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LATVIAN STUDENTS' UNDERSTANDING OF SUBSTANCE CHANGES: LONGITUDINAL RESEARCH 1998 – 2008

Janis Gedrovics
Dagnija Cedere
Daina Mozeika

Abstract. *One of the general problems in science education for different students at comprehensive school is understanding the nature of physical and chemical changes. Without a clear picture of the fundamental differences on sub micro level, it is not possible in the future to follow general rules of chemical reactions between substances, as well as to understand the use of different materials in everyday life. Students of the grades 9 and 11 were asked to fill in a special questionnaire, in which questions about real physical and chemical changes from students' daily life were included. The results testify that the knowledge and understanding of the essence of chemical reactions has slightly increased in Latvia, although the general results show that understanding of the nature of phase transitions and chemical reactions is still insufficient, especially at the grade 9 levels.*

Key words: *physical and chemical changes, understanding, longitudinal research.*

Janis Gedrovics,
Riga Teacher Training and Educational Management Academy, Latvia
Dagnija Cedere, Daina Mozeika
University of Latvia, Latvia

Introduction

Interest in science and mathematics is an essential precondition for students who choose to continue their career in science and technology, but a better understanding of nature and surrounding life processes along with the application of skills acquired in school is no less important. *Education in the nature sciences for everyone* is a future oriented approach to the issue (Orion, 2007).

Students initially come to know chemistry based on a simple definition: chemistry is the science of substances and their changes. Even this simple definition emphasizes the importance of substance changes or chemical reactions in the development of chemistry and the practical application of these changes. The chemical reaction is one of the fundamental concepts in chemistry and mastery of this concept is mandatory for success in the study of chemistry (Christen, 1990; Rehm, 2006; Eilks, 2007).

The formation of understanding is crucial in science education in general (Østergaard, Hugo, Dahlin, 2007), the approach is based on the interaction between what Szybek (2002) calls *the two stages* in science learning: the stage of scientific knowledge and that of everyday human experience. Linking the study process with the students' everyday experience and using household chemicals in chemistry lessons is the most popular study approach nowadays, especially for introductory years (Demuth & Nerdel, 2007; Demuth, Gräsel, Parchmann & Ralle, 2008). At the very start of learning chemistry, the students learn to recognize chemical and physical changes in the common substance changes they

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meet in their everyday lives. It should be noted that the characteristics of a chemical reaction taught in the beginning of chemistry curriculum vary among countries. In Germany, two main characteristics of chemical reactions (as opposed to physical changes) are recognized: the formation of a new substance and energy change (Asselborn, 2001; Parchmann & Freienberg, 2007). In Latvia, external characteristics of reactions are also mentioned as important: colour change, odour, precipitation and the emission of gases (Rudzitis & Feldmanis, 2000).

Unfortunately, the concept of chemical reactions and their significance is one that causes the greatest problems for students. A recent study on the students' understanding of the nature of substances in chemistry (Onwu & Randall, 2006) has found that many students have problems associating the chemical change of a substance in the macrolevel (observation) and the particle model of the corresponding substance in the submicrolevel. Although the creation of new substances is at the heart of the chemical change, unlike physical changes characterized only by state of substance, students often lack the ability to characterize the change and arrive at the incorrect conclusions.

As didactic specialists in the sciences stress, the concept of chemical reactions is connected with physical transformation in the mind of the student because it is easier to visualise (Andersson, Emanuelsson & Zetterqvist, 1993). The psychology for the formation of most of chemical concepts is quite different from that of the tangible world. Johnstone (2000) points out the complication of operating on and interrelating three levels of thought: the macro, the submicro atomic and molecular, and the representational use of symbols and mathematics. It is psychological folly to introduce students to ideas at all three levels simultaneously; this is where many misconceptions emerge. Concepts are better understood if chemistry teaching/learning process is connected with the practical everyday life (Demuth, Grasel, Parchmann & Ralle, 2008). It provides the understanding about the nature of substance changes.

Research was carried out on Latvian students` understanding of physical and chemical changes of chemical substances related to everyday life. The research was focused on the two questions:

1. Do students have conceptual knowledge based on the understanding?
2. Is chemistry learning influenced by students' attitude towards natural sciences?

In addition, the study results were compared to survey data gathered in 1998 and 2004 in order to evaluate how Latvian students' ideas about substance changes, especially chemical reactions, have changed.

Methodology of Research

Characteristics of questionnaire

The study used a questionnaire developed by one of the authors (J.G.) while he was a member of the Visby scholarship program at Linköping University in Sweden during the 1997/1998 academic year. The students were presented ten examples of substance changes, including some more complex changes exhibiting a chemical reaction. Some questions were excerpted from Andersson et. al (Andersson, Emanuelsson & Zetterqvist, 1993). The respondents' task was to distinguish between chemical reactions and physical changes by responding *yes* or *no* to the question - *Which of the given changes are chemical reactions?*

The students were presented an additional task dealing with *rust and an iron nail*; to solve this problem correctly it is vital to understand the essence of the chemical reaction. It was a closed question, but all students *were asked* to explain their answer.

Along with their understanding of substance changes, the students were asked to express their opinion, regarding various organizational issues in nature science class, the mandatory nature of secondary school subjects and their knowledge about metal corrosion was also tested. In addition, the students' attitude towards specific nature science subjects was evaluated.

In questionnaire used in 2008 16 new questions were added which were taken from the international project ROSE (Schreiner & Sjøberg, 2004). These additional questions gave the possibility to divide the respondents into 4 typological groups, (Group I – *science-negationists;* Group II – *science-dutifuls;* Group

III – *science-enthusiasts and* Group IV – *science-choosies*), based on students' attitude toward the natural sciences at school using the methodology presented in (Gedrovics, Lavonen & Byman, 2007).

Research conditions

The survey was conducted in January – February 1998, December 2004, as well as in November – December 2008. At the last investigation 2008 totally 1035 students from different regions of comprehensive schools of Latvia took part in the survey incl. 241 boys and 295 girls from grade 9, as well as 209 boys and 290 girls from grade 11.

The data was processed using the 16.0 version of the SPSS program with re-coding performed in specific cases. Descriptive analysis and Pearson correlation was used for the comparison of differences among groups' conceptions (grade and gender).

Results of Research

As shown by the data 2008 (Table1), the greatest number of correct responses, both in the grade 9 and grade 11 groups, were in identifying such chemical reactions, as burning (*petroleum*

Table 1. Understanding substance changes and processes (2008) (Number of correct responses in percents).

No	CHANGES and PROCESSES	Right answer	Grade 9		Grade 11	
			boys	girls	boys	girls
1	Petroleum burns	yes	89.1	92.5	88.9	87.4
2	An automobile rusts	yes	90.2	78.2	88.9	89.9
3	Water boils	no	37.7	46.6	55.1	46.5
4	Tin melts	no	36.3	39.9	49.8	42.3
5	Iron comes from iron ore	yes	75.0	73.1	69.7	65.6
6	An inflated balloon pops	no	65.7	66.7	75.7	72.2
7	Green plants give off oxygen	yes	73.8	67.5	79.9	78.0
8	A salt crystal grows	no	47.8	50.7	47.3	54.2
9	Pancreatic secretions break down fat	yes	69.5	60.9	72.2	68.1
10	Photosynthesis is a chemical reaction	yes	57.0	59.5	71.6	69.1

burns) and metal corrosion (*an automobile rusts)*. The correct answers made up to approximately 90% for both boys and girls in the both cases. The *water boils* and *a salt crystal grows* questions made many difficulties for students. The correct answers made up only about 50%. It should be noticed that the level of students understanding about physical and chemical changes is rather low.

Table 2. Distribution of respondents into typological groups (percents).

Grade	Typological groups				Total
	I	II	III	IV	
9	49.3	16.3	21.0	13.5	534
11	53.9	12.2	18.6	15.3	516

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As it can be seen in the methodology section of this paper, the 2008 questionnaires were also processed to group the students typologically, based on their attitude towards nature science subjects (Table 2). As shown by the χ^2_{calc} value, no statistically considerable difference was detected as regards the typological division depending on the school year, resp., grade 9 or 11 ($\chi^2_{calc}=5.504 < \chi^2_{crit}=7,81; a=0,95; p=0,138; df=3$).

Study shows that relatively greater and more significant differences can be found only between Group I (*science-negationists*) and Group III (*science-enthusiasts*). Figure 1 shows the results when considering only respondent answers from these two groups.

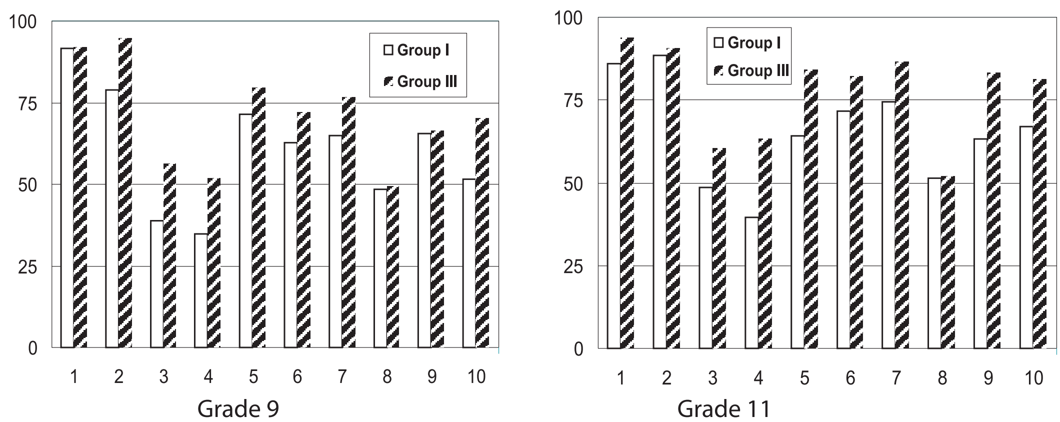

Figure 1. Different typological group correspond understanding of chemical reactions. (percent of correct responses; numbers on *x* axis correspond with question numbers on Table 1)

Comparing the responses of both groups, we see that the students who belong to typological Group III (*science-enthusiasts*), both in 9th and 11th grades, consistently show statistically significantly higher results, except for correctly characterizing *burning* and *pancreatic secretions breaking down fat* (grade 9) and correctly identifying the *salt crystal growth* process (grade 9 and grade 11).

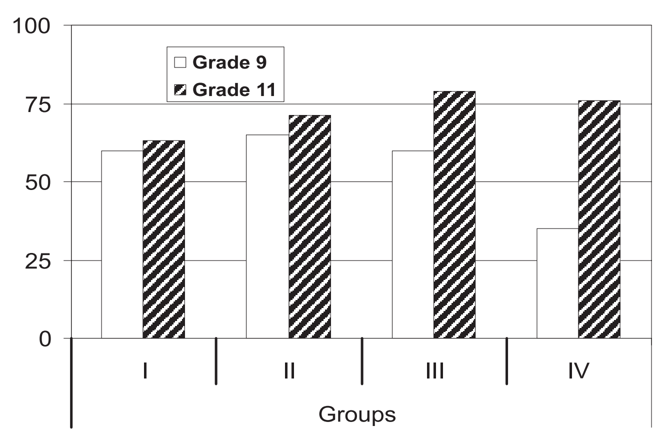

Figure 2. The location of rust (number of correct responses in percents). Answer distribution based on students` attitude towards natural sciences.

The Group III respondents (especially grade 11) also show better results when answering the supplemental question about the location of rust (Figure 2). In truth, Group IV respondents (*science-choosies*) in grade 11 had about the same results, as Group III, while grade 9 chooses had a result well below the average grade 9 group.

Discussion

Results (2008) were compared to the researches in 1998 (Gedrovics, 2001) and 2004 (Gedrovics, Jeronena, Kuusela & Vereborns, 2006). A relatively smaller number of students could identify the process of obtaining iron from iron ore. In addition, if we see a slight decline in results for the grade 9 group, the grade 11 group reveals a steady decline over the last 10 years both for girls and boys. This could be partially explained by the changes in chemistry curricula reflecting local market demands in the chemistry industry.

We get a slightly different picture when analyzing student responses to the two questions related to the process of photosynthesis (*green plants give off oxygen* and *photosynthesis is a chemical reaction*). A slight increase in understanding was observed in the grade 9 group with no significant difference between girls and boys. In the grade 11 group it was observed that the girls seem to understand the process better, but the boys' level of understanding has decreased over the last 10 years.

Pair correlation analysis can provide supplemental information since both questions dealt with the same process (photosynthesis). Although the Pearson correlation coefficients are not really pronounced: $r = 0.177$ (2008); $r = 0.280$ (2008); $r = 0.151$ (1998), the correlation is statistically significant at $\alpha = 0.01$ in both 2008 and 2004; $\alpha = 0.05$ in 1998. Nevertheless, despite the relatively higher statistical significance, the lower correlation coefficient obtained in 2008 as compared with 2004 leads us to think that the overall understanding of photosynthesis as a chemical reaction whereby green plants give off oxygen is again decreasing. Unfortunately, the students' less serious attitude towards this type of survey as observed by research assistants can not be ruled out as a factor in the lower correlation, but an additional study would be required to substantiate this allegation.

The changes in understanding the chemical reaction of pancreatic secretions breaking down fat are rather interesting. In 1998 a considerable difference was observed between the male and female responses, but over the last 10 years the difference has more or less evened out, although only 65 - 70% or about two thirds of the students responded correctly.

There is a consistently low number of correct responses identifying such typical changes of aggregative state, as boiling (*water boils*) and melting (*tin melts*). The situation is a bit more positive in the grade 11 group, which had a notable increase in correct answers. Relatively better results were observed in understanding a physical change, such as an inflated balloon popping. Salt crystal growth, however, is still a difficult process for students to understand and the number of correct responses over the last 10 years in some groups barely reached the 50% mark. It should be mentioned, however, that the curriculum really does not include a process as specific, as crystal growth and the process is not experimentally presented in all schools. The purpose of this survey is not only to test students` knowledge but also to see how well students can apply their knowledge.

The students were also presented a more difficult assignment – *to show where the rust is located before an iron nail starts to rust if it is known that the nail will rust in conditions of higher moisture.* It is clear that rust can form only as a result of a chemical reaction, i.e. the nail reacting with water. Of course, the process is more complex than a simple reaction of iron and water; it also involves oxygen from the air, as well as oxygen dissolved in water, but in this particular case students were required only to understand the basis process of rusting. The results are shown in Table 3.

As the table shows, a significant increase in understanding can be observed in the grade 9 group (from 45.8% correct responses in 1998 to 63.7% in 2004), but it is followed by a decrease to 59.7% in 2008. It is positive that there has been a 13.9% increase in correct responses, but the decrease after 2004 is a sign that reasons for this downward trend must be determined.

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Table 3. The rusting of an iron nail in conditions of increased moisture, %

Rust locale	Grade 9			Grade 11		
	1998	2004	2008	1998	2004	2008
Air	5.6	2.2	5.6	1.9	3.7	3.2
Water	12.1	8.1	10.1	0	2.2	6.9
It has not yet formed	**45.8**	**63.7**	**59.7**	**90.6**	**73.5**	**70.0**
Nail	23.4	11.1	13.6	0	8.8	9.5
I don't know	13.1	14.8	11.0	7.5	11.8	10.5

The grade 11 results are not at all encouraging – a stable decline of 20.6% in understanding can be observed over the last 10 years. In 1998 this group did not specify if the rust could be in the air or in the nail, which is wrong. In 2008 and 2004 students seemed to think that the rust could be either in the air, in the water, as well as in the nail itself. Of the three incorrect choices (air, water, nail), the students more often identified the nail as containing the rust. Although the answer is incorrect, it shows that students do connect rust and nails (a nail will rust). The answers and explanations show that students do not perceive the formation of rust as a chemical process, but rather a mixture of substances. Some of the students noted that since rust can not just appear out of nowhere, it had been located somewhere before. This clearly shows that not enough attention is paid to teaching natural processes at school, chemistry is taught separately from real life on an abstract theoretical level because of time constraints, and as a result, the student never develops a true understanding of chemistry and the knowledge he does acquire is short-lived.

It is interesting that in the mid-90s a similar study was conducted. The same problem was presented to a group of 8th grade students who had just started studying chemistry 2 weeks earlier. 51% of the students responded correctly (Gedrovics, 1997). It is possible that one factor that influenced these results was the students' approach to the formulation of the problem (*where is the rust located before the nail starts to rust*). Unfortunately, analysis of student explanations shows that only a small number of students actually explained that *the reaction has not yet occurred*.

Thus, we see that about one half of the students either knows the correct answer or have arrived at the correct answer based on previous experience. However, it is unlikely that one can speak of a correct scientific understanding at the 8th grade level, because students do not study such concepts as chemical reactions prior to the 8th grade. It is very important that the teacher helps the students scientifically understand (and apply) what is happening in the reaction.

When analysing study results in regard to distribution of respondents into typological groups it is evident that respondents' distribution into typological groups does not quite depend on the school year a student is in, as it was early observed in (Gedrovics, Lavonen & Byman, 2007). It is easy to understand that in general Group III *(science-enthusiasts)* shows better knowledge in both grade groups (Figure 1), however in specific topics the best result of grade 9 in 2008 is observed for the respondents of Group II (*science-ductiles*) (Figure 2). It is possible that exactly the diligence which could be sufficiently high for part of the grade 9 students has enhanced better knowledge for the respondents of this typological group.

It confirms that learning in chemistry is affected by students` general attitude to natural science subjects, and the most effective factors are learners' interest towards science and, partially, their diligence.

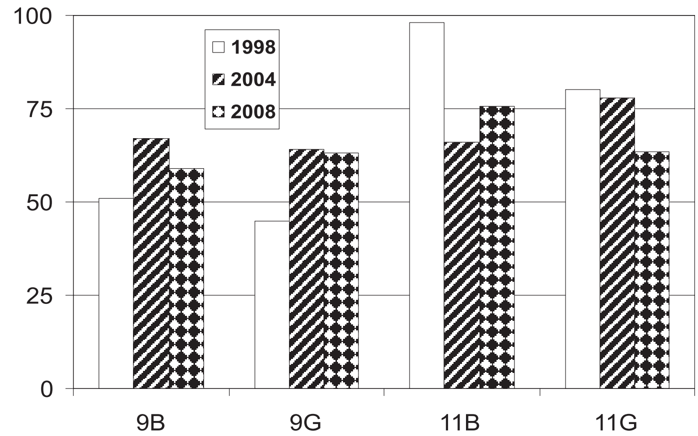

Figure 3. Dynamics of changes (1998 - 2004 - 2008) of the students` understanding on the location of rust. Correct answers (%) for boys (B) and girls (G) in various grades.

In reviewing student questionnaires over the last 10 years, it was already evident in 2004 that the overall increase in correct answers in the grade 9 group was largely due to the girls' result, while the grade 11 boys showed a decrease in correct responses (Figure 3) and grade 11 girls showed practically no change (Gedrovics, Jeronena, Kuusela & Vereborns, 2006). The number of correct answers has a tendency to decrease both in grade 9 and 11 after 2004, in spite of an increase in grade 9 (when compared with 10 year old results). The grade 11 group, however, shows a sharp decline in correct answers. One reason for this could be the fact that although chemistry is in all secondary school curriculum (grades 10 – 12), there is a considerable difference between taking *Chemistry* (Physics, Biology) as a separate subject (3 years, 2 – 3 hours per week) and taking *Chemistry* as part of a slightly integrated subject *Nature sciences* program with the same number of hours per week, but only for one year. The survey results also show that student's positive attitude towards a subject or subject group is very significant. The teacher's job is to promote a high level of self-motivation in any subject area.

The survey results show that in spite of radical changes in the national education system (including chemistry education), no significant changes in students` competence can be seen. Perhaps we should be satisfied that the results are not worse? As we know, the learning process at school is constantly subject to the influence of various internal factors at school and also external, mostly social factors which can cause impact on students' learning activities. During the last 10 years the classroom environment has changed noticeably, as well as culture-historical and economic conditions in the country. Since young people are more open to change, it is clear that teachers will be more conservative both in their opinions, as well as their teaching work. As a result, during this period of rapid change, the development of teaching methods lags far behind the student who is at the receiving end of these methods.

One of the basic questions remains: why students can not distinguish between physical changes and chemical reactions? A more detailed analysis of the answers reveals that most of the mistakes were made because the students' knowledge about chemical changes is merely formal and theoretical, not applied.

In truth, when a chemical reaction takes place, we also observe physical changes – colour change, precipitation, smell, light, heat and others – and inform the student that these are signs of a chemical reaction. Remembering that emission of gas is a sign of a chemical reaction, the students mistakenly call the boiling process a chemical reaction (gas can be seen in the boiling process). Such are the consequences of purely formal education based only on memorization.

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Conclusions

1. 1. Students' knowledge is not always based on understanding and leads to a low retention rate as shown by the lower number of correct responses in the grade 11 group.
2. It has been determined that over the last 10 years (1998 – 2008) 9th and 11th grade students have developed a slightly better understanding of substance changes, especially chemical reactions. However, student's skills in analyzing everyday chemical changes, such as rust formation and phase transitions, are still lacking.
3. It is vital that an applied aspect must be integrated into chemistry classes helping students make a connection between what they study, the nature and the various processes therein.
4. Going from grade to grade students' attitude against nature subjects is changing negligibly and in general the best results are shown by the Group III (*science-enthusiasts*). In the grade 9 slightly better results for specific topics are shown by the Group II (*science-dutifuls*), but at the secondary school (grade 11) by respondents of – Group III (*science-enthusiasts*).

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Janis Gedrovics	Associate Professor, Nature and Work Environment Institute, Riga Teacher Training and Educational Management Academy, Imantas 7 line No 1, Riga, LV-1083, Latvia. Phone: +371-29162147. E-mail: janis.gedrovics@rpiva.lv Website: http://www.rpiva.lv
Dagnija Cedere	Associate Professor, Center of Chemistry Education, University of Latvia, K.Valdemara Street 48, Riga, LV-1013, Latvia.. Phone: +371 27378719 E-mail: dagnija.cedere@lu.lv Website: http://www.lu.lv
Daina Mozeika	PhD Student, Center of Chemistry Education, University of Latvia, K.Valdemara Street 48, Riga, LV-1013, Latvia. Phone: +371 27378719 E-mail: tuttii@inbox.lv Website: http://www.lu.lv