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# Chemistry Teacher's Questions at Multiple Representation Levels in Inquiry-Based Chemistry Lessons

Winnie Sim Siew Li*, Mohammad Yusof Arshad

[a]Department of Educational Sciences, Mathematics and Multimedia Creative, Faculty of Education, University Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

*Corresponding author: winniesim50@yahoo.com

**Abstract**

Inquiry teaching provides teachers with ample opportunities to question at multiple levels of representation as such teachers should be encouraged to apply it in chemistry teaching. This article explores teacher's question in inquiry-based chemistry lessons. Twenty three chemistry secondary school teachers had participated in this study. An observation instrument, Observation Instrument in Inquiry Teaching through Verbal Interaction (OIITVI) used in this study was developed based on previous classroom observation instruments. Semi-structured interviews were carried out further understand teacher's questioning practices. Data were analysed quantitatively and qualitatively in order to explain teachers' questions at multiple representation levels of chemistry (macroscopic, submicroscopic and symbolic). Findings showed that most teachers' questions were at macroscopic level (50.66%). These questions were mainly closed-ended which requires cognitive-memory or convergent thinking. The most common sequence after teacher's questions were followed by another question by the teacher again, 6.57%. In conclusion, teaching chemistry should involve three levels of chemistry representation (macroscopic, submicroscopic and symbolic) since the nature of chemistry consists of abstract concepts. Hence, chemistry teachers should ask more open-ended questions, emphasize these three levels of representations equally, integrate the three levels of representation in their questioning session and practice wait-time in teaching chemistry.

*Keywords*: Inquiry teaching; teacher's question; verbal interaction; macroscopic; submicroscopic; symbolic

**Abstrak**

Pengajaran inkuiri memberi peluang yang luas kepada guru untuk menanyakan soalan pada pelbagai aras perwakilan dalam pengajaran kimia. Soalan guru yang menjurus kepada pelbagai aras perwakilan ini amat digalakkan dalam pengajaran inkuiri. Artikel ini meneroka soalan guru dalam pelajaran kimia berasaskan inkuiri. Dua puluh tiga orang guru kimia sekolah menengah terlibat dalam kajian ini. Instrumen pemerhatian iaitu Instrumen Pemerhatian Interaksi Verbal Pengajaran Inkuiri (IPIVPI) telah dibina berdasarkan instrument pemerhatian bilik darjah yang lepas. Temu bual semi-struktur telah dijalankan untuk memahami lebih lanjut berkenaan amalan penyoalan guru. Data dianalisis secara kuantitatif dan kualitatif untuk menerangkan soalan guru pada pelbagai aras perwakilan kimia (makroskopik, submikroskopik dan simbolik). Dapatan kajian menunjukkan kebanyakan soalan guru adalah pada peringkat makroskopik (50.66%). Kebanyakan soalan pada aras makroskopik adalah jenis tertutup yang memerlukan pemikiran kognitif-memori ataupun konvergen. Peratus tertinggi urutan selepas soalan guru lazimnya disusuli dengan soalan lain oleh guru juga iaitu sebanyak 6.57%. Kesimpulannya, pengajaran kimia harus melibatkan tiga aras perwakilan kimia (makroskopik, submikroskopik dan simbolik) memandangkan sifat semula jadi kimia yang terdiri daripada konsep abstrak. Oleh itu, guru kimia seharusnya menanyakan lebih banyak soalan terbuka, memberi penekanan yang sama kepada ketiga-tiga aras perwakilan, mengintegrasikan antara ketiga-tiga aras perwakilan tersebut semasa sesi penyoalan serta mengamalkan masa tunggu dalam pengajaran kimia.

*Kata kunci*: Pengajaran inkuiri; soalan guru; interaksi verbal; makroskopik; submikroskopik; simbolik



## ■1.0 INTRODUCTION

Teachers are prominent and authoritative persons in classrooms. Quality of teaching and learning process depends on the effectiveness of implementation of one's teaching approach. Many science educators believe that inquiry teaching is one of the best teaching approach despite other many teaching approaches (Audet and Jordon, 2005; Melville and Bartley, 2010). Back in year 2003, Ministry of Education, Malaysia has introduced new science curriculum that emphasises on thoughtful learning. Inquiry teaching is identified as one of the teaching approaches that contribute to thoughtful learning is inquiry teaching (Curriculum Development Centre, 2003; Yee, 2003 and Chin, 2004). Inquiry teaching has proven to increase student's understanding (Abd-El-Khalick *et al*., 2004; Blancard, Southerland and Granger, 2008; Minner, Levy dan Century, 2010), and also increase students' thinking skills (Hamizer, Baharuddin and Mohammad Bilal, 2003; Tan and Law, 2002; Minner, Levy dan Century, 2010; Opera dan Oguzor, 2011).

Teaching and learning process involves interaction among teacher and students, and between student and other student(s). Verbal interaction is the dominant form of interaction that occurs in classroom. In classroom, this form of communication could be in the form of either teacher's talk or student's talk. According to Parkinson (2004), vital part of verbal interaction is teacher's talk. Teacher's talk includes teacher's question and teacher's statement. Questioning is vital and it is part and parcel of teaching and learning process (Chin, 2006; Chin, 2007; Bass, Constant and Carin, 2009). Type of teacher's questions influence student's thinking. Generally, there are two types of teacher's questions; open question or closed-ended question (Blosser, 2000). This open question can be further categorised into type of thinking involved. Open question involves evaluation or divergent thinking; whereas closed-ended question involves cognitive-memory or convergent thinking. Inquiry-based classroom should focuses more on open questions; i.e. to trigger students to think; compared to traditional classroom which focuses more on closed-ended question. Teachers should allocate wait-time one after they asked questions. This wait-time is important as to provide sufficient time for students to think (Rowe, 1974; Rowe, 1986; Martin *et al.*, 2009; Haigh, 2010). What is the sequence after teacher's questions?

Chemistry, as one of science subjects, involves ample number of principles, theories, facts and concepts. The root in learning chemistry involves understanding the chemistry concepts. These concepts should be learned at multiple representation levels, namely macroscopic, submicroscopic and symbolic (Johnstone, 1991). It is a common scenario to hear students complaining about hurdles of learning chemistry and boredom in learning this subject (Tsaparlis, *et al*., 2010). Furthermore, students also face difficulty in understanding the link between these multiple representation levels (Frost and Turner, 2005). This may be due to the manner of how chemistry teachers teach the subject. The process of integration between these multiple representation levels is of utmost importance and should be given the top priority among chemistry teachers. Hence, this study investigates into teacher's talk at multiple representation levels in chemistry lessons via verbal interaction.

## ■2.0 RESEARCH QUESTIONS

This study addressed the following research questions:
1) What type of teacher's questions at multiple representation levels in inquiry-based chemistry lessons?
2) What are the sequences after teacher's questions at multiple representation levels in inquiry-based chemistry lessons?

## ■3.0 METHODS

Twenty three chemistry teachers from thirteen secondary schools in Kuala Lumpur, Malaysia having from one year to twenty years' experience in teaching chemistry were involved in this study. They were selected based on the scores obtained from Chemistry Teacher Questionnaire. This questionnaire was adapted and modified from various sources namely, Curriculum Development Centre (2001), Science Teacher Inquiry Rubric (STIR) (Bodzin and Beerer, 2003) and International Rubric (Council of State Science Supervisors (2001).

Non-participant observation was the main data collection method. Each chemistry teacher was observed twice using an observation instrument, known as Observation Instrument in Inquiry Teaching through Verbal Interaction (OIITVI) (Sim and Mohammad Yusof, 2012). This instrument consists of five main categories, which are teacher's question, teacher's statement, student's question, student's statement and silence or confusion. This observation instrument was modified from previous classroom observation instruments developed by Flanders (1970); Eggleston, Galton and Jones (1975); Mohamed Najib (1997) and Brandon *et al*. (2008). After obtaining respondents' consent, these observations were audio and video recorded to facilitate the researcher in analysing data.

Prior to the actual data collection, researcher has consulted and "trained" two chemistry education lecturers in using this observation instrument. This is done because the actual data collection involved only single observer. In terms of reliability, inter-rater reliability method was used as suggested by Creswell (2005) for study which involves observation. The value was computed using Statistical Package for Social Science (SPSS) PASW version 18.0. The value was expressed in terms of kappa value. Kappa values obtained were .977 and .808 for the first and second lecturer respectively. These values showed that there is a high agreement of categorisation as stated by Viera and Garrett (2005). Furthermore, to ensure the reliability of the results, the researcher listened at least twice to the recorded chemistry lessons. In addition, semi-structure interviews were carried out to further understand the reasons of particular observed teacher's behaviours.

Data were analysed quantitatively in terms of frequency and percentage using statistical software SPSS PASW version 18.0. Besides that, data obtained were also analysed qualitatively to determine the type of questions asked.

## ■4.0 RESULTS AND DISCUSSION

This part will discuss the findings based on the research questions mentioned earlier.

*What type of teacher's questions at multiple representation levels in inquiry-based chemistry lessons?*

Teacher's questions contributes 13.66% of the total verbal interaction that occurred during chemistry lessons (see Figure 1). Out of 13.66% of teacher's questions, 10.66% of questions asked were questions at multiple representation levels, while 3.00% were questions not related to chemistry content or science process skills (managerial questions). For the purpose of this research, questions not related to content or science process skills are not considered and therefore do not taken into account in the analysis.

Teacher questioning was supposed to be the main verbal interaction in inquiry-based classroom, as to interrogate students' thinking and ideas. However, the percentage of teacher's questions found were about only one-tenth of total verbal interaction occurred during chemistry laboratory lessons.

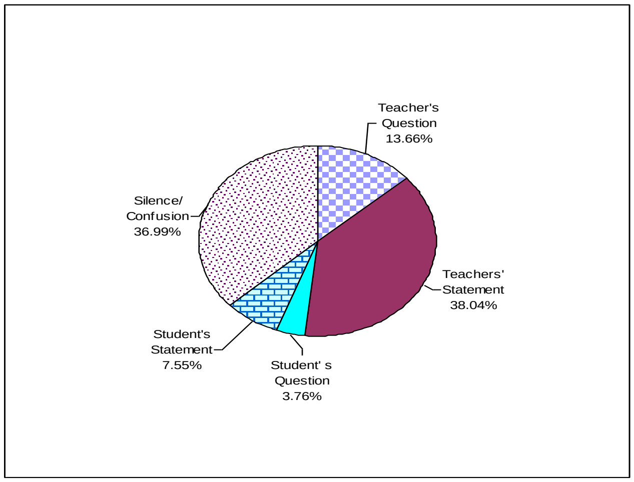


**Figure 1** Distribution of teacher's question and teacher's statement

Most of teachers' questions were at macroscopic level (50.66%), followed by questions at symbolic level (29.76%), and the least was questions at submicroscopic level (19.58%) (see Figure 2).

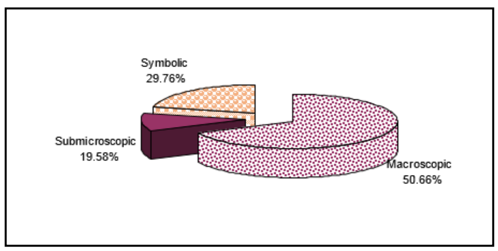


**Figure 2** Teachers' questions at multiple representation levels

This means that teachers emphasised more on macroscopic level as the observations made were during laboratory sessions. Examples of questions asked at macroscopic level were as shown below:

> *What is the colour change in the reaction*?
> *Will the yellow precipitate dissolve*? Respondent R01: Laboratory Session 1]

It can be seen clearly that chemistry teachers in this study tend to focus more on macroscopic level compared to at submicroscopic or symbolic levels. The discussion was merely at macroscopic level, they did not discuss why the colour changes in the reaction and regarding the yellow precipitate at particulate level. The question is, 'Why they emphasise more on macroscopic level?' From the transcript of interviews with several teachers, they prefer to talk at this level because they think students are unable to think at particulate level (R07) and they believed that this topic should be discussed at macroscopic instead of microscopic levels compared to others (R02) which is not true. Example of transcript of interview is as shown below:

Researcher: *Based on analysis of the observation, you tend to discuss the content in macroscopic level compared to microscopic and symbolic level. Could you explain further on this?*

R07: *Ooh. Ok. It is because my class is not good class. If I explain at microscopic level, they cannot get it. It depends on the ability of the class. If your class is good, can explain at microscopic level. This is a weak class, so… they need to know the general, the macroscopic.*

R02: *Ah, isn't that topic is more to macroscopic compared to submicroscopic? For me, if submicroscopic is more on topics, for example formation of ions, formation of protons, neutrons, isn't it? Those are more on microscopic*.

R07: Respondent 7; R02: Respondent 2

Consequently, they tend to structure their talk which focuses more at macroscopic level to conform to their belief. With related to type of questions, questions asked at these multiple representation levels were shown in Table 1. Most questions are of closed-ended questions which require either convergent or cognitive memory questions regardless at which representation level the questions were asked.

**Table 1** Observation instrument in inquiry teaching through verbal interaction (OIITVI) [a]

| Representation Level | Macroscopic | | | | Submicroscopic | | | | Symbolic | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type of question | Open | | Closed-ended | | Open | | Closed-ended | | Open | | Closed-ended | |
| Category of Thinking | E | D | C | C-M | E | D | C | C-M | E | D | C | C-M |
| Total questions | 9 | 493 | 1599 | 3589 | 0 | 101 | 1278 | 820 | 0 | 38 | 1802 | 1503 |
| Overall | 5690 | | | | 2199 | | | | 3343 | | | |
| Percentage (%) | 50.66 | | | | 19.58 | | | | 29.76 | | | |

E: Evaluation; D: Divergent; C: Convergent; C-M: Cognitive-Memory

Quantitative data obtained from OIITVI was analysed using Statistical Package for the Social Sciences (SPSS) PASW version 18.0. Data is in the form of frequency and percentage. In addition, semi-structured interviews were carried out after classroom observations. Observed chemistry lessons and interviews were transcribed verbatim to answer the research questions mentioned earlier.

These questions at multiple representation levels were mainly of closed-ended questions which require low order thinking, which is cognitive-memory thinking and convergent thinking, similar as in previous researches done by Ng and Siow (2003); Trowbridge and Bybee (1996).

Examples of questions at these multiple representation levels are shown below:

*Respondent 01* *What is the colour of iron three plus?*
*Is there any bubble formed in the reaction?*
*(Macroscopic: cognitive-memory)*

*Respondent 03*: *For elements in period 3, they have three shells filled with… ?*
(*Submicroscopic: cognitive-memory*)

*Respondent 03:* *Lithium is the least reactive metal. Lithium reacts with water, to produce… alkaline solution.*
*The solution is lithium…hydroxide. So what is the equation?*
*(Symbolic: convergent)*

*What is the sequence after teacher's questions at multiple representation levels in inquiry-based chemistry lessons?*

According to Rowe (1974), 'silence' for the purpose of wait-time one should be allocated after teacher's question. This is to ensure ample time is given to students to respond to the questions asked. Furthermore, Mercer and Hodgkinson (2008) stated that increase of wait-time improve the quality of student's answers. Nevertheless, the finding from this study found that the highest total mean was teacher's question followed by students' answers, 4.03% (see Table 2). Other two highest teaching sequences after teachers' questions were teacher's question followed by teacher's statement and teachers' question followed by wait-time one.

**Table 2** Sequence after teacher's question

| Category | Total mean (%) |
|---|---|
| Teacher's question followed by students' answers | 4.03 |
| Teacher's question followed by teacher's statement | 0.94 |
| Teacher's question followed by wait-time one | 0.83 |

The findings showed that students can easily answer questions posed by teachers at this level without the allocation of wait time, which is similar with Tay's finding (Tay, 2010). Most of the questions asked were spontaneously answered by the student (Tay, 2010). Quick responses from students were due to the questions posed by teachers were of closed-ended questions of low order thinking questions, such as questions that recall facts that they have learned or memorised as reported by Ng and Siow (2003); Trowbridge and Bybee (1996). This was proven by transcript of lesson as shown below.

*Teacher: What is the colour of the solid formed?* *(Teacher's Question)*

*Student: Black* *(Student's Answer)*

*Teacher: Ok, see the brown colour over here. What is that?* *(Teacher's Question)*

*Student: Copper* *(Student's Answer)*
[Respondent 07]

Not only in Malaysia, Tobin (1987) reported that closed-ended questions were asked frequently in many classrooms in Australia, United States and England to get quick responses and to ensure the lesson runs smoothly. Furthermore, as this type of questions enable them to cover syllabus faster as stated by Krystyniak dan Heikkinen (2007). From the semi-structured interviews carried out, it was found that these teachers were aware of the purpose of the questions they asked during the lesson as shown in excerpt of the transcript of interview below:

*Researcher : What is the purpose of teacher asking questions during the lesson?*

*Respondent 04: Ok… All the children now…, they are very easy to forget. Very forgetful. When I teach electrolysis, and then move to voltaic cell, they forget about electrolysis. So I must ask constantly to make sure they remember the facts, for example what is Electrochemical Series and so on.*

These teachers seem to have planned what to ask and they anticipate predetermined answers. If these teachers ask higher order questions and practice wait-time, maybe they will be surprised in getting better answers and students' elaboration on the macroscopic aspect. This means students should be able to explain the reason of the reaction observed at submicroscopic level and eventually able to write the equation for the reaction involved (symbolic level).

In the chemistry lessons observed; these teachers lack practice of wait-time, as less than one percent of the total verbal interaction was allocated for wait-time, merely 0.83% (see Table 2). Semi-structured interview with the teachers showed that these teachers *were not aware* of wait-time. After explaining to respondent the meaning of wait-time, the teachers were asked about the importance of wait-time in teaching and learning process. Furthermore, they said they don't practice this wait-time due to time constraint and syllabus to be covered.

Example of the excerpt of the interview is shown below:

*Researcher: Have you heard of wait- time?*
*Teacher : I don't know.*
[Respondent 01]

*Researcher : Is wait-time important?*
*Teacher : Yes. But not enough time as we want to cover the syllabus.*
*Researcher: Not enough time?*
*Teacher : Yes. Secondly, because lack of time. Sometimes we forgot about that wait-time.*
[Respondent 05]

Although the respondents are trained teachers in education field, they lack practice of wait-time in their teaching. Consequently, they tend to ask ample of questions. This left students with lack of time to think and respond to teacher's questions.

## ■5.0 CONCLUSION AND IMPLICATION TO TEACHING CHEMISTRY

Finding from this study revealed that teacher's questions were mainly at macroscopic level and of closed-ended. Chemistry teachers should not limit to talk at a certain multiple representation level only, as understanding of chemistry concept in any topic involves the understanding at multiple representation levels, which includes at macroscopic, submicroscopic and symbolic levels as stated by Johnstone (1991; 2000), Treagust, Chittleborough and Mamiala (2003); Johnstone and BouJaoude (2012). In terms of questions made, there should be a balance of the number of questions at these levels, namely macroscopic, submicroscopic and symbolic level to ensure thorough understanding of a chemistry concept discussed during chemistry lesson.

Sequence after teacher's question revealed that student's answer was the main verbal interaction. This was due to closed-ended questions asked by the teachers. Teachers in this study showed *lack practice of wait-time* as they were not aware and not heard of that terminology. Overall, findings in this study do not support inquiry-based teaching as it supposed to be. There is a gap between theoretical and what is practiced. Hence, it is time for chemistry teachers to re-examine their questions and should be aware of this multiple representation levels in teaching. Hence, emphasising on multiple representation levels is pertinent in teaching chemistry to provide a strong basis for students to embark into chemistry related field in future.

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