

THE IMPACT OF TEACHERS' PEDAGOGICAL KNOWLEDGE OF TRIPLET RELATIONSHIP ON THEIR DECISION TO TEACHING TRIPLET IN CHEMISTRY

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Abstract: Since early nineties, Johnstone (1991) introduced the idea of three levels of representation in chemistry, the first is 'descriptive and functional', the second is 'explanatory', and the third is 'representational'. These three levels of chemistry representation were named as 'triplet relationship' (Gilbert & Treagust, 2009). Despite considerable research evidence about the positive impact of explicit teaching of triplet relationship on students' conceptual understanding in chemistry, it is not commonly seen in Hong Kong chemistry classrooms. The lack of enthusiasm among chemistry teachers in implementing this approach in teaching chemistry suggests that there are issues and concerns to be resolved before teachers see considerable advantages of this approach over their current practices. This study follows Boz and Boz's (2008) arguments to explore: What and how much of pedagogical knowledge related to the triplet relationship do chemistry teachers possess, and does such pedagogical knowledge affect their decision to teach the triplet relationship in their lessons, and how? Three chemistry teachers were recruited for this multiple-case qualitative study. The data collected from each teacher includes field notes taken during the class observation, video record of all lessons observed, artefacts of lesson materials, and hours long in-depth interviews were conducted with each teacher. Simon's pedagogical knowledge of triplet relationship is comparatively weaker than others, he thinks linking up any two levels is adequate. Pamela has good pedagogical knowledge of triplet relationship, she uses macroscopic as the core of teaching, followed by (sub)microscopic level explanation and symbolic level representation. Johnson has very good pedagogical knowledge of triplet relationship, he thinks choosing the appropriate context is the most important idea of teaching triplet, such as teaching with demonstration as the core for the topic of acid, focusing on particle theory for the topic of periodicity, and using graphs as the major pedagogies to teach equilibrium.

Keywords: Chemistry, Instructional strategies, Teacher professional development

BACKGROUND AND RATIONALE

Since early nineties, Johnstone introduced the idea of three levels of representation in chemistry, the first being 'descriptive and functional', here named as 'macroscopic', which is mainly about something tangible in chemistry such as colour and conductivity. The second level is 'explanatory', here named as 'sub-microscopic', which is mainly about ions, atoms and molecules, while the third level is 'representational', here named as 'symbolic', which is mainly about symbols, formulae and equations (Johnstone, 1991). These three levels of chemistry representation were named as 'triplet relationship' (Gilbert & Treagust, 2009).

Johnstone and El-Banna (1986) encourage students to learn chemistry concepts by thinking about them at three levels: the macroscopic, sub-microscopic and symbolic levels. Kozma &

Russell (1997) suggest that the development of skills in translating/transforming among different levels of representation is advantageous to learning chemistry and Gabel (1999) believes that relating macroscopic/sub-microscopic/symbolic levels of chemistry representations could enhance conceptual understandings. Experimental studies were carried out in order to examine whether learning the triplet relationship benefits students' learning outcomes. For instance, educators (e.g. Bunce & Gabel, 2002; Treagust & Chandrasegaran, 2009) concluded their findings that if students are taught explicitly with 'macroscopic/sub-microscopic/symbolic' representations, they would have better conceptual understanding and competency in describing and explaining chemical reactions.

Despite considerable research evidences about the positive impact of explicit teaching of triplet relationship on students' conceptual understanding in chemistry, such an instructional practice is not commonly reported globally and it is not commonly seen in Hong Kong chemistry classrooms. The lack of enthusiasm among chemistry teachers in implementing this approach in teaching chemistry suggests that there are issues and concerns to be resolved before teachers see considerable advantages of this approach over their current practices.

FRAMEWORK

Teachers' decision making upon planning and implementing an instructional task could be fairly complex (Clark, 1988), it could be determined by teachers' knowledge base Shulman, (1986, 1987) which includes (1) subject matter knowledge, (2) pedagogical content knowledge, (3) curricular knowledge, (4) general pedagogical knowledge, (5) knowledge of learners and their characteristics, (6) knowledge of educational contexts, and (7) knowledge of educational purposes, and it could also be affected by teachers' beliefs and attitudes towards teaching (Van Driel, Beijaard, & Verloop, 2001). Boz and Boz (2008) argue that 'general pedagogical knowledge'; 'subject matter knowledge'; and 'knowledge about students' difficulties' are main factors affecting teachers' choice of teaching practices. The study follows on Boz and Boz's arguments to explore the three factors corresponding to triplet relationship that may affect teachers' decision about teaching the triplet relationship in their chemistry classrooms, illustrated by figure 1.

Here we report on the findings related to the one of the investigated factor, i.e. the findings centre around the following research question:

What and how much of pedagogical knowledge related to the triplet relationship do chemistry teachers possess, and does such pedagogical knowledge affect their decision to teach the triplet relationship in their lessons, and how?

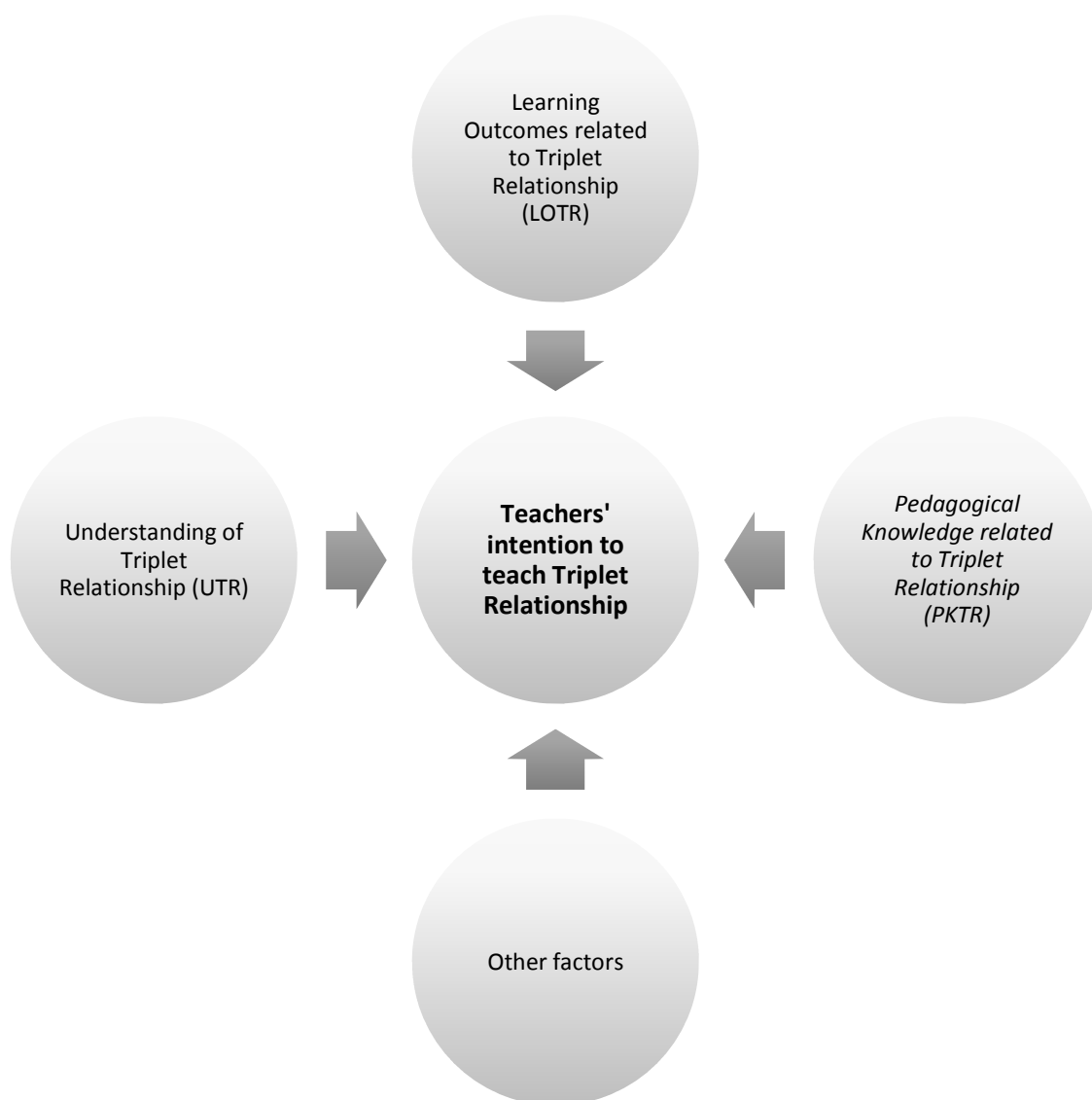


Figure 1. Theoretical framework of the study

METHODOLOGY AND METHODS

This is a multiple-case (Yin, 2003) qualitative study (Guba & Lincoln, 1994; Henning, et al., 2004), which aims to provide an in-depth description of a small number of cases. Three chemistry teachers were recruited for in-depth study using a purposive and convenience sampling approach.

Sample teachers were selected by means of two sampling methods, namely convenient and purposive. The convenient sampling method involved inviting teachers who had been recommended by two local science teacher educators in my Faculty. They all are former Postgraduate Diploma in Education (PGDE) students, major in chemistry education, who have maintained close contact with the educators. The purposive sampling method involved selecting

teachers who fulfil the requirements needed for the purposes of this study: (1) they are chemistry teachers who have been allocated with reasonable number of chemistry lessons by their schools so that arrangement of observations of their chemistry lessons can be made; (2) they are keen on improving the quality of their teaching and students' learning; (3) they show initial intention to teach the triplet relationship in their chemistry lessons; and (4) their schools will be cooperative in allowing teachers to participate in projects which they consider helpful to their own professional growth even though it might involve attempts of a new teaching approach. As a result, they are recruited and demographic data were collected during the first semi-structured interviewed and thus their backgrounds are summarized in table 1.

Table 1
General backgrounds of three sampled teachers

<i>Name</i>	<i>Johnson</i>	<i>Pamela</i>	<i>Simon</i>
Undergraduate study	Chemistry	Chemistry	Chemistry
Postgraduate study	PhD (Chemistry); Postgraduate Diploma in Education (PGDE)	Postgraduate Diploma in Education (PGDE)	MSc (Environmental Science); Postgraduate Diploma in Education (PGDE)
Years of teaching chemistry	4 years	8 years	10 years
Teaching level	s.1-s.7 (grade 7-13)	s.5-s.7 (grade 11-13)	s.3/4/7 (grade 9/10/13)
Teaching subject	Chemistry and Integrated Science	Chemistry	Chemistry

Explaining teachers' decision on teaching or not the triplet relationship with their pedagogical knowledge related to the triplet relationship, which includes pedagogical knowledge (and skills) of designing and implementing the lessons. Teachers choose chemistry topic(s) for teaching the triplet relationship and then start planning and designing the lessons. I visit them and observe their lessons. Field notes taken during the class observation, video record of all lessons observed, artefacts of lesson materials are carefully collected. The first author conducted post-lesson semi-structured interviews with each teacher, eliciting their thoughts on planning and designing of the lesson, their choices of teaching sequence, teaching strategies, and teaching materials. Where appropriate, the relevant video episodes of the classroom activities were showed to recall teachers' memories and facilitate their elaboration.

Data analysis is conducted once data collected throughout the year of data collection period. All different types of qualitative data are transcribed, coded, categorized, and analysed. For instance, data for 'teacher's pedagogical knowledge' are coded and categorized, sub-categories such as 'planning'; 'implementation'; 'teaching sequence'; 'teaching materials'; 'teaching pedagogies', etc are used. Further analyses are conducted from these sub-categories of data, and conclusions for unpacking the factors affecting chemistry teachers' decision on teaching triplet relationship or not will be drawn.

RESULTS

Simon's pedagogical knowledge reflected from his teaching

Simon teaches with a wide range of pedagogies, such as lecture, self reading, demonstration, hands-on activity, etc. Since Simon's school has its own teaching/learning theme yearly, and the theme of the year I observed his teaching was "graphic organizer", Simon planned some of his lessons aligning with the theme.

Simon does not teach the triplet relationship very explicitly as he said at the beginning of the study, but he talks about it either at the beginning of a topic as an introduction or towards the end of a topic as a summary. For instance, he chose teaching the triplet relationship on the topic of REDOX, and he chose to teach the triplet relationship at the beginning as an introduction. Simon drew a big triangle on the blackboard and asked students what labels he should put down on each corner of the triangle, and students knew clearly that they are "macroscopic", "(sub)microscopic" and "symbolic". He then facilitated students to list the learning issues under each corner, as a result they listed "observation", "reaction", "chemical cell", "electrolysis" for macroscopic; "what is happening inside the cell" for (sub)microscopic; and "REDOX equation", "oxidizing agent", "reducing agent", "acid/base" for symbolic. This was how Simon started to teach the triplet relationship of REDOX.

Pedagogies used by Simon for enhancing students' understanding of macroscopic level

Simon agrees that teaching Chemistry with demonstrations and hands-on activities enhancing students' macroscopic level of understanding, so that he arranges as many laboratory opportunities as he can on teaching each topic. According to one local exchange student's comment, comparing with other Chemistry teachers in her school, the numbers of hands-on activities Simon prepared are a lot more than that arranged by other Chemistry teachers in her original school.

After teaching the three ways of defining REDOX, "oxygen transfer", "electrons transfer" and "oxidation number change", many students were still not sure if all three conditions must be fulfilled or only fulfilling any one of them in order to determine whether the reaction is a REDOX. Simon realized students' difficulties and thought of a way to resolve it, he decided to use a demonstration on the following day in order to provide students some kind of visual impact and observable proof before he elaborate his teaching. Simon prepared to demonstrate the reaction between Magnesium and Copper (II) Sulphate, students predicted the observations of blue colour fading and reddish brown solid forming due to the change of Copper (II) ions to Copper metals, and they witnessed both observable predictions. Simon asked students if they could see any oxygen transfer from equation or observation, if they could see any electrons transfer from equation or observation, and if they could see any oxidation number change from equation or observation. Students said that they could not see any oxygen transfer, but they could see electrons transfer from equation and supported by observation, and they could also see oxidation number change from equation. Simon then told them if a reaction fulfils any one of the three conditions, it is a REDOX, and the demonstrated reaction is a REDOX.

Pedagogies used by Simon for enhancing students' understanding of (sub)microscopic level

Simon believes that his understanding in (sub)microscopic level is not so excellent that his teaching on this level is not good enough. Since (sub)microscopic level of understanding is not a usual assessing area in public examinations in Hong Kong, Simon never deeply reflects on how to improve his teaching in this area. Owing to two reasons, Simon seriously considered improving his teaching: (1) the yearly teaching/learning theme of his school was graphic organizer and (2) (sub)microscopic level is one of the critical elements of the triplet relationship.

When Simon taught Volumetric Analysis, instead of just teaching from the perspective of symbolic level of understanding such as $M_1V_1 = M_2V_2$, he tried to explain the concentrations before and after dilution, he used a pictorial representation (Figure 2) to facilitate his students' (sub)microscopic level of understanding, and he used some other authentic and macroscopic level of understanding, such as diluting tea or orange juice and cutting cake, to link up the abstract and difficult concepts.

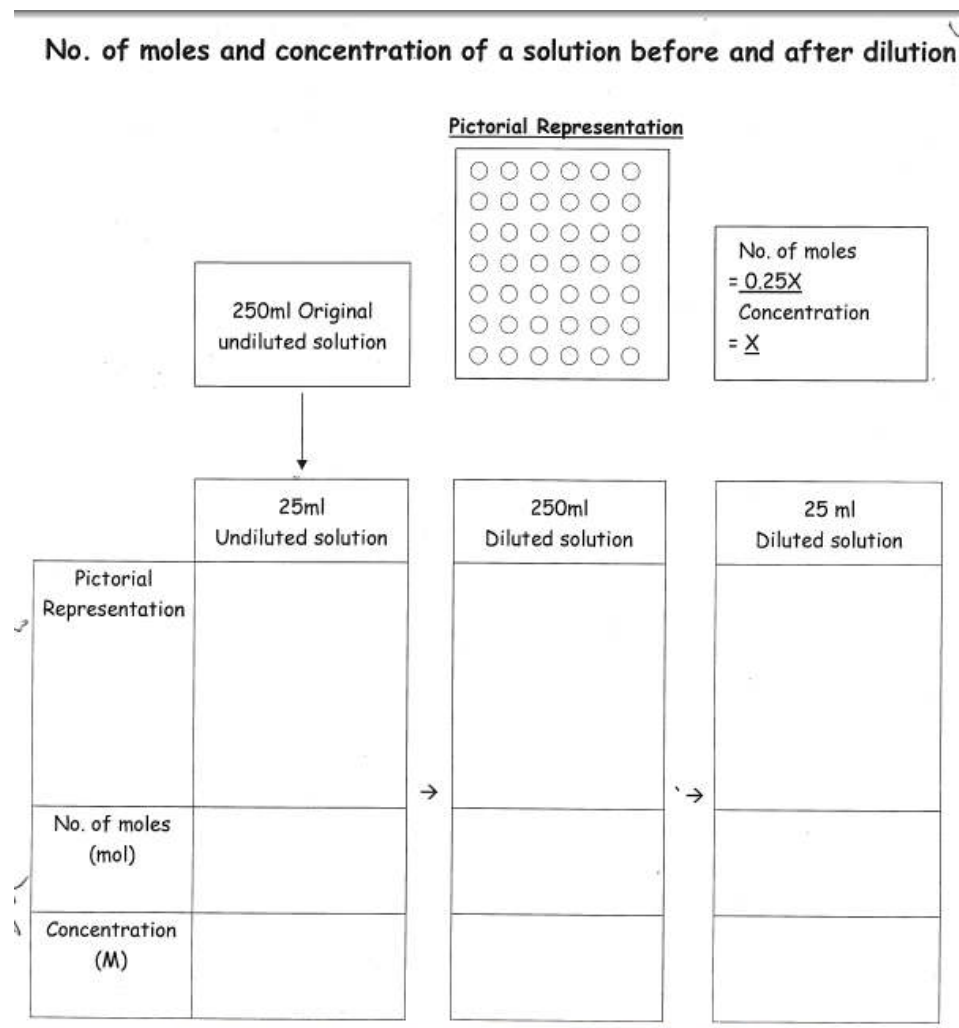


Figure 2. Enhancing understanding of (sub)microscopic level of Volumetric Analysis

Pedagogies used by Simon for enhancing students' understanding of symbolic level

Simon agrees that teaching symbolic level of understanding can be very arithmetic sometimes, so he usually tries to link up the symbolic level with another level of understanding. When Simon taught students choosing the appropriate indicator for different types of acid-base titration, he could have simply taught them four acid-base titration conditions and asked them to memorize using which indicator for which condition. However, he decided to teach them with deeper understanding since he believed that class of students were more capable cognitively. Using four titration graphs which typically taught in A-level in the past: strong acid and strong base; strong acid and weak base; weak acid and strong base and weak acid and weak base, Simon easily linked them up with the macroscopic level of understanding which is the colour change of different indicators, and hands-on activities were arranged to support students' observational impacts purposively.

Pamela's pedagogical knowledge reflected from her teaching

Pamela uses a wide range of teaching pedagogies in order to teach the triplet relationship in different contexts, and it seems to me that there is a pattern. For instance, she uses demonstrations to enhance students' observations in order to have better understanding in the macroscopic level, she uses models and animations to illustrate (sub)microscopic level of understanding, and she uses simulations to enhance students' understanding of the symbolic level such as getting data and plotting graph.

Pamela criticized that the textbooks used in Hong Kong do not spell out the triplet relationship clearly, Chemistry teachers have to be very experienced and skilful in order to dig out the triplet relationship from the textbooks and apply in their teachings. So Pamela designs her own teaching/learning materials, with careful considerations and explicit incorporation of the triplet relationship. She elaborated and said,

Pedagogies used by Pamela for enhancing students' understanding of macroscopic level

Pamela believes that different pedagogies enhance students' understanding on different levels of the triplet relationship. Macroscopic level of understanding is mainly focused on observations; Pamela usually uses either hands-on experience or demonstration to improve students' observational skills and thus their macroscopic level of understanding. Since her class sizes are usually small and she prefers to let her students to gain their own hands-on experiences. Only if dangerous chemicals such as concentrated acids are involved in the experiments, Pamela rather demonstrates the experiments. Moreover, if the experiments require extremely careful and precise observations, Pamela demonstrates the experiments and requests students to pay extra attentions on all observations.

Pedagogies used by Pamela for enhancing students' understanding of (sub)microscopic level

Pamela believes that the education system and examination system in Hong Kong do not demand a lot of (sub)microscopic level of understanding from students, so that many teachers usually put their teaching foci on the macroscopic level and symbolic level, especially if they put their teaching priority on coping with the public examination. (Sub)microscopic level of understanding is the weakest level among three for most of the students in Hong Kong. It turns

out that they cannot link up all three levels of relationship and thus they do not understand the Chemistry concepts deeply. As a result, Pamela tries to use different pedagogies to strengthen students' understanding of (sub)microscopic level, such as using models and computer assisted methods.

Pamela often uses "ball and stick model" to improve students' understanding of (sub)microscopic level such as atoms, ions, molecules, compounds, bonding, structures, shapes, etc. These are all abstract knowledge to many secondary school students and one of the major reasons leading to their learning difficulties is invisibility. Pamela usually encourages her students to play around with the ball and stick model and build their own knowledge from there.

For instance, Pamela taught her S.4 class on the topic of Polarity, she inspired her students to think of the differences between polar molecules and non-polar molecules from the perspective of their bonds and shapes such as CH_4 , NH_3 and H_2O , she asked her students to build the molecular models for each and pay attentions to the details such as bond pairs, lone pairs, repulsion forces, bond angles, etc.

When Pamela taught her S.4 class on the topic of Hydrogen bond, she taught the idea of ice floats above water, she explained it with the concept of shapes, structures and densities of both water and ice. Pamela used animations (<http://www.northland.cc.mn.us/biology/biology1111/animations/hydrogenbonds.html>) to illustrate the hydrogen bond formation within $\text{H}_2\text{O}_{(s)}$, the hexagon shapes formed by many $\text{H}_2\text{O}_{(s)}$, and thus the concept of open cage structure (http://www.worldofmolecules.com/interactive_molecules/ice.htm) leading to the explanation of the lower density than water. Finally, Pamela showed students the ball and stick model of ice in order to strengthen their understanding.

Pamela started to use computer assisted teaching methods since the first year of her teaching career to facilitate students to learn the (sub)microscopic level of understanding. She started to learn how to use "Flash" and "PowerPoint" to demonstrate atomic model instead of using text and verbal.

Pamela believes that different kinds of computer assisted teaching, such as animations and movie clips, are especially useful and helpful to accommodate some classroom teaching limitations, for example something too tiny that no one can never observe and large scale experiments which are not feasible to be carried out in school laboratories. She insists that animations and movie clips are not only visual impact or excitement like watching cartoon, but really helping her students especially those are less capable to understand the (sub)microscopic level of Chemistry a lot easier.

Pedagogies used by Pamela for enhancing students' understanding of symbolic level

From the classroom observations, I realize that Pamela often uses simulations to promote students' symbolic level of understanding. When I conducted interviews with Pamela, I clarified with her if this is her purposive arrangement and if this is her teaching pattern. Surprisingly that she said she did not realize with any teaching pattern, although she has some kind of intentions to use simulation. I asked her to reflect if simulations help in learning triplet and she said, "macro and symbolic... observe the change from the simulations, collect the very accurate data... for calculations and graphs... macro and symbolic".

Johnson's pedagogical knowledge reflected from his teaching

Johnson describes himself as a young teacher, not by means of age but teaching experiences, he said that he is still learning how to teach a mass class which usually consists of forty students with a big range of diversity. Johnson said that he wishes to teach small class that he could have better understandings on each student's needs and thus providing better teaching/learning interactions. Some students like to ask him questions after class instead of during class, Johnson describes that he knows more precisely how to help those students. On the other hand, he needs to cater the majority of the class, he needs to plan very carefully what he should teach and how to teach, and what not to teach and how to avoid touching them.

Johnson is not able to tell clearly what kind of pedagogy he prefers to use for teaching the triplet relationship, but he thinks the more important issue for teaching the triplet relationship is how to organize, how to interpret and present to his students, and the most importantly is helping his students to construct their own knowledge.

Pedagogies used by Johnson for enhancing students' understanding of macroscopic level

Johnson generally agrees that hands-on experiments and experiment demonstrations are the best means to enhance students' understanding of macroscopic level. He prefers experiment demonstrations than hands-on especially when he needs to probe students' deep understandings. Johnson used a very good demonstration to start his teaching on the topic of acid, he demonstrated contradictory behaviours between solid citric acid and aqueous citric acid in order to give his students some impacts before he taught them the abstract concepts of $H^+_{(aq)}$. Johnson demonstrated reactions between both solid state and aqueous state of citric acid with metal, carbonate/hydrogen carbonate and litmus paper, students witnessed clear observable changes on aqueous citric acid but nothing on solid citric acid, this kind of contradictory impacts impressed students and they certainly lead to certain level of learning curiosity and learning interest.

Johnson usually incorporates recalling, predict-observe-explain (POE), real life examples, etc. to enhance the experimental activities. He believes that recalling helps students to relate their preconception, gained from previous experimental experiences, to the current context. For example, before Johnson teaching students about the trend of conductivity of Group I metals, he tried to recall students' fundamental knowledge of Sodium and Potassium by reminding them the experiments they did about a year ago when they were in S3, reactions between water and Sodium or Potassium which produce flame balls. Johnson believes that experiment was so impressive that students should be able to recall, the macroscopic level of understanding could also be recalled as a preconception and thus link up with the current teaching/learning context.

Johnson always asks students to predict before observations especially when he does demonstrations, and he does the POE practices for different purposes. He believes that asking students to predict something based on their preconceptions helps them to transform from the level of recite and recall to the level of applications, applying their preconceptions on slightly different contexts. Johnson also believes that if students predict or guess correctly, students will have positive affective impacts. Moreover Johnson usually arranges discussions or writing exercises for students to explain what they have predicted and what they have observed.

Johnson uses real life examples to enhance students' consolidation of learnt knowledge, and I think such real life examples are also good means to arouse students' learning curiosity and

learning interest and thus start the link-up between authentic settings and macroscopic level of Chemistry. For instance, after teaching all important concepts of acid, Johnson used a couple of real life examples to summarize students' learnt knowledge; he used ENO, baking soda/baking powder and REDOXON. Although the core ideas among all ENO, baking soda/baking powder and REDOXON are more or less the same to the experts like us, they are totally different things to novice like students. Johnson tries to use as many real life examples as he can in order to promote the authenticity and importance.

Pedagogies used by Johnson for enhancing students' understanding of (sub)microscopic level

When Johnson taught the topic of acid, he wanted to emphasize the teaching and learning of the concept of ionization of acid and $H^+_{(aq)}$, and he wanted to try to use a pedagogy learnt from PGDE, he asked students to draw particle diagrams of pre-ionization of $HCl_{(g)}$ and post-ionization of $HCl_{(aq)}$. Johnson used chemical equation, another form of symbolic representation, to assist the teaching/learning of ionization of hydrochloric acid. He then asked a student to use particle diagram to represent the ionized hydrochloric acid. Student drew two sets of $H^+_{(aq)}$ and $Cl^-_{(aq)}$.

Johnson believes that particle theory, particle models, particle diagrams are the essences of the (sub)microscopic level of triplet relationship in the local context. Particle theory can be used to explain many of the school level chemistry concepts, such as gas pressure, heat transfer, periodicity, kinetic theory, rate, etc. Johnson wishes to repeat using the same model in different contexts, in order to make his students realize how to use the model and what the possible applications are.

Although Johnson agrees that (sub)microscopic level of triplet relationship mostly relates to particle model, he thinks it is not universal for all contexts and teachers should think thoroughly and thus teach with a more appropriate model. For instance, Johnson argues that the (sub)microscopic level of equilibrium should be the concept of rate instead of particles and collision theory which are usually used by many other chemistry teachers.

Pedagogies used by Johnson for enhancing students' understanding of symbolic level

Graph is not just a tool to enhance teaching/learning the symbolic level of triplet relationship, Johnson believes that it is also a very good tool to be used to assess students' true understandings. Johnson uses graphs to teach Equilibrium.

CONCLUSION

Different level of teacher's pedagogical knowledge affects his/her classroom instruction. Simon's pedagogical knowledge of triplet relationship is comparatively weaker than others, he thinks linking up any two levels of triplet relationship is adequate, and there is no need to teach triplet relationship very explicitly. Pamela has good pedagogical knowledge of triplet relationship, she insists to teach this on most of the school chemistry topics, and she uses macroscopic level as the core, followed by (sub)microscopic level explanation and symbolic level representation. Johnson also has very good pedagogical knowledge of triplet relationship, he thinks choosing the right context for teaching triplet is the most important issue, for instance,

demonstration (macroscopic) as the core to teach acid, particle theory (submicroscopic) as the core to teach periodicity, and graph (symbolic) as the core to teach equilibrium.

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