ORIGINAL ARTICLE

Translational Skills of Students in Chemistry

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ABSTRACT

Understanding chemistry requires the interplay of several modes of representations which can be observed in the translational skills of students. This paper investigated the extent of the translational skills of students exposed to conventional lecture method (CLM) and the integrated macro-micro-symbolic approach (IMMSA). Individual interviews were conducted, and the results were presented based on Johnstone's Chemistry Triangles. Findings revealed that the CLM group had a fair extent of translational skills, lacked two-way translations, and followed pattern 1 skills. On the other hand, the IMMSA group had satisfactory skills, included two-way translations, and followed patterns 1 and 2. This led to the conclusion that interplay within and between chemical modes of representation creates a relational understanding in chemistry. It was suggested that teachers should start their instruction from microscopic terminal for deeper understanding in the macroscopic and symbolic levels.

KEY WORDS: chemistry instruction; chemistry triangles; integrated approach; macroscopic, microscopic; symbolic modes; pattern; translational skills

INTRODUCTION

Science education is envisioned by education departments around the globe as providing students with the knowledge, skills, and understanding needed in the formation of a scientifically literate citizenry (Department of Education, 2013 and Royal Society of Chemistry, 2011). Contributing to the development of scientific literacy is chemistry education. Chemistry deals with the understanding of matter and its properties, uses, and behavior of its subunits such as atoms, molecules, and ions. This chemical understanding is often expressed and taught in three modes of representation, which are collectively included in a framework called Johnstone's Chemistry Triangle (Johnstone, 1982; Gabel, 1999; Gilbert and Treagust, 2009; and Talanquer, 2011). The Chemistry Triangle exposes the perspective of chemistry in three, dependent and closely related levels, namely macroscopic, submicroscopic, and symbolic levels (Johnstone, 1982; Gilbert and Treagust, 2009; Talanquer, 2011; and Cardellini, 2012). The levels can be presented by a triangle with the three levels at the vertices, as shown in Figure 1 (Johnstone, 1991 and Li and Arshad, 2014).

The macroscopic level refers to the level where senses are used to describe matter and observe changes in matter during laboratory experiments. The submicroscopic level deals with the representation of what is being observed in minute scale - at the level of electrons, atoms, ions, and molecules. The symbolic level makes chemical phenomena abstract through the use of chemical symbols, formulas, expressions, and equations (Johnston, 1982; Gilbert and Treagust, 2009; Talanquer, 2011; and Towns et al., 2012). The interplay of the three aforementioned levels makes sense in student learning and understanding of chemistry concepts and chemical systems. In fact, the use of these levels as modes of representations support students' learning, makes interpretation of a concept easier, and constructs deeper understanding of chemical systems (Ainsworth, 2007).

Students, however, often find the interplay of the levels difficult both to understand and use (Gilbert and Treagust, 2009). Some problems arising from such interplay include the lack of macroscopic experience (Nelson, 2002), misconceptions of the submicroscopic nature of matter (Harrison and Treagust, 2002), deficiency in using complex conventions in symbolic level (Marais and Jordaan, 2000), and the inability to move in between levels (Gabel, 1999). The inability to move in between levels poses a challenge in chemistry education, especially in bridging understanding concepts between the abstract and concrete levels, where students put their own experiences in making assumptions in the submicroscopic and symbolic levels (Driver and Ericsson, 1983; Gabel, 1999; and Adbo, 2012).

The ability to move from one level of the triangle to another is called the translational skill, an important skill in chemistry, wherein one can fully grasp the true meaning of the concepts taught and learned (Gilbert, 2008). As an important skill, two related studies were conducted to investigate the extent of translation among the three levels. Brandiet (2014) investigated students' understanding of the symbolic, macroscopic, and particulate domains of redox reactions. He found out that students seemed to have a better understanding of the macroscopic-symbolic conditions than the macroscopic-particulate or the symbolic-particulate relationships. On the other hand, Li and Arshad (2014) focused on the extent of how teachers linked between macroscopic, submicroscopic, and symbolic representation levels in teaching redox reactions. They found that most of their participating teachers emphasized the macroscopic mode, followed by the symbolic and the least in the submicroscopic mode. They also took note of the full integration of the three modes by two teachers in tackling the topic in hand.

Since the ability to being able to work within each of the three modes and to move mentally in between them leads to a full appreciation of the explanations that science provides on a given phenomenon (Gilbert, 2008), this study investigated whether an interplay among different modes of representation led to the relational understanding of chemistry through the students' use of their translational skills. Specifically, the paper sought to (a) determine the extent of the translational skills of the students exposed to conventional lecture method (CLM) and to the integrated macro-micro-symbolic approach (IMMSA), (b) determine the ways of translation used by them in fully understanding the given chemistry concept, and (c) determine the translational pattern obtained by them in chemistry.

METHODOLOGY

Research Design and Procedure

This study utilized a qualitative research approach to determine the extent, ways, and patterns of the translational skills of 10^{th}-grade students in chemistry. These students were studying the concepts on kinetic molecular theory of gases. Research permission was sought from the executive director of the secondary school as well as informed consent from the participants. Once permission was granted, two groups of 10^{th}-grade students underwent the experimentation phase. The first group was exposed to CLM, while the others were exposed to IMMSA. After a month of experimentation, five randomly selected representatives (coded as C for the CLM and E for the IMMSA) from each group were invited to participate in videotaped individual interviews.

Research Tool and Data Analysis

The interviewees had three tasks to do, which correspond to the macroscopic, microscopic, and symbolic modes of representation. Below is the interview guide:

Macroscopic mode

The student was tasked to execute the "vacuum glass experiment" by manipulating the materials given to him.

- Q1: What have you observed from the experiment?
- Q2: Why was the fire extinguished?
- Q3: Why did the water rise?

Microscopic mode

The student was tasked to construct an illustration of the experiment using conventions such as particles and arrows.

- Q4: Can you explain your illustration?
- Q5: What is the behavior of the molecules in the illustration?

Symbolic mode

The student was asked to answer a problem-based question: Use the same setup of the "vacuum glass experiment." Initially, oxygen and carbon dioxide gases around the flame exert 1.00 atm and are in equilibrium with the surrounding gases. When the source of the flame is covered with the glass, the temperature is decreased from 303.15 K to 293.15 K. How much pressure is exerted by the gases inside the glass now? Explain.

- Q6: What is the relationship between pressure and temperature?
- Q7: How much pressure do the gases inside the glass exert now?
- Q8: Does the answer justify your results in the experiment?

The extent of the translational skills exhibited by the students was determined through the use of the scoring guide (Table 1). Their skills were described as excellent (5.16–6.00), very satisfactory (4.33–5.15), satisfactory (3.50–4.32), moderately satisfactory (2.67–3.49), fair (1.84–2.66), or poor (1.00–1.83).

Moreover, the data obtained from the interviews were analyzed by identifying phrases, clauses, or statements which determined the mode of representation used by the students in explaining the given phenomenon. The results are presented using Johnstone's Chemistry Triangles (Li and Arshad, 2014). Line-by-line coding was used to represent the translation in between modes: One-headed arrows (→) represent one-way translations and two-headed arrows (←) denote two-way translations.

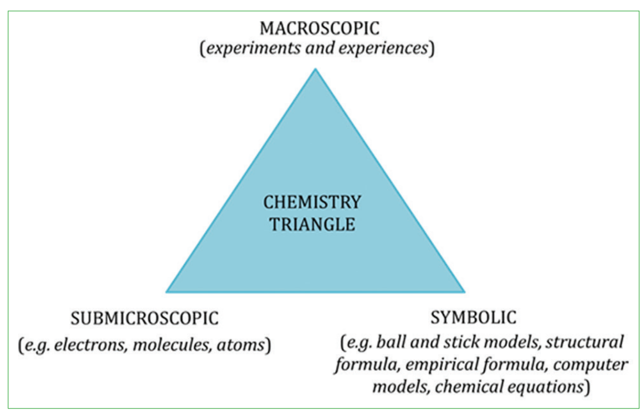


Figure 1: Chemistry triangle

Table 1: Scoring rubric for the extent of translational skill use

Pattern	Translation	Number of translations	Number of points
1	One-way	1	1
		2	2
		3	3
2	Two-way	1	4
		2	5
		3	6

RESULTS AND DISCUSSION

Table 2 summarizes the extent, ways, and patterns of the students' translational skills based on the analysis of videotaped interviews on selected students from the two participating groups.

Extent of Students Translational Skills

As noted in the table above, all of the students in the CLM group had a fair extent of translational skills (an extent average of 2.0). This is due to the fact that the CLM group did not take into account other modes of representation. It should be noted that the CLM students had little or no class participation during the course of the study (Kumar, 2004 and Kaur, 2011). Those in the IMMSA group, however, had a satisfactory extent of translational skills (an extent average of 4.00) because of the integration of several modes of representation which highlight relationships between the cross-link between macro, micro, and symbolic concepts (Bradley, 2014).

Students' Translational in Understanding the Chemistry Concept

The students had a varying set of translations, ranging from the most utilized (symbolic to macroscopic) to rarely used ones (macroscopic to microscopic, microscopic to symbolic, and symbolic to microscopic).

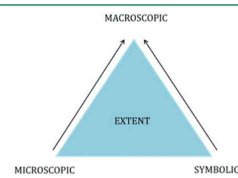
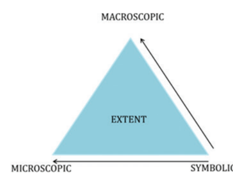
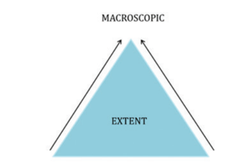
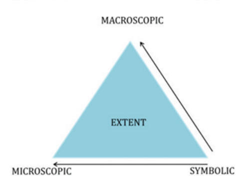
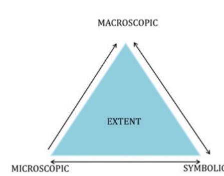
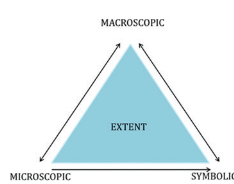
Symbolic to macroscopic translation

All of the participating students had translations from symbolic to macroscopic modes. Representative student E7 showed this translation while explaining his answer in the problem-based question:

"[…] *and you have 0.97 atm which then justifies why the water went up because of the decrease in pressure inside the glass, because 1 is >0.97 atm.*"

Student E7 justified his answer (pressure=0.97 atm) through utilizing what he observed in the given experiment (water goes up when pressure is <1 atm). This means that student

Table 2: Extent, ways, and patterns of translational skills of students in chemistry

Pattern	Subject	Extent	Pattern	Translation
1	C3 C7 C9 C10 C13	2.00 (fair)		One-way; two sets of modes are interplayed
	E13	2.00 (fair)		One-way; two sets of modes are interplayed
	E7	4.00 (satisfactory)		One-way; two sets of modes are interplayed
	E8	4.00 (satisfactory)		One-way; two sets of modes are interplayed
2	E4	5.00(very satisfactory)		One one-way, two two-way; three sets of modes are interplayed
2	E11	5.00 (very satisfactory)		One one-way, two two-way; three sets of modes are interplayed

E7 like all other participants used their experiences in the vacuum glass experiment to answer the problem-based question and to verify whether their answer was correct or not. Laboratory experiments strengthened the understanding at the symbolic level as these activities increased the problem-solving ability, among other skills, of the students (Hofstein, 2004).

Microscopic to macroscopic translation

All but one student had microscopic to macroscopic mode translations. Student E8 is an example of this translation:

> "[…] *here's the candle, and so it is lighting up. Since there is no oxygen that could come in, then the fire gets distinguished, right? And so, the water then rises up.*"

Student E8 explained his interpretation through the use of sensory details such as lighting, extinguishing, and rising up of water. This translation denotes that when students are engaged in laboratory activities, they tend to relate the behavior of the molecules to these activities. Practical work, another term for laboratory activities, provides the necessary concepts in explaining what happens in the submicroscopic level, thus enhancing the learning process (Gilbert, 2008). These activities link what is observable by the senses to what are inside the mind, which led to the understanding of a more abstract iconic representation of the phenomenon at the level of atoms and of molecules (Millar, 2004).

Other ways of translation

The other means of translation, such as macroscopic to symbolic, macroscopic to microscopic, microscopic to symbolic, and symbolic to microscopic, were rarely used by the students. These translations are common sites of misconceptions in understanding the concepts of chemistry and chemical systems (Chittleborough and Treagust, 2007).

It is interesting to note that the less-utilized translations were used by the students in the IMMSA group since they were exposed to different modes of representation. The use of multiple representations is an advantage in teaching and learning chemistry concepts as the different representations support one another and deepen understanding of the given phenomenon (Ainsworth, 2007; Sanchez, 2017).

Patterns of the Translational Skills in Chemistry

The translational skills of the students in chemistry could be visualized using Johnstone's Chemistry Triangles and be categorized into three patterns as used by Li and Arshad (2014).

Pattern 1 translational skills

Pattern 1 translational skills showed an incomplete interplay of modes, as only two sets of modes were related by the students. Among the interviewed students, eight of the 10 exhibited this pattern. All of the interviewed students in the CLM group manifested the pattern - most notable, they only had one-way translations. As observed in the translations, the students tended to relate only the phenomenon toward the macroscopic mode since only teacher-directed laboratory activities were included in CLM.

Just like the translational skills of CLM, three of the five interviewed students exposed to IMMSA had pattern 1 skills. Student E13 only had one-way translations. It is noted in this extent of translational skill that the student used only one terminal in relating to other modes of representation. This means that he was more inclined in the abstract level of learning. Meanwhile, the other two students, E7 and E8, showed at least one two-way translation. Student E7 had a two-way translation between macroscopic and symbolic modes, as he could relate laboratory activities to problem-solving activities and vice-versa. This two-way translation is transcribed in Transcription 1.

Student E8, like student E7, had at least one two-way translation that is between macroscopic and microscopic modes. This signifies that he could relate to concrete experiences when dealing with the behavior of molecules at microscopic level and vice versa. The transcription of the translation is shown in Transcription 2.

Pattern 2 translational skills

Pattern 2 utilizes the three modes of representation but is an incomplete interplay among the modes. Two of the interviewed students obtained this pattern of translational skills. Student E4 used two-way translations twice: Between macroscopic

Transcription 1: Two-way translation of student E7

*From the macroscopic terminal:

(Student E7 was performing the experiment and was asked by the researcher.)

Researcher: *Can you explain what happened?*

Student E7: *Ah, change in pressure. Pressure inside is, uhm, lesser which makes the atmospheric pressure outside greater, which pushes the water up through the glass.* → Symbolic mode

*From the symbolic terminal:

(Student E7 was asked to explain his answer in the problem-based question.)

Researcher: *Explain your answer.*

Student E7: […] *and you can 0.97 atm which then justifies why the water went up because of the decrease in pressure inside the glass, because 1 is > 0.97 atm.* → Macroscopic mode

Transcription 2: Two-way translation of student E8

*From the macroscopic terminal:

(Student E8 was performing the experiment and was asked by the researcher.)

Researcher: *Okay, what happens?*

Student E8: *Uhm, the water rises into the glass.*

Researcher: *Why do you think so?*

Student E8: *Because ah, the oxygen, ah the fire creates gas, and the gas once it runs out, then the water has to go in.*→ Microscopic mode

*From the microscopic terminal:

(Student E8 drew his illustration of the experiment.)

Student E8: […] *here's the candle, and so if it is lighting up. Since there is no oxygen that could come in, then the fire gets distinguish, right? And so, the water then rises up.* → Macroscopic mode

Transcription 3. Two-way translations of student E4

*From the macroscopic terminal:

(Student E4.)

Researcher: *What makes the water rise?*

Student E4: *The low pressure, since there is no pressure inside the glass. The air is all burned already. The water will tend to go the low-pressure area.* → Symbolic mode

*From the microscopic terminal:

(Student E4 finished constructing the illustration and was asked to explain.)

Student E4: […] *when you cover the candle, the molecules inside will tend to decrease, so only a few will be left. Since fewer were left, then the pressure will be lower compared to what is outside which is open air. Since there is a change in pressure, the pressure outside tends to push the water going up inside the glass.* → Symbolic mode

*From the symbolic terminal:

(Student E4 was writing the given and asked quantities, and was asked.)

Researcher: *So what is the relationship between pressure and temperature?*

Student E4: […] t*he pressure goes up, the temperature goes up. It is directly proportional.*

Researcher: *Why do you think so?*

Student E4: […] *if you get an Erlenmeyer flask and you fill it up with water and you cover it with balloon and you heat it. Since the temperature goes up, the more excited the molecules will be and will make the volume [of the balloon] expand. And if you cool the temperature, the water, the balloon goes inside the flask because pressure is gonna change. That is why low pressure area tends to suck in the objects around them.*

→ Microscopic mode

(After this, student E4 continued to answer the problem and was asked.)

Researcher: *Is your answer justifying the experiment?*

Student E4: *Yes.*

Researcher: *So what is P2 gain?*

Student E4: *Pressure 2 inside the glass which is 0.97 which is lower than the outside pressure which causes the water to rise up in the glass. → Macroscopic mode*

and symbolic modes, and between microscopic and symbolic modes. The two-way translations of E4 are included in Transcription 3.

Moreover, student E11 also had two-way translations between macroscopic and symbolic modes, as well as between macroscopic and microscopic modes. It was thereby noted that he could move between either of these modes to describe a phenomenon. The translation is transcribed in Transcription 4.

To sum up, most of the students utilized a one-way translation from symbolic to macroscopic modes or from microscopic to macroscopic modes. Furthermore, it was noted that all interviewed students from the CLM group had one-way translations only, which would seem to indicate that they experienced a pedagogy during their CLM that did not take into account other modes of representation. It was highlighted, however, that most of the students in IMMSA group had two-way translations which support research in the advantageous use of this approach in chemistry (Sanchez, 2017). Since the students used their learning within and between modes, the interplay created relational understanding in a given chemical phenomena. This finding supports Jaber and Boujaoude (2012)

Transcription 4: Two-way translations of student E11

*From the macroscopic terminal:

(Student E11 was performing the experiment and was asked by the researcher.)

Researcher: *Okay, what have you observed?*

Student E11: […] *There's less oxygen inside, so meaning uhm, the pressure wants to, the pressure outside is greater the one inside and then higher pressure tends to move to places that have lower pressure. So what happened was that the oxygen was taken up inside. It has uhm, the air inside, so if air has 10% oxygen, the oxygen was taken out, so zero oxygen. So that means the air outside trying to move inside so that's what pushes the water inside. → Microscopic, Symbolic modes*

*From the microscopic terminal:

(Student E11 was constructing his illustration and was talking about it.)

Student E11: […] *the fire was turned off because the oxygen was taken up. When that happened, there was uhm less oxygen inside. And then, the outer pressure is greater than the inner pressure, so what happens is that it forces its way inside the cup, so that is the balance of the environment.*→ Macroscopic mode

*From the symbolic terminal:

(Student E11 finished answering the problem-based question and was asked to explain his answer.)

Student E11: […] *so what happened here was that the pressure went down when the temperature went down because before the glass covered the flame, hot, so the temperature's up. And the pressure also up. But when the glass covered the flame, the fire went off, that means that the temperature goes down. And when the temperature goes down, pressure also goes down. And because now that the pressure inside the glass is a low-pressure area, the outside pressure tries to go inside it and that's what moves the water.*→ Macroscopic mode

when they concluded that students' relational understanding could be fostered by an explicit emphasis on teaching the nature of chemical knowledge in terms of macroscopic, microscopic, and symbolic levels and the relationship among them. Thus, this affirmed the theory of Johnstone's Chemistry Triangle, which states that students should integrate the modes of representation as these chemical representations complement each other.

CONCLUSION AND RECOMMENDATIONS

Exposing the students in various chemical representations led to the satisfactory extent of translational skills in chemistry. The interplay within and between chemical modes of representation creates a relational understanding in chemistry, confirming Johnstone's Chemistry Triangle. The study suggests that teachers should focus on the translation from the microscopic terminal to make students gain deeper understanding on what they experience in the laboratory and on what they should be skillful in the symbolic mode.

REFERENCES

Adbo, K. (2012). *Relationships between Models used for Teaching Chemistry and Those Expressed by Students*. (Ph.D. Dissertation, Linnaeus University, Kalmar and Växjö, Sweden). Available from: https://www.diva-portal.org/smash/get/diva2:506580/FULLTEXT01.pdf. [Last retrieved on 2018 Aug 20].

Ainsworth, S. (2007). The educational value of multiple-representations when learning complex scientific concepts. In: Gilbert, J.K., Reiner, M.,

& Nakhleh, M., (Eds.), *Visualization: Theory and Practice in Science Education*. Dordrecht, the Netherlands: Springer Science+Business Media. pp. 191-208.

Bradley, J. (2014). The chemist's triangle and a general systemic approach to teaching, learning and research in chemistry education. *African Journal of Chemical Education*, 4(2), 64-71.

Brandiet, A. (2014). *Investigating Students' Understanding of the Symbolic, Macroscopic, and Particulate Domains of Oxidation-reduction and the Development of the Redox Concept Inventory* (Ph.D. Dissertation, Ohio: Miami University, Oxford, Ohio). Available from: https://www.etd.ohiolink.edu/pg_10?0:NO:10:P10_ETD_SUBID:96474. [Last retrieved on 2018 Aug 20].

Cardellini, L. (2012). Chemistry: Why the subject is difficult? *Educacion Quimica*, 23(2), 305-310.

Chittleborough, G., & Treagust, D. (2007). The modeling ability of non-major chemistry students and their understanding of the sub-microscopic level. *Chemistry Education Research and Practice*, 8(3), 274-292.

Department of Education. (2013). K to 12 Curriculum Guide: SCIENCE (Grades 3 to 10). Available from: http://www.deped.gov.ph/sites/default/files/page/2014/Final%20Science%20CG%203-10%2005.08.2014.pdf. [Last retrieved 2018 Aug 20].

Driver, R., & Ericsson, G. (1983). Theories-in-action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science. *Studies in Science Education*, 10, 37-60.

Gabel, D. (1999). Improving teaching and learning through chemistry education research: A look to the future. *Journal of Chemical Education*, 76(4), 548.

Gilbert, J. (2008). Visualization: An emergent field of practice and enquiry in science education. In: Gilbert, J.K., Reiner, M., & Nakhleh, M., (Eds.), *Visualization: Theory and Practice in Science Education*. Dordrecht, the Netherlands: Springer Science+Business Media. pp. 3-24.

Gilbert, J., & Treagust, D. (2009). *Multiple Representations in Chemical Education*. Dordrecht, the Netherlands: Springer Science+Business Media.

Harrison, A., & Treagust, D. (2003). The particulate nature of matter: Challenges in understanding the submicroscopic world. In Gilbert, J.K., de Jong, O., Justin, R., Treagust, D., & van Diel, J.H., (Eds.), *Chemical Education Towards Research-based Practice*. Dordrecht, the Netherlands: Kluwer Academic Publishers. pp. 189-212.

Hofstein, A. (2004). The laboratory in chemistry education: Thirty years of experience with developments, implementation, and research. *Chemistry Education Research and Practice*, 5(3), 247-264.

Jaber, L., & Boujaoude, S. (2012). A macro-micro-symbolic teaching to promote relational understanding of chemical reactions. *International Journal of Science Education*, 34(7), 973-998.

Johnstone, A. (1982). Macro- and micro-chemistry. *School Science Review*, 64, 377-379.

Johnstone, A. H. (1991). W*hy is science difficult to learn? Things are seldom what they seem*. Journal of Computer Assisted Learning, 7(2), 75-83. Available from: https://10.1111/j.1365-2729.1991.tb00230.x.

Kaur, G. (2011). Study and analysis of lecture method of teaching. *International Journal of Educational Planning and Administration*, 1(1), 9-13.

Kumar, K. (2004). *Methods of Teaching Chemistry*. New Delhi: Discovery Publishing House.

Li, W., & Arshad, M. (2014). Application of multiple representation levels in redox reactions among tenth grade chemistry teachers. *Journal of Turkish Science Education*, 11(3), 35-52.

Marais, P., & Jordaan, F. (2000). Are we taking symbolic language for granted? *Journal of Chemical Education*, 78(10), 1355-1357.

Millar, R. (2004). *The Role of Practical Work in the Teaching and Learning of Science*. The University of York Department of Educational Studies. Available from: http://www.sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_073330.pdf. [Last retrieved on 2018 Aug 20].

Nelson, P. (2002). Teaching chemistry progressively: From substances, to atoms and molecules, to electrons and nuclei. *Chemistry Education: Research and Practice in Europe*, 3(2), 215-228.

Royal Society of Chemistry. (2011). Global Framework for Chemistry Education for 11-14 and 14-16 Ages Ranges. from http://www.rsc.org/images/DEVELOPING%20A%20GLOBAL%20FRAMEWORK%20FOR%20CHEMISTRY%20EDUCATION_tcm18-207914.pdf. [Last retrieved on 2018 Aug 20].

Sanchez, J.M. (2017). Integrated macro-micro-symbolic approach in teaching secondary Chemistry. *Kimika*, 28(2), 22-29.

Talanquer, V. (2011). Macro, submicro, and symbolic: The many faces of the Chemistry triplet. *International Journal of Science Education*, 33(2), 179-195.

Towns, M., Raker, J., Becker, N., Harle, M., & Sutcliffe, J. (2012). The biochemistry tetrahedron and the development of the taxonomy of biochemistry external representations (TOBER). *Chemistry Education Research and Practice*, 13, 296-306.