

AN ANALYSIS OF THE HIGH SCHOOL STUDENTS' ABILITIES TO READ REALISTIC, CONVENTIONAL, AND HYBRID IMAGES IN GENERAL CHEMISTRY

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Introduction

In science and science education the visualisations have significant role. In science education, visualisations or, more precisely, visual representations are static and dynamic visual signs (de Berg, 2012) that provide scientific understanding and transfer knowledge (Eilam & Poyas, 2010). According to Gilbert (2010), there are two different forms of visual representations: internal and external. It is difficult to define internal visual representations (IRs) as they are abstract constructs in the memory (Rapp, 2005; Zhang, 1997) that can not be observed directly (Rapp, 2005). However, IRs are important in enabling students to withdraw necessary information from long-term memory to generate hypotheses, transfer knowledge, solve problems, and make decisions (Rapp & Kurby, 2008). Also, IRs are constructs defined as mental outcomes of visual display of an object, experience or event (Rapp & Kurby, 2008) from the outside world (Rapp, 2005). Observing this definition, Eilam and Poyas (2010) have highlighted the need to distinguish internal and external visual representations. Namely, external visual representations (ERs) are objects, physical symbols, and dimensions from our environment (Zhang, 1997). Individuals can see ERs with the naked eye (Uttal & O'Doherty, 2008) which makes an opportunity to intrinsically think about abstract phenomena (Eilam & Poyas, 2010). For example, chemistry students encounter many abstract concepts in educational process. Therefore, in chemistry education various ERs, such as line or bar graphs, pie, maps, molecular models, photographs, drawings, and tables, can be effectively applied.

In this research, the textbook images as one particular type of ERs were of special interest. Colin, Chauvet, and Viennot (2002) have defined images as "a critical vehicle for (transformative) information transmission" (p. 313). Researchers from the field of science education have conducted an autonomous analysis of the images included in the science textbooks. For example, textbook images have been classified by their type and function



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Abstract. *This research considered students' abilities to read images about dispersed systems, taken from the chemistry textbook. 103 high school students (37 males, 63 females, and 3 unknown) from the school "Svetozar Marković" in Novi Sad, Republic of Serbia, were included as the research participants. Students' abilities to suggest the titles of the realistic, conventional, and hybrid textbook images about dispersed systems, as well as their written interpretations of images contents, were examined. The collected data were analysed qualitatively, and information about students' conceptual understandings and misunderstandings about selected chemistry topic was provided. Identified misunderstandings, some of which are the contribution of this research, gave significant results. Additionally, it was concluded that the majority of students' difficulties were related to reading realistic textbook images. Students relied on what they literally saw in the photography without making proper connections with chemical contents about dispersed systems. The findings of the present research could be helpful for science teachers and educators, interested in how and why students use textbook images to learn science concepts. They will also alert authors and textbook illustrators to pay more attention to the selection of appropriate textbook images.*

Keywords: *image types, general chemistry, reading images, textbook images, visual representations.*

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and regarding their type, images have been classified as realistic, conventional, and hybrid (Dimopoulos, Koulaidis, & Sklaveniti, 2003). The *realistic* images, such as photographs and drawings, represent reality according to the human optical perception. *Conventional* images are designed according to the techno-scientific conventions, and they represent reality in a codified and the most condensed way (Devetak & Vogrinc, 2013). Conventional images cover line and bar graphs, two-dimensional representations of molecular models, maps and they are significant for scientific writing. *Hybrid* images are the combinations of elements from the previously described two types of images (Dimopoulos et al., 2003). They combine the realistic and symbolic entities in an image (Devetak & Vogrinc, 2013). Each type of images has some special features that enable its effectiveness. For example, photographs are predominantly used in school science textbooks (Pozzer & Roth, 2003), as they have more impact on students outside the science classroom in comparison to the graphs or equations, which may often be incomprehensible to them (Myers, 1990, cited in Pozzer & Roth, 2003). However, within conventional images, maps are effective in conveying qualitative relations between concepts of interest (e.g. functional, spatial, or structural relations). Additionally, graphs effectively display quantitative relations (Eilam & Poyas, 2010). They play a pivotal role in communicating science concepts from the experts to the students (Chen & Gilbert, 2009). The hybrid images have been recently introduced in the literature, and there are a lot of possibilities for examination.

Although there is an interest in visual language for science education, the empirical studies on using images in the science classroom are insufficiently presented (Ametller & Pintó, 2002). Some of these studies have focused on students' abilities to "read" images. For example, students' difficulties in reading images in optics, together with the teachers' awareness of such difficulties, have been examined (Colin et al., 2002). In this study, five documents with images and corresponding text elements found in the textbooks have been used. Also, the authors of some studies have used textbook images as an exemplar to design own images, particularly for the research. With the aim to investigate secondary school students' abilities to interpret the image content about energy, Ametller and Pintó (2002) have developed a theoretical semiotic frame. They have highlighted specific features of science images that can affect the students' comprehension and cause difficulties while reading images. One of them is the polysemic use of the arrows. A similar study has been conducted by Stylianidou (2002) who has also investigated students' difficulties while reading science textbook images about energy. This author has noted several textual and graphic features of images that may cause difficulties: simultaneous interpretation of both realistic and conventional (i.e. schematic and symbolic) elements; reading of symbols that could be polysemic, synonymous and homonymous; reading of textual elements that could be included in the image; and interpretation of several images that should be observed as a whole (interpretation of relations between them). Additionally, Cook (2008) has conducted research to examine high school students' abilities to recognize, interpret and understand the textbook images in biology, within the topic of meiosis. After the instruction, the students have been given the image of meiosis without verbal explanations and required to label the structures in the image, then to label the phases of meiosis, and finally to give the overall summary. This has been followed by the interview protocol. Even though the findings of the study have indicated that the students have not had many misconceptions about the topic of meiosis, they have not understood the process completely (Cook, 2008). In chemistry, Harrison and Treagust (1996) have asked 8-10 grade students to choose a diagrammatic representation of an atom (atomic nucleus surrounded by electrons) and also to draw what they perceive to be an atom. The findings of such a study can be very important as they inform the chemistry teachers about students' previous conceptions when they start to learn more complex models of atomic structures (Chen & Gilbert, 2009).

Research Problem

The fact that dispersed systems are one of the most important but yet challenging topics of secondary school chemistry considering its abstract nature and conceptual difficulties, makes it a good choice for the research. In the literature, there are research findings that have demonstrated students' conceptual understanding and/or difficulties with this topic, especially about solution chemistry which is one of the most often examined topics in chemistry (Çalik, 2005). For example, the researchers in this field have investigated the dissolution concept (Noh & Scharmann, 1997), solubility equilibrium that includes concepts of dissolution, solubility, chemical equilibrium effects, Le Châtelier's principle, stoichiometry (Raviolo, 2001), and solution concentration (de Berg, 2012). Noh and Scharmann (1997) have conducted interesting research observing four chemistry topics with one of them being the concept of dissolution. These researchers have included textbook images about dissolution as both instructional materials and as a part of the evaluation instrument (along with multiple-choice and open-ended questions).



The quantitative results have indicated that the treatment group outperformed the control group on the subtest about dissolution. However, there was no significant difference between the groups in the pictorial test scores. It has been noted that the ability to solve the pictorial problems demands deep conceptual understanding. Until now there have been a few studies about students' ability to read images about dispersed systems, and no study about reading images categorized separately as realistic, conventional, and hybrid.

Research Focus

Taking into account the research problem, this research put the focus on high school students' abilities to read textbook images. Two aspects were analyzed: (i) suggestion of the image title, and (ii) interpretation of the image content. There were three research tasks:

1. To analyse students' abilities to suggest the title for the set of realistic, conventional, and hybrid textbook images about dispersed systems.
2. To analyse students' abilities to interpret the content of the realistic, conventional, and hybrid textbook images about dispersed systems.
3. To analyse students' misunderstandings while reading images about dispersed systems.

Research Methodology

General Background

This research utilized qualitative design to solve the research tasks associated with the students' abilities to read images about dispersed systems, as well as about their misunderstandings while reading images. The researchers collected the data using the test of knowledge that included three basic types of images (i.e. realistic, conventional, and hybrid) retrieved from the chemistry textbook. In this respect, the students were required to suggest the title for each image and to interpret the image content during one school class. The research was implemented on the high school students who attended the second semester of the first grade of high school in the 2017/2018 school year.

Participants

This research included 103 students (37 males, 63 females, and 3 unknown) from four classes of high school "Svetozar Marković" in Novi Sad, Republic of Serbia. The first-grade students were 15-16 years old. Most of the students were from a middle-class socioeconomic level and were recruited into the study as voluntary participants. They were informed about the nature of the research, about the instrument that will be used, and they could leave the research before the testing has started.

The same chemistry teacher taught all the students. She holds a Master's degree in chemistry education. According to her evaluation, at the end of the first semester of the first year, 52% of high school students had excellent achievement (grade 5), 39% had very good achievement (grade 4), 7% had good achievement (grade 3), and 2% had satisfactory achievement (grade 2) in general chemistry.

Instrument and Procedures

For the purpose of this research, one general chemistry topic was chosen: "Dispersed systems". According to the national curriculum regulations of the first grade of the science-oriented and general high school approved by Ministry of Education, Science and Technological Development of the Republic of Serbia, the selected teaching topic is taught after the following topics: „Chemistry as a science“, „Types of the substances“, „The structure of the atom“, and „The chemical bond“. After these, the following three topics were processed: „Chemical reactions“, „Acids, bases, and salts“, and „Oxidation-reduction reactions“. Table 1 shows the teaching topic chosen for this study, as well as the specific contents of the topic.



Table 1. Teaching topic and corresponding teaching contents.

Teaching topic	Teaching contents
Dispersed systems	Classifications of dispersed systems.
	The importance and application of dispersed systems.
	Solutions.
	Solubility and factors affecting solubility.
	Saturated, unsaturated and supersaturated solutions.
	Thermal changes in dissolving.
	The quantitative composition of a solution.
	Colloids.
Colligative properties of solutions.	

With the aim to analyze students' abilities to read images about the dispersed systems, it was decided to use textbook images. The recommended and one of the most used textbooks in the Republic of Serbia ("General Chemistry 1: Textbook for the first grade of the secondary school") was selected (Nedeljković, 2016). As von Zeipel (2015) suggested, this chemistry textbook was chosen for two main reasons. First, the students were already using this textbook and they were familiar with the format. Second, it includes an appropriate number of images or relative density of the images. The relative density of the images was calculated as the number of images per 1000 words (according to Dimopoulos et al., 2003). The relative density of the images through the whole textbook was 0.004 (i.e. 4 images per 1000 words), and for the chosen topic it was also 0.004. The selected topic included 18 images in total: the same number of realistic and hybrid (i.e. 8 within each category), and 2 conventional. For choosing images for research, one full professor and two assistant professors in the field of Chemistry education, and one master student who was profiled to be a chemistry teacher were selected. The expert team decided to use the same number of images from each category. Therefore, 2 realistic, 2 conventional, and 2 hybrid images were included in the knowledge test. In this section, these six images on which our investigation was based, will be presented and explained.

Figure 1 presents realistic textbook images. The left image should illustrate Tyndall's effect, i.e. the scattering of light by colloidal particles. The right image shows a white island of salt floating in the Dead Sea, as an example of natural crystallization of salt. The author and the illustrator of the selected textbook included narrative realistic images from everyday life to illustrate the abstract concepts of the topic of dispersed systems.

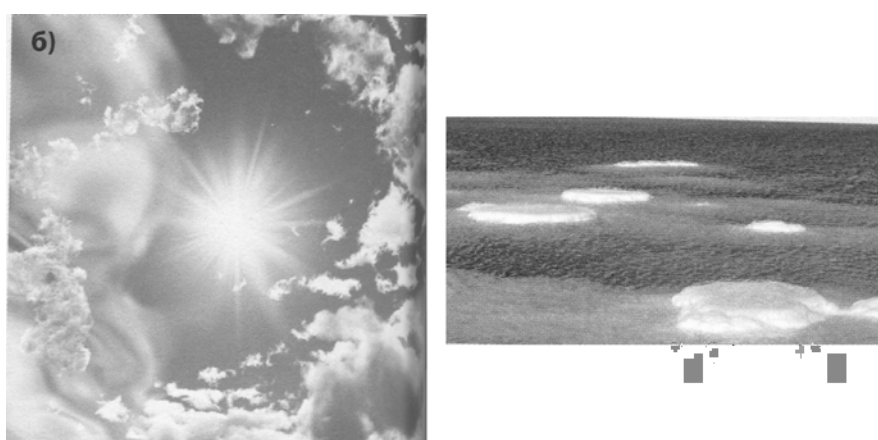
**Figure 1. The realistic images included in the knowledge test.**

Figure 2 includes the conventional textbook images. The left image represents models of molecules and ions as conventional elements and depicts water molecules and their interactions with the sodium and chlorine ions.



The right image is a typical conventional representation of solubility curves which show what mass of different solutes (salts) will dissolve in 100 g of water over a range of temperatures.

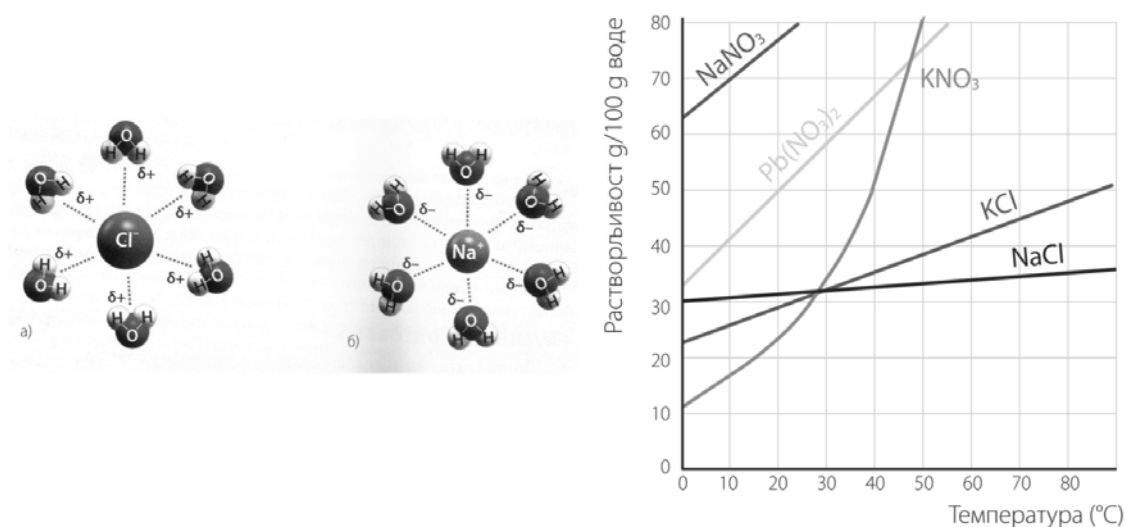


Figure 2. The conventional images included in the knowledge test.

Finally, Figure 3 includes hybrid textbook images that combine both realistic and conventional elements. The laboratory equipment (i.e. beakers and Erlenmeyer flask) and magnifying glass are realistic elements, while models of molecules and ions, arrow, pointers, and chemical formulas are conventional elements. The left hybrid image shows the concentrating of the solution by water evaporation. The right hybrid image shows the dissolution of sodium chloride in water.

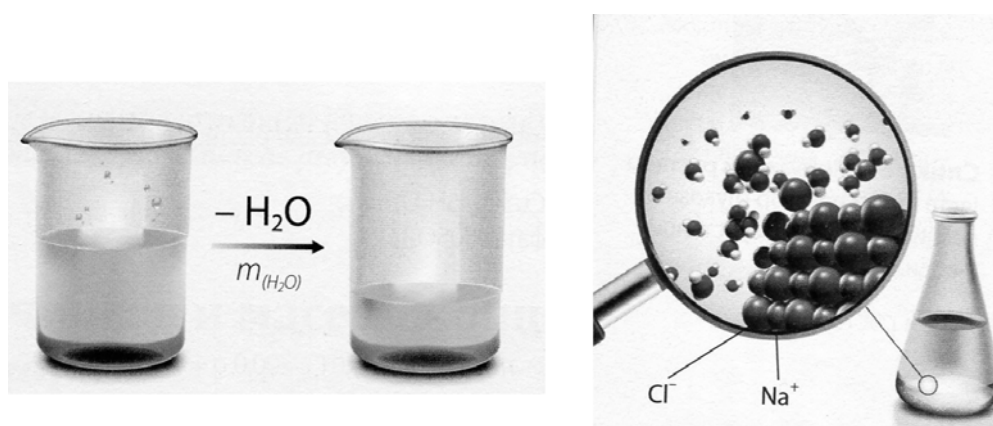


Figure 3. The hybrid images included in the knowledge test.

All images were included in the knowledge test using a black-and-white pattern. In the classroom, the computer and video projector were used by the researcher in order to present images in the original color, one by one. This provided the opportunity for students to see the content of the image more clearly. After that, the knowledge test was conducted in one school class (45 minutes) in May 2018. The students were asked to suggest the image title and to interpret the content for each of the six images. Therefore, two types of data were collected: (i) suggested titles of realistic, conventional, and hybrid images, and (ii) written interpretations of images contents.



Data Analysis

This research was designed to be qualitative. According to Mertens (2010), qualitative methods predominantly use interviews, observations, and document reviews. The document reviews can include curriculums, students' works, and images. This study included textbook images, but with the aim to analyze written evidence of learning from the students' responses. Henceforth, statistical generalizations are not suited for such methodological design.

Firstly, two researchers analyzed students' written answers for each of the six images together, in order to establish the validity of the evaluation process. After that, six tables were developed; one for each image with several categories of suggested titles and variations of the main titles. Also, the number of students who suggested that titles and corresponding percentages were included in the table. In the end, developed tables were additionally analyzed by three other researchers. Each disagreement that appeared among the researchers was solved through a thorough discussion.

Several title categories of images pointed out the presence of students' misunderstandings of observed topic ("Dispersed systems"). Therefore, the researchers looked into their written interpretations of images contents to collect more specific information about such misunderstandings. Due to the abundance of the collected data, the presented results and discussion will refer to one realistic (Figure 1, left image), one conventional (Figure 2, right image), and one hybrid image (Figure 3, right image).

Research Results

Provided tables for the realistic, conventional, and hybrid images include the image title category (first column in the table) and variations of the suggested titles (second column in the table). The separated titles in the first column in each table indicate the highest number of students who suggested that title in the given category. Within some variations of the titles, additional words of several students are placed in parentheses in order not to duplicate the answers. It should be highlighted that within each presented image, only several students did not provide any answer as a possible title for the realistic (2.9%), conventional (1.9%), or hybrid (1%) images.

In order to analyse titles of the realistic image (Figure 1, left image) suggested by the research participants, Table 2 was constructed. Six main title categories were identified: *Tyndall's effect* (19.4% of participants' responses belonged to this category), *Solar radiation* (21.4%), *Sunny skies with clouds* (41.7%), *Air as a dispersed system* (11.7%), *Atmosphere* (1.9%), and *Chemical phenomenon* (1%). Along with these six main titles, the other sixteen variations were suggested by the students. Also, there were three students who were not able to suggest any title for this image.

Table 2. Categories of suggested titles for the realistic image.

Suggested titles	Variations of the titles	Number of students	Percentage
Tyndall's effect	The blue color of the sky as a result of Tyndall's effect.	20	19.4
Solar radiation	Sunlight; Sunlight and heat; Reflection of sunlight; The effect of sunlight on the Earth's environment; Luminosity.	22	21.4
Sunny skies with clouds	Sunny skies; Sun in the sky; Sun and clouds; Sky; Sky and clouds; Cloudiness; Sunny day; Warm weather.	43	41.7
Air as a dispersed system	Dispersed system; Coarse dispersion.	12	11.7
Atmosphere	-	2	1.9
Chemical phenomenon	-	1	1
Without the title	-	3	2.9



Analysing the conventional image from Figure 2 (right image), the students suggested seven main image titles, such as: *Solubility curves of various ionic substances* (9.7%), *Graph* (19.4%), *Solubility of substances* (39.8%), *The rate of a chemical reaction* (11.6%), *Chemical equilibrium* (5.8%), *Energy changes in chemical reactions* (9.7%), and *Concentration of elements* (1.9%) (Table 3). In addition to this, twenty-eight variations of main titles were noticed. The highest number of variations were recorded within the title category *Solubility of substances* (fourteen variations in total). Only two participants did not suggest the title or provide some interpretation for this conventional image.

Table 3. Categories of suggested titles for the conventional image.

Suggested titles	Variations of the titles	Number of students	Percentage
Solubility curves of various ionic substances	Solubility curves of various ionic (solid) substances; Solubility curves; Lines.	10	9.7
Graph	Graphical display; Solubility graph; Diagram; Solubility diagram; A graph of the solubility (of substances) as a function of temperature; A diagram of the solubility as a function of temperature.	20	19.4
Solubility of substances	Solubility at a specified temperature; Solubility of mass; Solubility; Solubility system; Solubility of compounds (in 100 g of H ₂ O at a specified temperature); Solubility of an ionic compounds; Solubility as a function of temperature; Dissolution at a specified temperature; The influence of temperature on the solubility (of substances in water); The temperature dependence of solubility; Change in solubility with increasing temperature; The relationship among temperature and solubility; The influence of temperature on the rate of a dissolution; The influence of temperature on the rate of a solubility.	41	39.8
The rate of a chemical reaction	Chemical rate; The influence of temperature on the rate of a reaction; The influence of temperature and solubility on the rate of a reaction.	12	11.6
Chemical equilibrium	Equilibrium.	6	5.8
Energy changes in chemical reactions	Enthalpy of different compounds; Graph of standard enthalpy (of different compounds).	10	9.7
Concentration of elements	-	2	1.9
Without the title	-	2	1.9

Table 4 was constructed for the first hybrid image presented in Figure 3 (right image). Looking at the students' responses on knowledge test, twelve main categories of the suggested image titles were highlighted: *Dissolution of sodium chloride in water* (31.1% of participants' responses belonged to this category), *Electrolytic dissociation of sodium chloride* (6.8%), *Solution of sodium chloride in water* (9.7%), *NaCl* (15.5%), *Ions* (9.7%), *Molecules* (11.6%), *Oversaturated salt solution in water* (1.9%), *Chemical experiment with the magnifying glass* (3.9%), *The composition of the substance* (4.8%), *Acids* (1.9%), *Infusion* (1%), and *Compounds* (1%). In addition, even 42 variations of these titles were noticed (Table 4). The highest number of such variations were found for the title category *Dissolution of sodium chloride in water* (nine variations in total). In this part of the analysis, the highest number of suggested titles were noticed, which was followed by the smallest number of students who did not suggest any title for the hybrid image from Figure 3.



Table 4. Categories of suggested titles for the hybrid image.

Suggested titles	Variations of the titles	Number of students	Percentage
Dissolution of sodium chloride in water	Representation of dissolution of sodium chloride in water; Dissolution of sodium chloride; Dissolution of salt in water; Dissolution of salt; Dissolution of salt in water into ions; Dissolution of substance into negative and positive ions; Microscopic view of dissolution of the salt; Depiction of a magnifying glass of salt dissolution in water; Solubility of NaCl in water.	32	31.1
Electrolytic dissociation of sodium chloride	Electrolytic dissociation. Positive and negative ions, cations and anions; Dissociation ($\text{NaCl} \rightarrow \text{Na}^+ + \text{Cl}^-$).	7	6.8
Solution of sodium chloride in water	Sodium chloride solution; Molecular dispersions; Solutions; Electrolyte solutions; The composition of the solution; Microscopic view of the solution.	10	9.7
NaCl	Sodium chloride – table salt; The structure of NaCl; Synthesis of sodium chloride; Table salt under the magnifying glass; Enlarged view of the sodium chloride (as a soluble substance in water under the magnifying glass); Chemical experiment with sodium chloride.	16	15.5
Ions	Positive and negative ions in the solution; Interaction of ions Na and Cl; Reaction of sodium and chlorine ions; Salt. Enlarged view of the ions of sodium chloride; Enlarged view of ions of the soluble substance.	10	9.7
Molecules	Molecules of sodium and chlorine; Chemical molecules; Molecular content; Molecules under magnifying glass; Enlarged molecules of sodium chloride; Enlarged view of the molecules in the container; Mixture of the sodium and chlorine atoms; Atoms.	12	11.6
Supersaturated salt solution in water	Precipitation of the particles.	2	1.9
Chemical experiment with the magnifying glass	Test tube and the magnifying glass; Liquid content from the bottle; Enlarged view of the content from the glass container.	4	3.9
The composition of the substance	Analysis of the substance	5	4.8
Acids	Acids and their solutions	2	1.9
Infusion	-	1	1
Compounds	-	1	1
Without the title	-	1	1

Discussion

The original title of the realistic image included in the knowledge test is *The blue color of the sky as a result of Tyndall's effect*. From the total number of students included in this research, 19.4% (Table 2) recognized that the realistic image is related to Tyndall's effect. It should be highlighted that only 7.8% of participants explained the image content in the sense of Tyndall's effect. Looking at this group of students, one of them wrote: "Sunlight is scattering on particles in a colloid where a bright spot is on each one, and we see blue light scattered". Other 6.8% knew that the blue color of the sky is the consequence of Tyndall's effect, but could not explain it in more detail. Also, 4.8% of students did not provide any interpretation, or provided an inappropriate interpretation (e.g. "The sun shines and the rays pass through the clouds"). In the next category of suggested titles, the students who saw *Reflection of sunlight; Solar radiation; or Luminosity* were placed. Tyndall's effect is the phenomena related to sunlight, therefore,



these variations of titles are generally acceptable. To provide valid conclusions, students' interpretations of image content were further analysed. It was found that suggested titles were a reflection of what students literally saw on the realistic image. The same was found within the relatively big group of students (41.7%) who suggested the titles: *Sunny skies with clouds*; *Sun in the sky*; *Sun and clouds*; *Cloudiness*. Taking this into consideration, it might be said that the majority of the students missed the main message of the realistic image presented in Figure 1. There are at least two reasons. Firstly, it is noticeable that the realistic image is a lack of explicit visual information about Tyndall's effect, which according to Stylianidou (2002), could cause difficulties to the students. Certainly, it can be improved, for example by including adequate textual or symbolic elements. Secondly, this large group of students did not look at the image while learning about the abstract concept of Tyndall's effect from the chemistry textbook. Additionally, the title: *Air as a dispersed system* was suggested by the third group of students. For example, some students from this group (3.9%) suggested the title: *Coarse dispersion*. They believed that air is coarse dispersion where dispersed phase particles can be seen by a naked eye as they are bigger than 100 nm. Therefore, the first misunderstanding within our research participants was identified. In the end, within each analysed image, there were students' answers that were too general (e.g. *Chemical phenomenon* or *Atmosphere*).

The original title of the second conventional image (Figure 2, right image) retrieved from the chemistry textbook is *Solubility curves of various ionic (solid) substances*. Only one student suggested the title that fully matches the one from the chemistry textbook. Six students (5.8%) suggested similar titles (*Solubility curves of various ionic substances* or *Solubility curves*). This group of students (6.8%) have conceptual understanding as they explained that increasing the temperature increases the solubility of the most ionic solid substances (salts). However, two of the research participants wrote *Lines* as the suggested title for this conventional image (Table 3). In their interpretations, they noted curved lines or just lines, numbers, and chemical symbols. Namely, they saw only the mathematical and chemical objects. It should be mentioned that more than half of the total number of students suggested the correct titles for the conventional image, such as *A graph of the solubility of substances as a function of temperature*; *Solubility of compounds in 100 g of H₂O at a specified temperature*; *The influence of temperature on the solubility of substances in water*. It was pleasing to find many students who developed important skills to handle with series of visual data represented as graphs. According to Glazer (2011), students will need such skills in everyday life situations, outside of the classroom. In future research it might be important to combine this instrument with the interview protocol in order to examine students' thoughts, as in the study by Stojanovska (2017), high school students thought that all substances are more soluble at higher temperatures, regardless of the state of matter. In our study, some students did not specify the nature of substances in their answers (e.g. *A graph of the solubility of substances as a function of temperature*) and therefore, further examination is needed. In addition, there were several students who showed misunderstandings. Two of the students thought that the graph from Figure 2 illustrates how the temperature affects the dissolving rate of the substances in water, not noting that there are no coordinates with the time taken for the dissolution. Also, it is interesting to note that some students mixed a graph of the solubility of substances with a graph showing the changes in energy in chemical reactions and with a chemical reaction rate graph. This data is not negligible as these students form groups of about 10% of respondents. Also, the small number of students (5.8%) possessed misunderstanding believing that conventional image presented in Figure 2 shows a chemical equilibrium graph. They did not observe the fact that salts included in the graphical display are strong electrolytes that are fully dissolved in water.

The title of the hybrid image taken from the chemistry textbook is the *Illustrative representation of the dissolution of sodium chloride in water*. Even though students were not able to suggest a title that would completely match with the one from the textbook, one student suggested a very similar title: *Representation of dissolution of sodium chloride in water*. The most of them suggested the title *Dissolution of sodium chloride in water*, or just *Dissolution of sodium chloride*, or *Dissolution of salt in water* (Table 4). Instead of "dissolution" some of the research participants used the term "dissociation" (i.e. electrolytic dissociation), which is acceptable. To test whether this group of students (37.9%) possessed a conceptual understanding of the process of dissolution of sodium chloride in water, their interpretations of the hybrid image content were analysed. Namely, 30.2% of students showed more or less developed conceptual understanding, providing the following interpretations:

- "In the sodium chloride crystal lattice, ionic bonds break down in water."
- "In the sodium chloride crystal lattice ionic bonds break down, as well as hydrogen bonds between water molecules, and ion-dipole interactions occur between the ions and water molecules."



However, some students from this group did not provide any written interpretation of the image content (2.9%), and several of them (4.8%) showed misunderstanding believing that "the magnifier zooms in the liquid and molecules are seen". It must be highlighted that many students were focused on a magnifying glass as a separated realistic element and/or on a conventional element which is a model of the sodium-chloride structure (see Table 4). The students noted titles such as *Table salt under the magnifying glass*; *An enlarged view of the sodium chloride as a soluble substance in water under the magnifying glass*. Surely, hybrid images can stimulate higher-order cognitive processes and thinking skills (Devetak & Vogrinc, 2013), but only if the student observes the unity of realistic and conventional elements included in one hybrid image. Furthermore, it was observed that many students (35.9%) believed that the sodium chloride particles can really be viewed under the magnifying glass. The students interpreted the image content in the following way:

- "The magnifying glass can show a detailed dissolution of sodium chloride".
- "A bowl is placed under the magnifying glass to facilitate the study of the obtained solution".
- "Enlarged view of the solution with a microscope to give the viewer a clear and larger image of the content".
- On the other hand, one student noted:
- "The substance from the image is dissolved into positive sodium ions and negative chlorine ions that are observed under magnifying glass which I believe is not possible!"

Additional misunderstanding was attributed to the group of students who suggested the titles like *Enlarged molecules of sodium chloride*; *Molecules under the magnifying glass*. Taking into consideration both suggested titles and students' interpretations, it was found that 13.6% of students showed a misunderstanding believing that sodium chloride exists in the form of molecules in a solution. Noted misconception was previously recorded in the literature (Tien, Teichert, & Rickey, 2007). Apart from this, there were students (9.7%) who thought that there are atoms or molecules of sodium and chlorine in the solution. In the literature, it was noted students' misconception about salt dissolution into neutral atoms (Tien et al., 2007). It is interesting to mention the suggested title *Infusion*. Probably, the students know the use of 0.9% solution of sodium chloride in water in medicine. Additionally, two of the students wrote that hybrid image shows the supersaturated solution of sodium chloride since the whole amount of salt in water is not dissolved and the particles are deposited. In the literature, the students' difficulties with the concept of supersaturated solutions are often mentioned (e.g. Pinarbaşı & Canpolat, 2003).

Conclusions and Implications

The present study was conducted with the main aim to examine the high school students' abilities and difficulties while reading images on the topic of dispersed systems. The students were required to suggest the titles of the set of images and to interpret their content. Images included in the test of knowledge were taken from the chemistry textbook for the first grade of secondary school and were associated with the basic types of images: realistic, conventional, and hybrid. Even though the test of knowledge contained six images in total, in this report, one realistic, one conventional, and one hybrid image were analysed.

The results highlighted that high school students developed the ability to read images satisfactorily. The students had the greatest difficulties in reading the realistic images which can often be without a clear connection to the observed chemical contents, confusing (metaphorical), and decorative. Taking into consideration conventional and hybrid images, significant results appeared. The students were very familiar with the conventional visual representations, such as graphs. However, some of the students showed misunderstandings, especially while reading hybrid images, some of which had already been recorded in the literature, and some are reported here for the first time.

The findings of the present research could be helpful for science teachers and educators who are interested in how and why students use images to learn science (chemical) concepts. But also for the authors and textbook illustrators in order to pay more attention to the selection of appropriate textbook images. Although everyone agrees that textbook images assist in understanding the scientific text, they must be well chosen and clearly linked to the text to which they refer.

As a main task for future research, it could be a combined application of images and multiple-tier tests to identify the students' misconceptions more precisely. In addition to this, the students' abilities to read three basic types of images will be examined as a second part of this study, and also in other teaching topics from organic, inorganic chemistry, or biochemistry.



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