the PCA layout of Evonne's second SSI argumentation activity (Chemical cosmetics). The percentage of variance for the first two principal components was 70% (48% +22%), indicating that the objects in the clusters of the figure were truly related. There were also three clusters identified in Figure 3. Cluster IV was composed of one objective, namely, 'increasing the degree to which the students value environmental protection.' and one strategy, namely, to 'assign students to interview their parents, teachers, and friends about the issue.' In addition to its social and commercial aspects, the chemical cosmetics issue is also related to the subject of environmental protection. Evonne expected that the students would be able to understand that using cosmetics is a factor that causes various environmental problems. She assigned a task for students; specifically, they had to interview their parents, experts, and their friends to get their opinions about the issue. As Evonne explained:

> During the interview, students may have opportunities to learn that views on this issue may vary from person to person. Thus, they have opportunities to evaluate these various viewpoints after these interviews. These interview activities enable them to reflect on what should be considered when deciding to use or not use chemical cosmetics … I expected them to generate arguments based on the consideration of environmental protection after the task of conducting the interviews.

Cluster V consisted of two objectives and two strategies. The two strategies were as follows: (1) to show the students some information on cosmetic product ingredients and to engage them in discussion and (2) to ask the students to conduct simple scientific experiments to investigate ingredient properties. The two objectives were: (1) generating arguments based on scientific evidence and (2) applying evidence from the scientific experiments and information from their literature reviews to back up their arguments. At the beginning of the debate activity, Evonne showed the students some popular cosmetic products (e.g. foundation, lipstick, mascara, and so on) and then pointed out a number of chemical

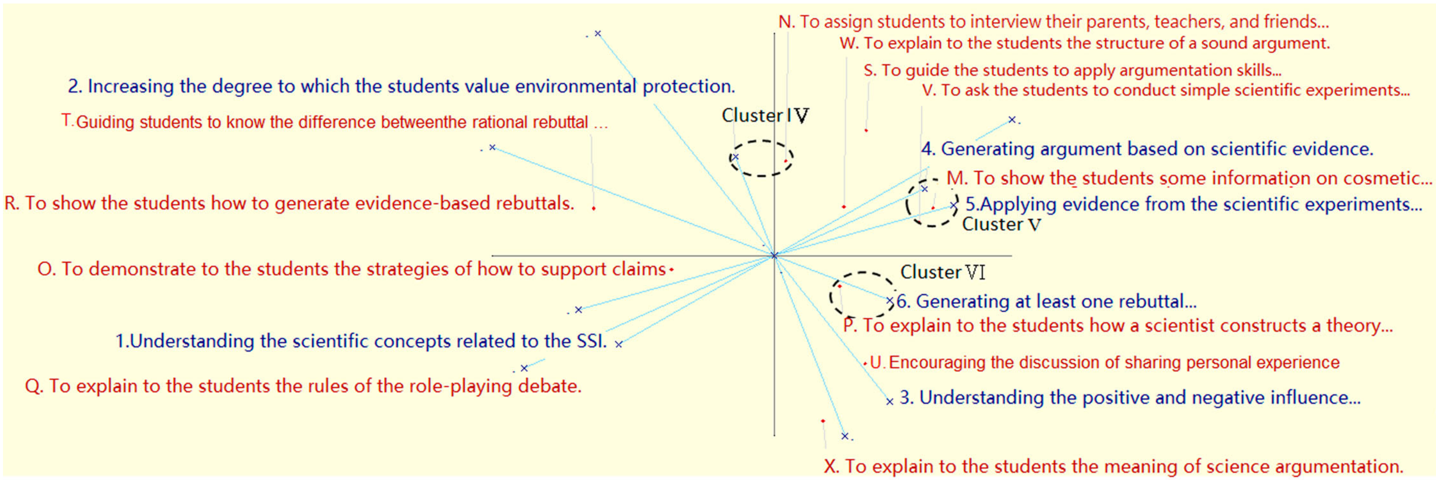

Figure 3. The PCA layout of Evonne's second argumentation activity.

ingredients on the ingredient lists for the products which seem to be harmful to our skin. To investigate these ingredients, Evonne asked the students to explore relevant information on the internet and conduct a simple scientific experiment. The following statements show how Evonne looked back on the scientific experiment activity.

The experimental group object was a small piece of bread with foundation smeared on it. The control group object was also a piece of bread but without anything added to it. After one week of observations, the students found that the control group bread became moldy more easily than the experimental group bread. The result of the experiment enabled the students holding the opposite position to claim that foundation may contain some preservatives.

Cluster VI contained one objective, namely, 'generating at least one rebuttal based on scientific evidence or expert opinions,' and one strategy, namely, to 'explain to the students how a scientist constructs a theory based on evidence.' Generating a rebuttal was considered to be a kind of higher thinking skill in comparison to generating a claim or a warrant, as reported in a previous study. Evonne believed that students do have the ability to generate rebuttals. However, she thought that it might be difficult for them to create a rebuttal based on scientific evidence or expert opinions. As she explained:

> The students may think that to 'persuade' is an important goal in an argumentation activity. Hence, I believe that they have the ability to generate low quality rebuttals. They may need guidance, however, to construct a high quality rebuttal, that is, a rebuttal based on scientific evidence or expert opinions rather than on personal opinions. For this, I explained to them how Charles Darwin collected evidence in the Galapagos Islands, and how he used this evidence to defend his theory of natural selection against challenges provided by other scientists.

Through our analysis of Cluster VI, we were made aware of Evonne's goal of trying to improve the students' ability to generate evidence-based arguments by explaining the process of how scientists make observations, collect data, construct a theory, and face challenges by using evidence.

These six clusters in the two PCA layouts above indicate the features of Evonne's MSK of teaching argumentation. She emphasised teaching the students how to generate evidence-based arguments and expected that this goal would be achieved through activities consisting of knowledge explorations, such as literature reviews, interviews, the role-playing activity, and experiments in the lab. Moreover, she also integrated Charles Darwin's story and explained how he collected evidence and used that evidence to defend his theory. Evonne tried to extend the learning of scientific argumentation beyond the classroom and sought to cultivate an atmosphere in which the students could use the language of science in argumentation.

Dialogue interactions in Evonne's classroom

Based on the findings regarding the clusters discussed above, we selected two episodes from the transcripts of Evonne's classes to show how she provided the students with guidance for improving their argumentation.

Episode 1

Evonne: Do you agree that is okay for people to use chemical cosmetics? Please provide your comments according to the career you have chosen.

Lee: I'm a biologist [in the role-playing debate activity] … I don't agree, because some chemical cosmetics are toxic and will damage our skin.
Evonne: What kind of chemical ingredients are toxic?
Lee: Studies have reported that a number of chemical elements such as mercury, alcohol, and hydroquinone are always added to cosmetics.
Ben: I have similar findings. These ingredients are hazardous to our environment, and will damage our skin. Therefore, I don't agree with people using chemical cosmetics.
Evonne: Good, anyone want to share ideas? Lai, what did your parents say in the interview?

At the beginning of the excerpt, Evonne asked the students to share their opinions regarding the use of chemical cosmetics. A student named Lee said that she disagreed with people using chemical cosmetics because she found that, from the point of view of biologists (the career she had chosen for the role-playing activity), some chemical cosmetics will damage our skin. Evonne agreed with Lee's opinion, but was unsatisfied with the reason Lee provided as backing. Evonne expected that Lee and the other students in Lee's group would be able to provide more explanation based on Lee's opinion. After that, Lee and Ben both repeated a passage from their notes referring to a number of chemical ingredients which are regarded as being harmful to our skin. Their argument was based on scientific studies and could thus also be regarded as a high-quality argument. The above excerpt shows that the learning atmosphere in Evonne's classroom was harmonious. The learning atmosphere supported the students' co-construction of knowledge, and also supported their production of evidence-based arguments. Episode 2, which followed immediately after Episode 1, shows how the teacher guided the students in generating rebuttals, which are usually regarded as a factor in causing dialogue conflicts and negative learning atmospheres during argumentation.

Episode 2

Evonne: … Lai, what did your parents say in the interview? Please share your interview experience with us.
Lai: My mother said that using cosmetics is a kind of polite behavior, especially for ladies, and that when they must attend an important ceremony, they need cosmetics.
Evonne: Do you agree with Lai's opinion? Anyone agree or disagree with her?
May: I agree that using cosmetics is necessary; it makes us good looking …
Evonne: Julie, would you please …
Julie: I don't agree with Lee [a student taking the opposing position] because not all cosmetics have chemical ingredients; some cosmetics are totally made from natural materials …
Evonne: Julie's comment is important; we must choose safe cosmetics before using them … Julie, can you give us some examples of cosmetics that are made with natural materials?
Julie: I know some cosmetic products that are organic. Here, this is my summary: 'In contrast to traditional cosmetic products, natural products are made of materials such as minerals, fruit oils, and natural colors derived from plants … '
Evonne: Julie uses important information to back her argument. Obviously, her argument is persuasive. Thus, evidence such as facts, reports, examples, and figures are important not only in argumentation, but also in making decisions. That is

> why it is important for scientists, like Charles Darwin, whose story we discussed before.

At the beginning of Episode 2, Lai shared her interview experience with her mother, and stated that she agreed that it is okay for people to use cosmetics because it is a kind of polite behaviour, especially for a lady. May and Julie (who were in same group as Lai) participated in the conversation after Lai's statement. Julie made a rebuttal against Lee's argument (in Episode 1), stating that she had found that there are natural and organic cosmetics available on the market. She then provided empirical evidence as a backing for that rebuttal. Based on Julie's statements, Evonne explicitly explained to the students the importance of using evidence in argumentation. In our analysis, we found that Evonne asked her questions strategically. First, Evonne knew that Julie was a member of the group taking the opposite position on this issue, and so purposely asked her to make a response. Evonne expected Julie to be able to use evidence, like Lai, to support her assertion. Second, Evonne found Julie's first statement to have some ambiguity, even though she had already generated a reasonable backing. Consequently, she expected Julie to provide some further explanation regarding what kinds of ingredients are made from natural materials. Evonne's guidance enabled the argumentation to be more focused on evaluating the quality of the dialogic interactions, rather than on evaluations of the students' persuasiveness.

The PCA for Sue's instruction

Figure 4 shows the PCA layout for Sue's first argumentation teaching design. It was found to indicate a high percentage of variance, with the first and second components accounting for 80% (59% + 21%) of the total variance. The layout thus met the standard for PCA.

There was just one cluster (Cluster VII) identified in Figure 4. That cluster was composed of one objective and three strategies. The objective was 'working collaboratively on the task of completing a literature review.' The three strategies were as follows: (1) to guide the students to explore related information about the SSI in the school library and on the internet; (2) to encourage the students to share and communicate their ideas about the SSI, and (3) to ask the students to generate arguments from multiple perspectives. Cluster VII indicated that Sue thought that it was important to improve the students' communicative and collaborative skills so that they could look at the issue from various points of view and generate arguments from multiple perspectives.

I will improve their communication and collaboration skills before teaching them how to argue scientifically. I think that these communicative and collaborative skills are closely

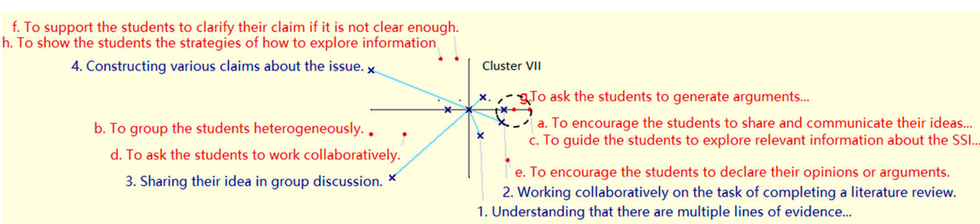

Figure 4. The PCA layout for Sue's first argumentation activity.

related to their argumentation ability. Thus, I asked them to work together in literature exploration, and encouraged them to communicate their ideas in a group discussion. I expected that this would improve their ability to think flexibly and to understand that every topic can be probed from different angles.

Figure 5 shows the PCA layout of Sue's second argumentation issue (chemical cosmetics). The percentage of total variance accounted for by the first two components was 81% (69% + 12%). Cluster VIII was composed of two objectives and one strategy. The objectives were as follows: (1) generating at least one claim in argumentation, and (2) understanding the scientific concepts related to the issue. The strategy was to 'ask students to reflect on how they argued during the first argumentation activity, and then apply these learning outcomes to the second one.' The cluster indicated that Sue considered the capacity to make a statement, assertion, and claim to be important for students in learning how to argue scientifically, although the capacity to do so is regarded as a basic-level argumentation ability compared to the ability to generate claims with backing, warrants, and rebuttals (Erduran et al., 2004). The following statements from the interview with Sue show her considerations.

I think it was still too difficult for them to generate arguments with backing, warrants, or rebuttals, even during the second SSI activity. As we know, they are used to learning in traditional lecture-based classes. So I wanted to give them more time to change their learning habits. That is why I asked them to reflect on what they learned in the first argumentation activity, during the instruction for the second one. For me, the good thing about the teaching argumentation was that the two SSIs were both related to environmental protection. So this provided students more time to learn how to use scientific concepts as backing in argumentation.

Sue believed that the students needed more time to get used to learning through the argumentation activity. She also believed that she had opportunities to improve the students' higher level argumentation abilities if the students kept sharing, discussing, and using the basic-level argumentation skills. The main reason for these beliefs was that Sue considered the first and second SSI to both be related to the issue of environmental protection. This meant that the students had a chance to apply what they had learnt in the first SSI argumentation during the second activity and that Sue would have more opportunities to reemphasise important concepts to improve students' argumentation abilities.

Dialogue interactions in Sue's classroom

The following excerpt shows the dialogue interactions of Sue, the novice teacher, in discussing the cosmetics topic.

Episode 3

Sue (Teacher):	Do you agree with people using cosmetics? Please …
Cheng:	Yes, I agree …
Sue:	OK!
Alexis:	I don't agree. Cheng, you are wrong …
Sue:	OK! Why?
Cheng [a little bit angry]:	I still agree …

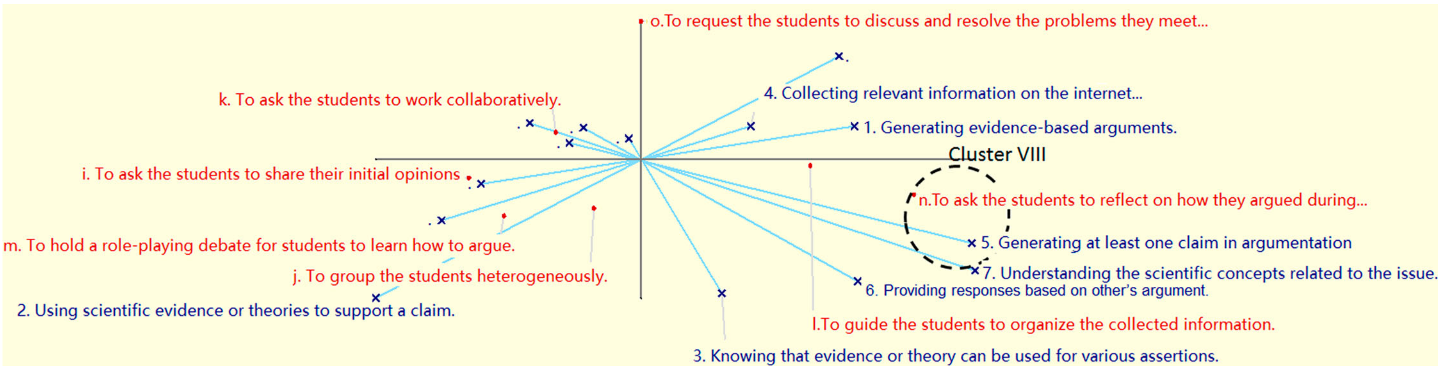

Figure 5. The PCA layout of Sue's second argumentation activity.

Sue: Ok, listen to me. Please give me some reasons? [No students raised their hands or talked at first.]
Sue: Don't be shy, any reason will be accepted, so share your opinions. You may say: I don't agree or I agree … because …
Joe: Cosmetics are important, women always need cosmetics.
Tina: Many women are born with beauty and they don't really need cosmetics.
Sue: Both reasons are okay. Please follow the template I gave you, you can say … I don't agree with … because …

At the beginning of the above episode, Sue encouraged the students in both positions to share their opinions and the reasons for their opinions. There was a disagreement between Cheng and Alexis. Sue noticed this situation and tried to prevent any discord. She first reasserted control over the discourse by withdrawing the students' permission to speak (when she said 'listen to me'), and then asked them to provide reasons and explanations. To improve the students' ability to argue based on reasons, Sue stated a simple template consisting of 'I don't agree or I agree … because … ' She expected that this would encourage the students to talk more about the issue. Continuing from Episode 3, Episode 4 shows how Sue provided more detailed guidance for the students on how to generate reasons to back up their claims.

Episode 4

Wendy: I don't agree with people using cosmetics, because there are preservatives in most cosmetic products. These preservatives will make our skin older quickly.
Sue: This is a good reason; can anyone in the affirmative position tell me why cosmetics are important …
Cheng: Using cosmetics will make a lady look good.
Sue: I agree with that. Do you agree with Cheng, Alexis? She said using cosmetics makes people look good …
Alexis: Yes, using cosmetics is important for a lady, because it is a kind of politeness.
Sue: Yes, you get a point. Good reason.

At the beginning of the episode, Wendy stated that she does not agree with people using cosmetics because she found out that there are preservatives added to some cosmetics. In contrast with Wendy, Cheng and Alexis both agreed with people using cosmetics because they considered it to be impolite for girls to go out without make-up on. It is worth noting that Sue encouraged Alexis to make comments based on Cheng's opinion rather than based on Wendy's opinion. There was a scientific term, 'preservatives,' included in Wendy's statement. This chemical term could have been clarified and discussed if Sue had asked the students to explain it more. On the other hand, what Cheng stated was just a simple claim, which did not include any scientific terms or concepts. The interactions in Episode 4 showed that Sue spent more time on encouraging students to discuss the issue of using or not using cosmetics, rather than on discussing any scientific concepts they brought up. Sue explained this situation to us as follows:

> I still can't expect Wendy or the other students to provide scientific explanations of what a preservative is. On the other hand, I believe that more students will join the discussions and give their opinions if I encourage them constantly. I want to change their learning habits, and the first step in doing so is to nurture their ability to communicate. I chose an easier question

> for them to make responses to, rather than asking them to explain what preservatives are. They may know what preservatives are, but few of them can identify what they are from a scientific perspective.

Sue emphasised the students' communicative abilities during the argumentation activity. In Sue's view, asking questions to encourage students to give their opinions is easier than asking questions requesting that they make explanations scientifically. From our viewpoint, Sue's approach was reasonable, because she thought that most of the students were still used to learning in a traditional lecture-based classroom. Sue wanted to change this learning style, and her first step in doing so was to encourage the students to participate in the group and classroom discussion.

Discussion and suggestions

Previous studies of argumentation teaching have indicated that science teachers rarely integrate scientific argumentation into their science teaching because the teaching of argumentation requires training (Duschl & Osborne, 2002; McNeill & Knight, 2013; Simon et al., 2006; Zembal-Sual et al., 2002; Zohar, 2008). In our study, however, we found that even teachers with little experience in teaching argumentation have the ability to integrate argumentation into their teaching. Thus, our first suggestion regarding professional development for teaching argumentation is that the teaching of argumentation itself be encouraged. This suggestion is also supported by previous studies advocating that argumentation should be emphasised in science learning (Clark & Sampson, 2007; McNeill et al., 2016; Simon et al., 2006; Zohar, 2008). Indeed, the results of the present study showed that both of the teachers who participated could teach argumentation; however, their teaching processes were quite different. One obvious difference was that the experienced teacher was able to utilise more varied instructional strategies and objectives than the novice teacher. For example, she requested that her students collect data through interviews and scientific experiments, held a public hearing activity, and explained to the students various methods for constructing a sound argument. These strategies were not applied in the novice teacher's classrooms; however, the results of the experienced teacher's PCA indicated that these strategies were components of the explainable clusters, which means that they play an important role in achieving the proposed instructional objectives in the experienced teacher's MSK.

The PCA results also indicated a difference between the two teachers' MSK for argumentation teaching. There were more explainable clusters identified in the experienced teacher's PCA than in the novice teacher's PCA. This result enabled us to claim that the experienced teacher had more organised MSK than the novice teacher had. That is, most of the instructional strategies used in the experienced teacher's classrooms were developed with more of a focus on improving the students' argumentation ability, and they also exhibited a greater degree of consideration regarding the proposed objectives. In other words, her strategies were more directly relevant to the objectives. In the beginning of episode 1, for example, she asked the students to provide comments regarding the issue of chemical cosmetics based on the careers they had chosen, such as economist, politician, ecologist, or doctor. According to the content analysis, this questioning strategy was mainly employed to achieve the objective of 'generating evidence-based arguments from multiple points of view.' The results of the experienced teacher's PCA supported our content analysis. Cluster II of that analysis revealed that the relationship between the questioning strategy and the objective above was a close one. In episode 2, the teacher explained to the students how Charles Darwin had defended his theory against rebuttals from other scientists, and then asked the students to use scientific evidence in the construction of their arguments. Such guidance was also highlighted in cluster VI, which pointed out that the relevant objective of the guidance was that of 'generating at least one rebuttal based on scientific evidence or expert opinions.' In our view, these guidance and questioning strategies in the experienced teacher's MSK and instructions were developed based not only on the proposed objectives, but also on the students' prior knowledge and experiences. She emphasised the students' experiences of exploring relevant texts and scientific data. She guided them to take notes while reading, carry out experiments, and conduct interviews, and gave them advice on how to organise their findings and thinking into a knowledge framework. These data exploration and organisation experiences enabled the teacher to have confidence in her expectation that the students had the ability to discuss relevant scientific knowledge surrounding the issue and to construct more sound arguments through collaborations with and evaluations by their peers. For example, she asked Lee to explain what ingredients make cosmetics toxic, asked Lai to share their interview data, and also asked Julie to explain the issue further based on May's argument regarding the ingredients of cosmetics. This guidance enabled the students' argumentation to be more focused on scientific knowledge, rather than on the students' emotional and personal opinions. This approach also aligned with a suggestion provided in McNeill et al. (2016) that science teachers' PCK of argumentation should be focused on 'dialogic argumentation in terms of the quality of student interactions in which they build off of and critique each others' claims, rather than goals such as persuasion that are difficult to observe' (p. 261).

On the other hand, the instructional strategies used in the novice teacher's classrooms were not so clearly based on the objectives she had set out before providing the instruction to her students. In episode 3, the novice teacher asked the students to provide reasons to support their positions. However, most of the reasons were based on personal opinions rather than on scientific evidence, in spite of the fact that a template of 'I (don't) agree … because' was provided to the students by the teacher as scaffolding. The feature of using personal opinions as backing in argumentation was also reported in previous studies (Albe, 2008; Baker, Bernard, & Dumez-Féroc, 2012; Golanics & Nussbaum, 2008; Osborne, Erduran, & Simon, 2004; Zohar & Nemet, 2002). The authors of those studies suggested that students need explicit guidance on how to argue collaboratively (Asterhan & Schwarz, 2007; Clark & Sampson, 2008; Nielsen, 2013), what counts as scientific evidence (Kelly & Bazerman, 2003; Kelly & Takao, 2002; Zeidler, 1997), and how to construct a sound argument (Hogan & Maglienti, 2001; Kuhn, 1991; Simon et al., 2006). In our case, the guidance (template) provided by the novice teacher seemed to be insufficient, in spite of the teacher's belief that the students did have the necessary abilities to engage in argumentation. As such, Sue's argumentation teaching reflected a number of challenges in terms of her PCK about what types of questions may be appropriate for framing the argumentation in order to achieve the teaching objectives laid out beforehand, as well as her PCK regarding how to guide students' dialogue interactions based on scientific evidence. In terms of her MSK, Sue indicated the belief that students need time and practice to change the learning habits that they have developed in traditional environments. Hence, the instructional objections developed in Sue's instructions had a greater emphasis on the basic level of argumentation abilities, such as the ability to generate a claim, the ability to make various claims, the ability to use different pieces of evidence to support a claim, and so on. For her instructional strategies, she chose easier questions intended to help the students to practise how to share and communicate ideas, stopped the students' dialogue conflicts, and encouraged the students to engage in learning reflections. The analysis of Sue's MSK revealed a process of change in her teaching from approaches with an emphasis on traditional lecture-based learning to approaches that emphasised peers' dialogue interactions, collaborations, and a humorous learning atmosphere. Moreover, it also implied that the educational change required for the teaching and learning of scientific argumentation takes time and practice (Fullan, 2001; Sadler, 2006). We expected that our analysis of these two teachers' argumentation teaching would inspire science teachers to integrate scientific argumentation in their classrooms.

Conclusion

The present study investigated and compared two science teachers' MSK of argumentation teaching through the application of the RGT. According to the results of our analyses, the instructional objectives and strategies for argumentation learning in the experienced teacher's instructional design were more varied than those in the novice teacher's design. Moreover, more explainable clusters were identified in the experienced teacher's PCA results, which implied that the experienced teacher's MSK of argumentation teaching was more organised than the novice teacher's MSK of argumentation teaching. A primary feature of the novice teacher's teaching of argumentation was that she tried to make a difference in terms of her science teaching and the students' traditional learning style. One strategy she used to encourage this change was to establish a humorous learning argumentation atmosphere in which the students were encouraged to explore relevant information, share their findings, and communicate their opinions collaboratively. To support the students in getting used to learning in a more student-centred environment, the novice teacher provided a more basic level of questions to facilitate their argumentation, and then gradually guided them to use scientific evidence as backing. In contrast with the novice teacher, the experienced teacher's argumentation teaching emphasised the students' knowledge and experience construction. She indicated the belief that students can only generate more sound arguments when they have opportunities to explore the related information and, more importantly, to organise and create a knowledge framework of their own. Another feature of the experienced teacher's argumentation teaching was revealed through the PCA results, which indicated that most of the instructional strategies she used in her teaching were closely related to the proposed objectives, which implied, in turn, that these strategies were quite effective in eliciting improvements in the students' argumentation ability. Both teachers in our study demonstrated learning and adaptive processes for the teaching of argumentation. They developed instructional objectives and strategies, identified problems in the students' learning, and continuously adjusted the guidance they provided in order to improve the quality of the students' argumentation. We believe that these processes are important in their professional development with respect to the efficacy of their science teaching. Based on the discussion of the two teachers' MSK of argumentation, we considered the possibility that creating a humorous and supportive learning environment might constitute a first step towards encouraging students to discuss their own ideas and listen to those presented by others. However, more guidance is required in order to improve students' argumentation such that it is more based on scientific knowledge than on personal opinions. From the classroom observations in this study, it seems appropriate to guide students to explore both empirical and theoretical data collaboratively and then construct knowledge frameworks of their own, so that they can use these frameworks in a convenient and precise manner in their argumentation. Methodologically, the application of the RGT in this study enabled us to investigate both teachers' MSK, and led our qualitative analysis to be more systemic and focused on the field of meaningfulness in the teachers' cognitive structures. We believe that the RGT can provide new insights and a new approach for future research into the teaching and learning of argumentation.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Cheng-Yu Hung http://orcid.org/0000-0002-6869-290X

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