Trends in visualization in chemistry teaching

Tendencias en la visualización en la enseñanza de la química

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Abstract

This study presents a profile and major trends of research being carried out in the field of visualization in chemistry teaching from 2001 to 2010. Based on general categories such as main authorship's country, chemical concept and teaching level approached, theoretical framework indicated, research methodology, type of teaching resources used and nature of the paper, a total of 178 studies published in 15 different journals were analysed and classified. As regards the nature of the paper, a selection was made to focus on those studies aiming specifically at educational research, and such studies were submitted to a cross-category analysis so as to identify possible correlations among the classification categories. In general, it was found that research in visualization in chemistry teaching, by exploring primarily the use of interactive learning support used by high school students, has investigated how individual learning processes take place.

Keywords: *chemistry teaching, educational research, vizualization.*

Resumen

Este trabajo presenta las principales tendencias de la investigación que se lleva a cabo en el campo de la visualización en la enseñanza de la química 2001-2010, basado en categorías generales como país, el autor principal, el concepto químico , el nivel de la enseñanza abordado, marco teórico indicado, metodología de la investigación, el tipo de enseñanza, recursos utilizados y la naturaleza del trabajo. 178 estudios se analizaron y clasificaron en 15 diferentes revistas. Se hizo una selección para centrarse en aquellos estudios destinados específicamente a la investigación eduddcativa, y fueron sometidos a un análisis comparativo de la categoría de dichos estudios con el fin de identificar posibles correlaciones entre las categorías de clasificación. En general, se encontró que la investigación en la visualización en la enseñanza de la química, explorando principalmente el uso de apoyo interactivo al aprendizaje utilizado por los estudiantes de secundaria, ha investigado como realiza el aprendizaje.

Palabras clave: *educación química, investigación educativa, visualización.*

INTRODUCTION

Chemistry studies matter and its transformations both at a macroscopic and a microcospic level, a fact which may explain many of the difficulties experienced in teaching and learning this science. That happens because, although both levels are real, only the former is accessible to the naked eye (Chittleborough abd Treagust, 2008). Many students face difficulty imagining interactions at the microscopic level, which may be assigned to different learning styles. In this context, visualization can play an important role in the task of making chemical concepts – and the phenomena they explain – more concrete and tangible (Cook, 2006).

Sharing the same view, Wu and Shah (2004) carried out a literature review focusing on the relationship between visualization and teaching/learning processes in chemistry education. In their research those authors analysed how the abilities of visualization shown by the students could influence their learning and how teaching with a focus on visualization could contribute to make the study of chemistry easier.

Although such researchers found data indicating the correlation between chemistry visualization and teaching/learning, it is common knowledge that not every chemistry teacher has realized the importance of visualization, as Schonborn and Anderson (2006) point out. For these authors, teachers in general start from the assumption that the ability to visualize develops naturally as the student, more and more urged to do this, is exposed to situations in which such an ability is required.

Bearing in mind that visualizations are not automatically transformed into knowledge, visual abilities are indeed important. Therefore, it is crucial to understand the processes through which such transformation can take place and, accordingly, the factors that might influence such processes.

According to Gobert (2005), when it comes to theoretical terms, psychology and educational research usually refer to visualization by assigning it three possible meanings: i) visualization as external representations comprising tools for use in teaching, fit to "materialize" an intrinsically abstract concept, such as schemes, illustrations, animations and infographics; ii) visualization as internal representations comprising the mental models individually formulated during the learning process; iii) visualization as visual-spatial ability comprising the treatment of information that is visually displayed in a given space.

Gilbert et al. (2010), in turn, establish a link between internal and external representation to define what visualization is. According to them, visualization is the formation of a mental model, therefore, an internal representation based on the exploration of a visualization tool, that is, an external representation. They further emphasize that the most fundamental conceptual, temporal and spatial features of the external representation must be expressed in the internal representation developed by the subject. In a more practical way, Uttal and O'Doherty (2008) define visualization as any kind of physical representation devised to make visible an abstract concept.

In view of the above, visualization and its relation with the teaching of chemistry has drawn the attention of teachers and researchers in the field of education (Wu and Shah, 2004), which accounts for the fact that this theme has become a more recurring object of study in science teaching; it also accounts for an increased use of visualization as a fundamental tool in chemistry learning in the hope that, by relying on it, students can more adequately internalize the chemical concepts being taught (Chittleborough and Treagust, 2008; Costa et al., 2008; Marson e Torres, 2011). In contrast, the use of visualization in chemistry teaching still shows some gaps, as Schonborn and Anderson (2006) and Ferreira and Arroio (2009) suggest. Thus, it is deemed interesting to establish a profile of what kind of research is being carried out in the area of chemistry visualization and teaching, aiming at learning about the state of the art in this subject. In a previous study of this matter, a panorama of the evolution of more general issues on visualization in chemistry teaching was presented; it covered the 2001-2010 period (Teruya et al, 2013). The general trends concerning the issue indicate that: there is still some prevalence of papers originating from English-speaking countries; the use of qualitative research methodologies has increased, although quantitave research methodologies still prevail; studies involving students being organized in groups have been more frequent, despite the fact that not always are group interactions used; the majority of papers published is restricted to reporting visualization tools with emphasis on those based on software. It was also found that there is "the need to direct research toward the theme of visualization to expand the understanding of that theme and its direct and indirect implications for chemistry teaching". The present paper retrieves and expands the analysis of the production of visualization tools by delving into the characterization of those papers with an investigative goal.

METHODOLOGY

The methodology used in the present research is state-of-the art, aiming at characterizing studies involving research in visualization, within a time frame outlined in terms of the significant increase in production between 2001 and 2010 (Teruya et al., 2013). The list of journals examined is shown in Figure 1.

The selection of these journals took into consideration those which are admittedly relevant in the field of science education such as *Int.J.Sci.Educ.* and *J. Chem. Educ.*, besides others such as *JSE* and *PEC*, the publications of which have contributed more and more to this line of research. It is worth noticing that some journals began their publications after 2001, the year when this survey started; however, that was not a determining factor in their selection.

The following parameters have been adopted for the articles under examination:

Identification parameters, used only as reference for the papers: *volume and issue number, number of pages, language and authors.*

Classification parameters, used in data analysis: *journal, year, main author's country of origin, chemical concepts involved, nature of the article (original, review, etc), target audience, theoretical references, application*

Biochemistry and Molecular Biology Education (BAMBED)
Chemical Education Research and Practice (Chem. Educ. Res. Pract.)
Computers & Education (Comput. Educ.)
International Journal of Science Education (Int. J. Sci. Educ.)
Journal of Chemical Education (J. Chem. Educ.)
Journal of Research in Science Teaching (J. Res. Sci. Teach.)
Journal of Science Education (JSE)
Journal of Science Education and Technology (J. Sci. Educ. Technol.)
Problems of Education in 21 st century (PEC)
Research in Science Education (Res. Sci. Educ.)
Revista Brasileira de Pesquisa em Ensino de Ciências (RBPEC)
Revista Electrónica de Enseñanza de las Ciencias (REEC)
Science & Education (Sci. Edu.)
Química Nova (Quím Nova)
Química Nova na Escola (QNESC)

Figure 1. Journals examined in the 2001-2010 time frame.

Table 1. Percentage correlation between main author's country of origin and journal for the total number of articles (n=178).

Country	Journal					
	J. Chem. Educ. (43)	BAMBED (12)	J. Sci. Educ. Technol. (7)	Chem. Educ. Res. Pract. (6)	Comput. Educ. (4)	Others (28)
The United States (44)	27	7	6	2	0	3
Brazil (10)	2	1	0	0	0	7
Israel (5)	0	0	1	1	1	3
The United Kingdom (4)	2	1	0	1	1	0
Australia (4)	1	1	0	0	1	2
Others (33)	12	3	1	3	2	12

methodology, investigation methodology and teaching support. It should be mentioned that, except for the *journal, country and type of article* criteria, the other criteria allowed for multiple classifications. In such cases, the accounting of data within the same criterion may be higher than the total number of articles analysed. The following types of article were taken into consideration: original research; original methodology, didactic resource; and review. Original research papers mean those papers of an investigative nature, with a clear definition of a question to be answered with the research and the due referencing of the investigation methodology used for that end.

The data collected were compiled into an electronic worksheet and subjected to

a quantitative treatment which indicated the number of articles published according to each one of the classification criteria established. The results of such survey were grouped into two populations of articles. Review articles, didactic and methodological innovations were grouped together as *Non Research*, whereas the original research articles were grouped together as *Research*. For the *Research* group of papers, cross-section analyses were conducted for some categories and associations were defined between concept and education level; concept and teaching support; theoretical references and investigation methodology.

RESULTS AND DISCUSSION

General characterization of the articles on visualization in teaching Chemistry

i. Origin of the articles analysed

This study has analysed 178 articles on visualization in the teaching of Chemistry and as a first finding it identifies the origin of such papers as regards the journals where they were published and the main author's country of origin. Such characterization can be seen in Table 1, which shows the correlations between these two parameters for the total bibliographical production.

The findings indicate that the United States account for 44% of the publications in the area of visualization, followed by Brazil, Israel, the United Kingdom and Australia, in descending order, as the countries which have most contributed papers. It is interesting to notice three out of five of these are English-speaking countries. Lee et al. (2009) suggest that having English as a mother tongue may make it easier for these articles to be published in such countries. According to review by these authors, the United States, Australia, the United Kingdom and Canada – all of which are English-speaking countries – accounted for most papers published on research in the teaching area between 2003 and 2007.

As to the journals where such studies were published, *J. Chem. Educ.* is the one with most publications in the area of visualization, 43% of the total, followed by BAMBED, *J. Sci.Edu.Technol., Chem. Edu.Res.Pract.* and *Comput. Educ.* It must be mentioned that *J. Chem. Educ.* shows the highest number of publications in general, with monthly issues and many articles published by each issue number. Moreover, it is relevant to mention that this journal is specifically directed toward the teaching of Chemistry, besides having a section publicizing instructional material with emphasis on information technologies such as software, which distinguishes it from many other journals that publish research on the teaching of science in general.

By analysing the correlations between country and journal, it was found that the main correlation is between the United States and *J. Chem. Educ.*, so 27% of papers on visualization are published in this journal and were written by North-American researchers. In this context, it is worth pointing that *J. Chem. Educ.* is published by the American Scientific Society, which might account for such a high correlation.

The origin of *Research* and *Non Research* articles separately was also identified, with a view to defining the profile of these two types of studies. The first group comprises 51 papers, almost 30% of the total number of publications. The second group comprises articles of teaching resource type (69), methodology (54) and review (4), amounting to a total of 127 publications.

Tables 2 and 3 present, respectively, the correlations between main author's country of origin and journal for non research and research articles. An analysis of these data in parallel with those supplied by Table 1, shows interesting findings.

Table 2: Percentage correlation between main author's country of original and journal for non research articles (n=127)

Country	Journal					
	J. Chem. Educ. (53)	BAMBED (15)	Chem. Educ. Res. Pract. (6)	J. Sci. Educ. Technol. (5)	JSE (5)	Others (17)
The United States (50)	32	9	2	5	1	2
Brazil (11)	2	1	0	0	0	8
Australia (5)	1	1	0	0	0	3
Greece (5)	3	0	1	0	1	1
The United Kingdom (5)	2	1	1	0	0	0
Others (25)	12	4	2	0	3	4

An initial comparison of data shown in tables 1 and 2 reveals that the profile of the total bibliographical production reflects the trends found in non research articles. The countries and journals which stand out with a higher number of total publications on visualization are virtually the same when only non research articles are taken into consideration. The high correlation between the United States and *J. Chem. Educ.* is also repeated for these two groups.

Table 3. Percent correlation between main author's country of original and journal for research articles (n=51)

Country	Journal					
	J. Chem. Educ. *(20)*	Comput. Educ. *(12)*	J. Res. Sci. Teach. *(12)*	J. Sci. Educ. Technol. *(12)*	Chem. Educ. Res. Pract. *(8)*	Others *(37)*
The United States *(31)*	14	0	0	8	2	8
Israel *(14)*	0	0	8	2	0	4
Turkey *(12)*	0	4	2	0	0	6
Taiwan *(6)*	0	0	2	2	0	2
Brazil *(6)*	2	0	0	0	0	4
Others *(31)*	4	8	0	0	6	14

This scenario, however, undergoes modifications when only research articles are analysed. As it was found by comparing the three tables, the contribution of the United States for papers on visualization increases from 44% to 50% when total articles and non research articles are compared, but decreases to 31% when it is compared with research articles. This picture changes even more for *J.Chem. Educ.*, which accounts for 43% of the total publications, 53% for non research articles and only 20% for research articles. Such a result seems to be in accordance with the profile of the journal, which stands out for the teaching innovations presented, with wide publicizing of educational software. The correlation between the United States and *J. Chem. Educ.* is still the highest one for any group of articles, which confirms the hypothesis that such correlation is justified by the fact that this journal is an American Chemical Society publication. On the other hand, a less sharp decrease in the number of papers from the United States when a comparison is made with the decrease in the numbers of *J.Chem. Educ.* figures, suggests that, in fact, the hegemony of the English language in the academic world favors publications by those countries where English is the oficial language.

Another difference in the profile of research and nonresearch articles has to do with the publications contributed by different countries. Countries which do not appear as first-ranking ones when the total number of articles are analyzed, such as Taiwan and Turkey, emerge in the best ranking positions when only research articles are analysed. Apparently, this change in the scenario of countries indicates that research of an investigative nature is being conducted in countries that publish less, but whose researchers are directing their studies towards the investigation of issues related to visualization. Conversely, countries with a high number of publications stand out by the high amount of papers directed specifically toward methodological and didactic innovations. Still with reagard to the origin of the articles, it was found that research papers, when compared to non research papers, are more widely spread among different journals and countries. Such information can be obtained from the percentage numbers assigned to countries and journals which are not ranked in the first five positions, represented by the term 'others' in the tables. The percentages of other countries and other journals are 25% and 17%, respectively, for non research articles, but increase in the same order to 31% and 37% when research articles are taken into consideration, which indicates that teaching resources and methodology articles focus primarily on certain groups of countries and journals.

Chemical concept in research and non-research articles

Table 4 shows a comparison for the concepts approached. It must be mentioned that various concepts were listed in the data survey; however, to make both treatment and interpretation of the data easier, these concepts were combined into seven classes as suggested in this paper:

Such data reveal that research articles deal mostly with concepts related to matter structure and biochemistry, considering issues such as the particulate nature of matter, molecular structure, chemical bonds and proteins. These subjects are also largely approached in other articles, but the mostly cited ones are, for instance, those related to molecular properties, such as symmetry, isomerism, spectroscopy and intermolecular interactions. With respect to concepts of matter structure, it is appropriate to mention that they are focused on all the educational levels, with a higher or lower degree of depth, which

may account for their appearing in a large number of papers. Considering that these contents involve considerable level of abstraction, establishing relations with everyday phenomena is more difficult and complex when compared with other topics.

Table 4. Concepts approached in research and non research articles.

Concept	% Research (n = 56)	% Non Research (n = 135)
Matter structure	26	19
Biochemistry	14	19
General Chemistry	12	8
Physical-Chemistry	12	14
Lab Techniques	9	3
Molecular properties	9	25
Others	18	12

Correlations between the parameters analysed in research articles

The first correlation established is between the concept approached in the research and the educational level in question. What motivated this cross-section of data is the idea that the different chemical concepts dealt with in each educational level are closely connected with the curricular planning adopted. The findings obtained in such correlation are shown in Table 5.

Such findings deserve some consideration. One of them has to do with more diversified concepts approached in higher education in comparison with primary and secondary school; thus, whereas the latter tends to present only more elementary concepts of chemistry as, for instance, the particulate nature of matter, higher education studies consider many more and more complex Chemistry topics.

Table 5. Correlation between concept investigated and educational level

Concept	HE	HSE	PE	TF	Total
Lab techniques	4	0	1	0	5
General Chemistry	4	2	0	1	7
Matter structure	2	9	5	1	17
Biochemistry	3	5	0	0	8
Physical-chemistry	4	3	0	0	7
Molecular properties	5	0	0	0	5
Others	2	3	0	4	9
Total	24	21	6	6	57

Legend: HE:higher education; HSE: high school education; PE: primary education; TF: teacher training.

Incidentally, a more in-depth look into the subjects also represents a demand for a more abstract and microscopic reasoning on the part of undergraduate students. This accounts for more research on visualization, considering that through visual representations the more abstract phenomena and concepts can be better understood (Cook, 2006; Treagust et al., 2003). This table also shows the importance given to topics related to matter structure in all teaching levels, since more elementary concepts such as chemical bonds, for example, clarify various properties of matter and various phenomena (Carvalho et al., 2009). An approach of these topics is recurring, therefore, in every educational level, for it shows its relevance when other subjects are discussed, such as concepts connected with molecular properties, a more frequent topic in research dealing with higher education.

Connections between the concepts approached and the type of teaching support used in the research

The diversity of visualization resources has to do with the fact that each type of tool can be more appropriate for a given learning difficulty, as Wu and Shal (2004) argue; and they also mention the potentialities of the different visualization resources. The findings obtained from the correlation between concept and type of teaching support used are shown in Table 6.

Table 6. Correlation between the concept investigated and teaching support

Concept	Inter.	I. Electr.	I. Paper	Phys.M.	Anim.	Others	Total
Lab techniques	5	1	0	0	1	3	10
General Chemistry	4	2	0	0	3	2	11
Matter structure	11	5	0	0	2	5	23
Biochemistry	5	2	2	2	1	2	14
Physical-chemistry	6	2	1	0	0	4	13
Molecular properties	5	2	1	3	0	2	13
Others	6	3	1	1	2	4	17
Total	41	17	5	6	9	22	100

Legend: Inter.: interactive; Electr.: electronic; Il.: illustration; P.: paper; Phys.M.: physical model; Anim.:animation.

The first piece of information which can be inferred from this table is the small number of research with paper illustrations as opposed to the large number of investigative papers using interactive support, comprising computer software which enables interactivity. Concerning computer visualization tools, Wu and Shah (2004) attribute their large use to the fast technological development. It is worth noticing as well that computer programs focus mainly on concepts of matter structure. This may be related to more the technical ease for developing programs that enables visualization of molecular structures in comparison with computer tools aimed at other chemistry topics.

Connections between theoretical reference and methodologies of investigation and application in the investigative context

Table 7 shows the correlation between theoretical reference and investigation methodology. It must be mentioned that the theoretical reference recorded was that one used by the authors. As regards theoretical reference the two most cited ones are 'multiple representations' and 'cognitive abilities', which are mainly correlated with quantitative tests.

Table 7. Correlation between theoretical referencing mentioned and investigation methodology.
(Would "learning process" be a better term than "theoretical reference"?)

Theoretical reference	Tests QT	Quest QT	Interv. QL	Dr	V/A	Likert	Quest QL	Others	Total
Multiples Repres.	13	6	8	4	4	4	3	0	42
Cognitive abilities	12	8	4	7	4	4	3	0	42
Alternative conceptions	6	4	7	3	4	1	1	0	26
Constructivism	4	6	6	1	4	0	1	1	23
Visual/spatial abilities	6	3	0	3	0	3	0	0	15
Mental Models	2	1	0	2	1	1	2	0	9
Others	11	3	3	2	1	9	4	0	33
Total	53	31	28	22	18	22	14	1	189

Legend: QT: quantitative; QL: qualitative; Quest.: questionnaire; Interv.:Interview; Dr.: drawing; V/A:video/audio; R.: representations; ab.: abilities; C.: conceptions

A higher correlation of "alternative conceptions" theoretical referencing, the third most cited item, occurs with the interview method. Thus, it is plausible to infer that researchers determine their methodologies according to the theoretical reference adopted.

These data suggest that the focus of the investigation research has been predominantly on individual learning processes mediated by visualization rather than on the effect of social relations in learning processes using visual representation as a support tool.

FINAL CONSIDERATIONS

Studies in this area have resorted mostly to individual activities and visualization computer tools. Such data indicate that research on visualization has focused on individual learning processes. The prevalent use of computer programs seems to reiterate this trend, once the interactions analysed take place between student and instructional support. Researchers have shown interest in learning how students' individual abilities influence the use and benefit of the teaching resources and, in parallel, what effect they have on students' abilities.

The notion of learning as an individual process seems to be confirmed by the use of diversified methodologies. Although some of them are more recurring than others, using more than one research methodology and applying more than one type of activity have been common procedures. This practice may be related to the attempt to investigate more carefully how students learn, that is, considering the particularities of each one, which is more difficult to deal with when only one research methodology is adopted and only one type of activity is used. It was found that there is a predominance of studies referring to learning styles and their relation with cognitive theories. Despite the relevance of investigating individual learning processes, it was found that more research is needed on visualization that looks more closely into student-to-student dialog with regard to both sharing and expressing their visual representations among their peers as well as the effect of such relations on the students' learning. The difficulties in understanding visual representations, which result in learning problems in Chemistry at high school and higher education levels, should be better examined with regard to primary school students for an early identification of such problems.

The teachers' visualization abilities, both in their initial and continuing training also deserve to be investigated by researchers, as the difficulties teachers are faced with in this area may reflect on the way they use visualization in the classroom and, as a consequence, result in a less adequate teaching and learning process when they employ visual tools to support teaching.

This research has also found that there is some lack of studies discussing public policies aiming at guiding actions in the educational process supported by visual tools, be it through apparatuses available in schools with adequate infrastructure and equipment for such practices, be it in the production of didactic material and innovations aimed at promoting significant changes in teaching and learning processes, and, most importantly, in the more and more necessary formation of teachers prepared for such situations. The present paper has pointed, therefore, that some study areas are favoured in visualization research and that others should be explored, thus seeking to contribute possible guidelines to current research on such relevant and complex issues.

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