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INFORMATIONAL VALUE OF SUBMICROSCOPIC REPRESENTATIONS IN SLOVENIAN CHEMISTRY TEXTBOOK SETS

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Abstract. This research focuses on the informational value of submicroscopic representations (SMRs) in chemistry textbook sets for Slovenian primary schools (Grade 8 and Grade 9, students' age 13-15 years). For the purpose of analysis a holistic criteria related to the accompanying descriptors of SMRs in textbook sets was developed. The research revealed four main holistic descriptors accompanying SMRs, i.e. direct descriptor (D), indirect descriptor (I), combined descriptor (C), and SMRs without descriptors (W), which support learners' recognition of SMRs' informational value on different levels by providing different accompanying add-ons of SMRs. In-depth analysis identified 14 main categories of the underlying representational types of SMR add-ons. The significance of the research is in initiating a discussion about the holistic criteria for the description of SMRs integrated in the textbook sets, because in practice the learner perceives each SMR as a whole.

Keywords: chemistry learning, chemistry textbook sets, informational value, submicroscopic representations, textbook analysis.

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Introduction

Learning in the information age is characterised by abundant proliferation of information from various sources that are communicated to the learners by a variety of means, which are usually supported by information-communication technology (ICT), such as the internet, social media, virtual classrooms, etc. However, the textbook sets continue to have the central role in supporting effective teaching and learning of science as they should be, by their intent, synchronised with national curriculum for specific subject at certain educational levels. They are used for studying at school as well as at home (Gkitzia, Salta & Tzougraki, 2011). Therefore, significant attention has been paid to textbook analysis in science education. For example, Devetak, Vogrinc, and Glažar (2010) studied explanations of states of matter in Slovenian science textbooks; Majidi and Mäntylä (2011) studied the knowledge organisation in magnetostatics in Finnish textbooks; Laçin-Şimşek (2011) studied female scientists in Turkish science and technology textbooks; Mumba, Chabalengula, and Hunter (2007) studied inquiry levels and skills in Zambian high school chemistry textbooks.

The understanding of chemistry is based on creating mental images for corresponding molecular phenomena. The mental images are internal representations that can be in chemistry visualised through special symbolic systems, so-called external representations of the particulate nature of matter, which are referred to as submicroscopic representations (SMRs) in this research (Gilbert, 2005; Gilbert, Reiner & Nakhleh, 2008). Researchers, starting with Johnstone (1991), pointed out that the representing of science concepts and processes is based on representations of three levels: macroscopic (observable phenomena), submicroscopic or particulate (different representations of atomic, molecular, and particle structure), and symbolic (mathematical and chemical symbols). Thereby, the interpretation of the phenomenon, perceived on a macroscopic level by the use submicroscopic representations, is considered to be one of the fundamental ideas of contemporary chemistry teaching (Eilks, 2013), because visualisations support students when connecting the three levels of concept representations (Al-Balushi & Al-Hajri, 2014; Barke & Wirbs, 2002; Ferk Savec, Sajovic & Wissiak Grm, 2009; Kelly & Jones, 2008).

It is often assumed that students comprehend and efficiently learn with the use of SMRs, because experienced chemists (e.g. authors of textbook sets) can simultaneously use them as a part of a triple representation of chemistry concepts (submicroscopic, macroscopic and symbolic level), as defined by Johnstone (1991). However, the abundant presence of SMRs in a textbook does not ensure efficient learning (Furió- Más, Calatayud, Guisasola et al., 2005; Gkitzia et al., 2011; Harrison, 2001). Researchers (Hinze, Willamson, Shultz et al., 2013; Stull, Gainer, Padalkar et al., 2016; Stieff, Scopelitis, Lira et al., 2016) have found that in order to efficiently use the visualisations it is crucial to develop students' representational competence. According to Stieff et al. (2016), representational competence comprises a distinct set of skills for constructing, selecting, interpreting, and using disciplinary representations for communicating, learning, or problem solving. Research evidence (Ferk, Vrtacnik, Blejec et al., 2003; Kozma, Chin, Russell et al., 2000; Stull, Hegarty, Dixon et al., 2012), indicates that students' successful learning with SMRs is significantly impacted by representational competence in chemistry. Kozma and Russell (2005) elaborated its role in learning chemistry as in order to achieve expertise in the domain, students have to master a specific set of skills, e.g. the ability to analyse features of a representation, transform one representation into another, generate different representations, clarify the usefulness of a given representation, and explain the distinctive affordances of different representations.

This research focuses on the descriptors of SMRs in textbook sets from the perspective of supporting learners in the effective learning of chemistry. Thus far, several authors developed the criteria for evaluating of chemical representations in school textbooks from various aspects (Hinze, Williamson, Deslongchamps et al., 2013; Nyachwaya & Gillaspie, 2016). For example, Gkitzia et al. (2011) proposed five criteria (C1-C5): (C1) the type of the representation; (C2) the interpretation of the surface features; (C3) the representation's relationship to the text; (C4) the existence and the properties of a caption; (C5) the degree of correlation between the components comprising a multiple representation. Kapıcı and Savaşcı-Açıkalın (2015) used the rubric developed by Gkitzia et al. (2011) and focused only on the particulate nature of matter by using three criteria (C1–C3): (C1) the type of the representation; (C2) relatedness to text; (C3) properties of captions. All of the above criteria examined particular characteristics one by one. Because in practice the learner perceives each SMR as one whole, there is a need to develop more holistic criteria for the description of SMRs integrated into textbook sets, including various possible add-ons. The following research questions (RQ) were stated:

1st RQ: What are the holistic descriptors of SMR add-ons in Slovenian chemistry textbook sets?
2nd RQ: What are the underlying representational types of holistic descriptors of SMR add-ons in Slovenian chemistry textbook sets?
3rd RQ: What proportion of representations belong to a particular category of holistic descriptors of SMR add-ons in Slovenian chemistry textbook sets?
4th RQ: What proportion of representations belong to a particular category of the underlying representational types of holistic descriptors of SMR add-ons in Slovenian chemistry textbook sets?

Methodology of Research

General Background

In Slovenia, students enter primary education at age 5-6 (Grade 1) and finish it by the age of 14-15 (Grade 9). After primary school, they enter different secondary schools that last from two to four years. Primary education is compulsory for all students in Slovenia.

There is a national curriculum that all teachers should implement in their classrooms; furthermore, textbooks' approval by the National Commission for Textbook Approval at the Ministry of Education, Science and Sport depends on following of the curriculum objectives. In other words this means, that various authors write textbooks in accordance with national curriculum and these are submitted to the National Commission for Textbook Approval for approval. In this research, we focused only on the chemistry textbooks in primary school (Grade 8 and Grade 9, students' age 13-15 years) that were approved by the National Commission for Textbook Approval at the Ministry of Education.

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Sample

The approved textbook sets for chemistry in Grades 8 and 9 of Slovenian primary schools in the 2016/17 school year were analysed. A list of analysed textbook sets is shown in Table 1.

Table 1. The list of the analysed textbook sets.

Textbook set* title	Author(s)	Publisher	Year of publication (Edition) Textbook/ workbook	Number of Pages Textbook/ workbook	Special Section**	Grade/ Learner's age
Kemija danes 1	Gabrič, A., Glažar, S. A., Graunar, M., Slatinek-Žigon, M.	DZS	2014 (1st Ed.)/ 2013 (1st Ed.)	125/106	No	8/13
Kemija 8, i-učbenik	Sajovic, I., Wissiak Grm, K., Godec, A.,Kralj, B., Smrdu, A., Vrtačnik, M., Glažar, S.	Zavod RS za šolstvo	2014	264	No	8/13
Moja prva kemija	Vrtačnik, M., Wissiak Grm, K. S., Glažar, S. A., Godec, A.	Modrijan	2015 (1st Ed.)/ 2014 (1st Ed.)	240/92, 61	Yes	8, 9/13, 14
Peti element 8	Devetak, I.,Cvirn Pavlin, T., Jamšek, S.	ROKUS KLETT	2010 (1st Ed.)/ 2010 (1st Ed.)	103/71	No	8/13
Pogled v kemijo 8	Kornhauser, A., Frazer, M.	MK	2003 (1st Ed.)/ 2004 (1st Ed.)	140/126	No	8/13
Od atoma do molekule	Smrdu, A.	JUTRO	2012 (2nd Ed.)/ 2012 (2nd Ed.)	128/160	No	8/13
Kemija danes 2	Graunar, M., Podlipnik, M., Mirnik, J. (textbook) Dolenc, D., Graunar, M., Modec, B. (notebook)	DZS	2016(1st Ed.)/ 2016 (1st Ed.)	152/96	No	9/14
Kemija 9, i-učbenik	Jamšek, S., Sajovic, I., Wissiak Grm, K., Godec, A., Boh, B., Vrtačnik, M., Glažar, S.	Zavod RS za šolstvo	2014	271	No	9/14
Peti element 9	Devetak, I.,Cvirn Pavlin, T., Jamšek, S.	ROKUS Klett	2011 (1st Ed.)/ 2011 (1st Ed.)	77/ 79	No	9/14
Pogled v kemijo 9	A. Kornhauser, M. Frazer	MK	2005(1st Ed.)/ 2006 (1st Ed.)	140/115	No	9/14
Od molekule do makromolekule	Smrdu, A.	Jutro	2013 (2nd Ed.)/ 2013 (2nd Ed.)	128/152	No	9/14

The term "textbook set" refers to all materials for students in the written or electronic form. The term "special section**" denotes a section that intends to clarify notations and characteristics used in SMRs.*

Development of the Criteria for the Analysis of SMRs in Textbook Sets

In order to derive holistic descriptors and the underlying representational types, two researchers separately analysed the SMRs in the textbook sets of Table 1. In this manner, 283 pages (10% of all analysed textbook set pages) were randomly selected and analysed to develop a rubric for the evaluation of SMRs in the textbook sets. The development of the rubric was based on the recognition of different possible holistic descriptors regarding the SMR add-ons (such as without, direct, indirect, combined) and, consequently, the categorisation of the underlying representational types that are characterised by the occurrence of a compounds' name and the triple-nature representational level (submicroscopic, macroscopic, symbolic) of the SMR add-ons. The descriptions of the triple-nature representational levels of the SMR add-ons were found to be presented in various modes, such as: (1) for the *submicroscopic level of the SMR add-ons* - pictorial or textual, (2) for the *macroscopic level of the SMR add-ons* - pictorial, textual, and their integrated notation, and (3) for the *symbolic level of the SMR add-ons* - structural formula or other symbolic notations and their integrated notation. The criteria and their description were then constructed based

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on these core characteristics. Each researcher independently grouped the characteristics into individual criteria. Finally, to reduce bias issues, through discussion, reconstruction and agreement, both researchers came to the final version of the rubric, which enabled a 95% inter-rater reliability about the categorisation of the analysed items. The outcome of the whole analysis is the development of a fully-fledged typology specifically designed for SMRs in textbook sets. The developed criteria were used in the analysis of the chemical representations of the entire sample of chemistry textbook sets (Table 1).

Results of Research

The results of the analysis are presented with regard to the research questions stated, the subchapters are named accordingly.

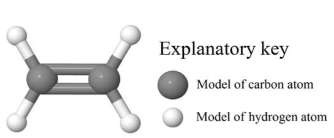
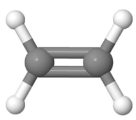
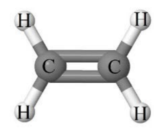
The Holistic Descriptors of SMR Add-ons in Slovenian Chemistry Textbook Sets

In the analysis, it was found that the informational value of SMRs for the learners differs with regard to various SMR add-ons. To assign the occurrence of add-ons accompanying SMRs, four descriptors were proposed.

1st descriptor: direct SMR add-ons (D)

The direct SMR add-ons enable the learner a direct and unambiguous recognition of particles. Thereby, various types of explanatory keys can be used. For example, pictorial, textual, integrated structural, or other symbolic notations used in the explanatory key.

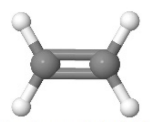
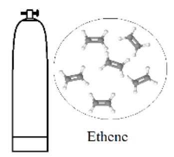
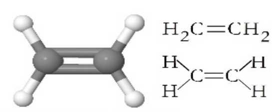
Table 2. Examples of direct SMR add-ons.

	 Hydrogen atoms are represented with white cycles, carbon atoms are represented with black cycles.	
Pictorial SMR add-on	**Textual SMR add-on**	**Integrated symbolic notation**

2nd descriptor: indirect SMR add-ons (I)

Indirect SMR add-ons do not enable the learner a direct recognition of particles. The nature of the particles can be derived e.g. based on the compound's name, structure-properties relation or symbolic SMR add-ons, etc.

Table 3. Examples of indirect SMR add-ons.

 Molecular model of ethene	 Ethene	 Molecular model of ethene
Name	**Name and pictorial macroscopic SMR add-on**	**Symbolic SMR add-on**

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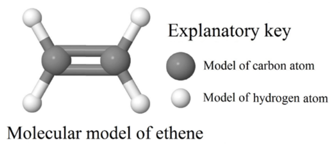
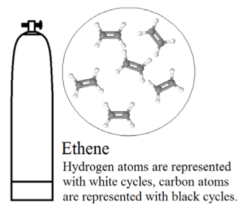
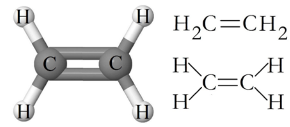
3rd descriptor: combined SMR add-ons (C)

Combined SMR add-ons enable the learner a direct recognition and provide other information. It is a combination of the 1st and the 2nd descriptor.

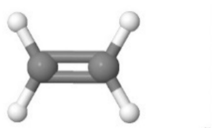
Table 4. Examples of combined SMR add-ons.

		
Name and pictorial SMR add-on	**Name, pictorial macroscopic and textual SMR add-on**	**Symbolic SMR add-on and integrated symbolic notation**

4th descriptor: without SMR add-on (W)

The SMRs without add-ons.

Table 5. Example of SMR without add-on/s.


Without add-ons

The Underlying Representational Types of Holistic Descriptors of SMR Add-ons in Slovenian Chemistry Textbook Sets

Analysis of textbooks revealed 1419 cases of SMRs, which could be categorised into 47 representational types of SMR add-ons. However, further analysis revealed that 90% of cases (N=1272) belong to only 14 categories. Therefore, the remaining 33 representational types were ascribed to a group of combined representational type representing 10% of all cases (N=147); consequently, there are 15 or fewer cases in each of the recognised categories. A detailed description of representational types of SMR add-ons in analysed textbook sets is presented in Table 6; additionally, the SMRs with add-on examples of each representational type are presented in Table 7.

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Table 6. Description of SMR add-ons in analysed textbook sets.

Descriptor	Representational type	Description								
		Name	Submicroscopic level		Macroscopic level			Symbolic level		
			Pictorial	Textual	Pictorial	Textual	Integrated	Structural formula	Other symbolic notations	Integrated
Direct (D)	I									
	II									
Indirect (I)	III									
	IV									
	V									
	VI									
	VII									
	VIII									
	IX									
Combined (C)	X									
	XI									
	XII									
	XIII									
Direct or Indirect or Combined (D,I,C)	XIV	Group of combined representational type including 10% of all cases								
Without (W)	XV									

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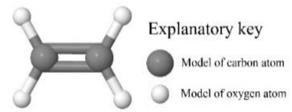
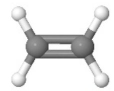
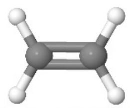
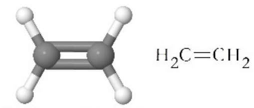
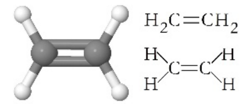
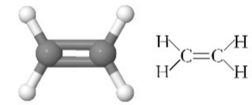
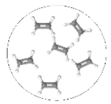
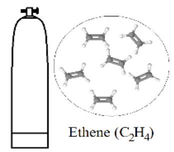
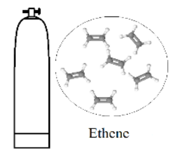
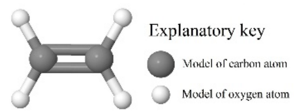
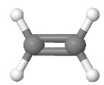
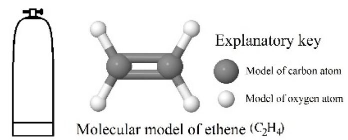
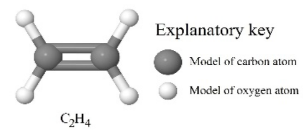
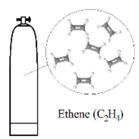
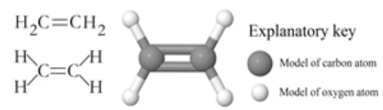
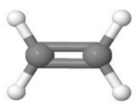
Table 7. Examples of cases of representational types of SMR add-ons.

Descriptor	Examples of representational types			
Direct (D)	 Representational type I	 Hydrogen atoms are represented with white cycles, oxygen atoms are represented with black cycles. Representational type II		
Indirect (I)	 Molecular model of ethene Representational type III	 Molecular model of ethene Representational type IV	 Molecular model of ethene Representational type V	 Molecular model of ethene Representational type VI
	 Ethene is a gas. It consists of C_2H_4 molecules. Representational type VII	 Representational type VIII	 Representational type IX	
Combined (C)	 Molecular model of ethene (C_2H_4) Representational type X	 Molecular model of ethene Hydrogen atoms are represented with white cycles, oxygen atoms are represented with black cycles. Representational type XI	 Molecular model of ethene (C_2H_4) Representational type XII	 Representational type XIII
Direct or Indirect or Combined (D,I,C)	 Representational type XIV	 Representational type XIV	 Molecular model of ethene Representational type XIV	
Without (W)	 Representational type XV			

Proportion of Representations in a Particular Category of Holistic Descriptors of SMR Add-ons in Slovenian Chemistry Textbook Sets

As can be seen from Table 8, the textbook set analysis revealed that students' learning of chemistry with SMRs is rather rarely (14.80% of cases) facilitated by implementation of SMRs accompanied with a *direct add-on descriptor - D* (4.44%) or its *combination* with *indirect add-on descriptors - C* (10.36%); the details about the categorisation are elaborated in the 1st RQ. With the use of such descriptors of SMR add-ons, a direct and unambiguous recognition of particles is enabled for learners.

It was found that the majority (55.67%) of SMRs can be categorised as *SMRs with an indirect add-on descriptor - I*. In these cases, the recognition of the informational value of a particular SMR is supported by SMR add-ons and the learners' previous experience, knowledge, and their representational competence.

Surprisingly, it was found that as many as one third of SMRs (29.53%) do not include any information that would support learners' recognition of SMRs - *no descriptors attached to the SMR - W*. In these cases, the recognition of the informational value of particular SMRs depends entirely on learners' previous experience, knowledge, and their representational competence.

Table 8. Proportion of SMRs with add-ons descriptors.

Descriptor	General	
	N	f (%)
Direct (D)	63	4.44
Indirect (I)	790	55.67
Combined (C)	147	10.36
Without (W)	419	29.53
SUM	1419	100.00

Proportion of Representations in a Particular Category of the Underlying Representational Types of Holistic Descriptors of SMR Add-ons in Slovenian Chemistry Textbook Sets

As described earlier, the textbook set analysis revealed 1419 cases of SMRs that were categorised into a total of 47 representational types of SMR add-on/s; 90% of cases (N=1272) belong to only 14 categories. The details about the categorisation are elaborated in the 2nd RQ.

From Table 9, it can be derived that the most commonly occurring representational type of holistic descriptors of SMR add-ons in Slovenian chemistry textbook sets is the *representational type XV* (29.53%). SMR cases categorised in the representational type XV do not have any descriptors attached to the SMR; therefore, that representational is categorised as the descriptor without SMR add-ons (W).

The second most frequently used SMR representational type in the analysed textbook sets is *representational type III* (16.35%), followed by *representational type IV* (16.77%). Both these representational types are categorised as the descriptors of indirect SMR add-ons (I) with the name of the compound attached to the SMR, whereby representational type IV also includes a further indirect SMR add-on, i.e., the rational formula of a compound.

The textbook set analysis revealed that approximately two thirds (62.65%) of the SMRs belong to only three different representational types; however, from the SMRs categorised in the remaining third (37.35%), a variety of SMR add-on combinations could be observed, including 33 different combinations in the combined *representational type XIV*.

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Table 9. Proportion of SMRs with add-ons representational types.

Descriptor	Representational type	General	
		N	f (%)
Direct (D)	I	24	1.69
	II	24	1.69
Indirect (I)	III	232	16.35
	IV	238	16.77
	V	83	5.85
	VI	72	5.07
	VII	27	1.90
	VIII	25	1.76
	IX	21	1.48
Combined (C)	X	51	3.59
	XI	23	1.62
	XII	17	1.20
	XIII	17	1.20
Direct or Indirect or Combined (D,I,C)	XIV	146	10.29
Without (W)	XV	419	29.53
	SUM	1419	100.00

Discussion

Textbooks have the central role in the learning of science and can be used for studying at school as well as at home (Gkitzia et al., 2011). Hinze, Rapp, Williamson et al. (2013) suggests that understanding the kinds of information and inferences that the visualisations in various learning materials provide requires explicit instruction and practice. Consequently, researchers have recently paid more attention to examining the importance of the possible features and notations of visualisations for the learners with eye-trackers, e.g. Williamson, Hegarty, Deslongchamps et al. (2013) studied students' use of ball-and-stick images versus electrostatic potential maps when considering electron density, positive charge, proton attack, and hydroxide attack; O'Keefe, Letourneau, Homer et al. (2014) examined how the integration of multiple representations was associated with learning in a multimedia simulation; Ferk Savec, Hrast, Devetak et al. (2016) examined some of the features of the explanatory key, such as coloured versus black-and-white explanatory key, and pictorial versus textual explanatory key, etc.

Previous research proposed various criteria for evaluating of representations in school textbooks, e.g. the *five criteria* (C1-the type of the representation; C2-the interpretation of the surface features; C3-their relationship to the text; C4-the existence and the properties of a caption; C5-the degree of correlation between the components comprising a multiple representation proposed) of Gkitzia et al. (2011); or *three criteria* (C1-the type of the representation; C2-relatedness to text; C3-properties of captions) of Kapıcı and Savaşçı-Açıkalın (2015), thereby examining only the particulate nature of matter.

The presented research focuses on studying the presence of descriptors of SMRs in textbook sets to support efficient learning and, through that, to be acquainted with learners' opportunities regarding textbook sets. As previous research considered particular characteristics of different features of representations one by one, the most valuable added value of this research is in recognising the need to develop more holistic criteria for the description of SMRs integrated into textbook sets, as in practice the learner perceives each SMR as one whole.

The novelty of the presented research is based on that, the analysis of the textbook sets that revealed four main holistic descriptors accompanying SMRs, i.e. direct descriptor (D), indirect descriptor (I), combined descriptor (C) and SMRs without descriptors (W). These descriptors support learners' recognition of SMRs' informational value to a different level; namely, they provide different accompanying add-ons in relation to SMRs. It was found that more than half of SMRs can be categorised as SMRs with an indirect add-on descriptor (I), with which the learner needs to rely on his/her own previous experience, knowledge, and representational competence when recognising the informational value of the particular SMR. In contrast, it was found that as much as one third of SMRs does not include any information that would support learners' recognition of SMRs, as no descriptors are attached to the SMR (W). Further analysis of textbooks revealed 1419 cases of SMRs that could be categorised into 47 representational types of SMR add-ons. It was found that 90% of cases belong to only 14 categories of underlying representational types of holistic descriptors of SMR add-ons; each of categories includes more than 15 cases of SMRs (more than 1% of SMRs in each of the categories).

It would be valuable if the future research could examine the usefulness of the SMRs in the particular 14 categories postulated in the presented research from the learner's perspective, e.g. with the use of an eye tracker. The results of such research could then serve as a foundation for future development of the textbook sets and other learning materials in order to support students' learning. It would also be valuable to further examine the types of supports and practice that are most helpful for students at different levels when learning with SMRs. It might be interesting to focus especially on fostering representational competence, e.g. by asking students to choose or construct representations that will be most useful for reasoning about particular chemical problems or relationships, as suggested by Kozma and Russell (1997). It would also be interesting to study the order in which certain representational types of holistic descriptors of SMR add-ons first appear in textbook sets, and their placement in the learning process, e.g. whether SMRs appear in the textbooks before being integrated into homework and exams (Sanger, 2000).

Conclusions

In this research, chemistry textbook sets for Slovenian primary schools were examined from the perspective of the information value of SMRs. The added value of this research from the international perspective, is in recognising the need to develop more holistic criteria for the description of SMRs integrated into textbook sets, as in practice the learner perceives each SMR as one whole. From this point of view, the novelty of the presented research is also the analysis of the textbook sets, that revealed four main holistic descriptors accompanying SMRs, i.e. direct descriptor (D), indirect descriptor (I), combined descriptor (C) and SMRs without descriptors (W). These descriptors support learners' recognition of SMRs' informational value on a different level through providing different accompanying add-ons of SMRs. It was found that as much as one third of SMRs do not include descriptors attached to the SMR. In these cases, the recognition of the informational value of a specific SMR depends entirely on learners' previous experience, knowledge, and their representational competence. The majority of SMRs can be categorised as SMRs with an indirect add-on descriptor, such as name, pictorial macroscopic SMR add-on, symbolic SMR add-on, etc. The recognition of the informational value of a particular SMR in such cases is supported by SMR add-ons as well as with learners' previous experience, knowledge, and their representational competence. The analysis also revealed that approximately two thirds of the SMRs belong to only three different underlying representational types of SMR add-ons.

It would be valuable to examine the usefulness of the most commonly used categories of SMRs from the learner's perspective, by using an eye tracker. The results of such research could then serve as a foundation for future development of the textbook sets and other learning materials in order to support students' learning.

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