International Journal of Learning, Teaching, and Educational Research
Vol. 15, No. 8, pp. 49-57, July 2016

Exploring Estonian Students' Ability to Handle Chemistry-Related Everyday Problem Solving

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Abstract. In today's scientific world, it is important to solve science-related problems, because each person during his/her studies, needs these skills both at workplace and in every day. Research has shown that in order to solve everyday science-related problems, it is necessary to develop an ability to transfer skills acquired in science class. The aim of this study is to analyse students' ability to transfer science-related skills and factors that affect this ability. A 7-item instrument, related to an everyday situation and based on chemistry, but including interdisciplinary elements related to physics and biology, is developed, validated and administered to 10th grade gymnasium students (N=1129) at the beginning of their studies in gymnasium and to 11th grade students (N=953), having completed four compulsory chemistry courses at the gymnasium level during two academic years. The findings show that (1) progress in the transfer of problem solving skills after completing the compulsory chemistry courses involved only a few science-related skills in addition to academic knowledge and (2) the transfer of knowledge and skills was most successful in items limited to one subject – chemistry, rather than in an interdisciplinary context. This suggests the need to review the national curriculum and teaching methods that are in use in gymnasium chemistry lessons. It can also be concluded that the ability to apply transfer skills is most successful in items limited to one subject – chemistry, while in an interdisciplinary context, the transfer of skills in chemistry and physics contexts are transferred better than a chemistry and biology context.

Keywords: science-related skills; everyday science-related problems; transfer of skills; interdisciplinary.

Introduction

Students, in order to become successful citizens, need to possess expertise in a range of competences. The European Commission (2004; 2007) has adopted this by broadening its definition of educational goals to being expressed in terms of competences. Although a range of competences are stipulated in curricula, the actual selection of competences developed for study, is carried out by the teacher at school level. Among these competences is the need to achieve the transfer (or transferability), which, according to the National Research Council

(2000), is the generalization of the learning outcomes including knowledge and skills gained in school to practical environments such as the home, community and workplace. However, a lack of ability to transfer skills to new situations is seen as one of the main problems in the teaching –learning situation (van Gog et al., 2004). Unfortunately, the literature points to a multitude of different treatments with different emphases to describe transfer (Johnson, 1995).
In this article, transferability, as applied to problem solving, is defined as the ability to transfer acquired problem solving skills learned in chemistry class, to everyday scientific context which has interdisciplinary and everyday dimensions.

The main objective of the current study was to analyse the transfer of problem solving skills, acquired in science class, to solving everyday scientific problems. The following research questions were posed:

1. What differences in the ability of students to transfer acquired problem solving skills to new everyday situation occurs after two academic years of gymnasium study?
2. Is the transfer of problem solving skills to everyday situations context-related?

Literature review

In today's world, it is important to solve science-related and everyday problems. Students' problem-solving and decision-making skills play an important role in development of students' scientific literacy (Rannikmäe, 2016), as well as help to generate cognitive interest in the lessons (Cēdere, Jurgena, Helmane, Tiltiņa-Kapele & Praulīte, 2015).

Research has shown that in order to solve everyday science-related problems, it is necessary to transfer skills acquired in science class into new contexts (Bransford, Brown & Cocking, 2001). Contemporary science teaching is expected to stress the development of skills, which constitute the core of the problem solving process and also their transfer (Solomon & Perkins, 1987). Some authors conclude that such skills and their transfer improve (Molnár, Greiff & Csapó, 2013) across grades.

Problem solving. The scientific literature identifies problem solving using different approaches. For example, in psychology, Lovett (2002) defined problem solving through three key sub processes each involving analysis and transformation of knowledge and skills. Bransford and Stein (1984) described the problem solving process as a "cyclic higher-order cognitive process". This approach (this is indicated later) describes 5-7 problem solving stages, including fundamental skills such as explanation and reasoning. This approach can be called 'general' or 'analytical' and has found support in a number of studies (Montague, Warger & Morgan, 2000; Scherera & Tiemann, 2014). However, Bassok and Novick (2012) reported, that the level of domain knowledge determines students' problem-solving success, especially in knowledge-rich academic disciplines. Applying knowledge via explanation plays an important part in solving problems (von Aufschneider, Erduran, Osborne & Simon, 2008).

However, the success of the problem solving depended on the type of the problem. Surif and co-authors (2014) reported that students were more successful in solving algorithmic problems, but have difficulties in solving open-ended problems. This statement was supported by the results from international PISA tests (OECD, 2013).

To solve problem, the problem solving skills need to be transferred. These skills considered to be transferrable based on the literature (Montague et al., 2000).

Transfer. According to Ausubel and co-authors (1978), meaningful learning necessarily involves the ability to transfer. In the literature, different treatments with different emphases are used to describe transfer. In this article, transferability, as applied to problem solving, is defined as a process where problem solving skills learned in the chemistry class, can be transferred into new, science related or everyday contexts. Everyday context is rich in non-routine, ill-defined problems, which may have multiple solutions (Gilbert, 2006; Chang & Chiub, 2008).

Based on the literature, the success of any transfer depends on the difference between the contexts of learning and that in which it is used. Johnson (1995) uses the terms - near and far transfer, referring to students applying their knowledge and skills to contexts very similar or to contexts where the performance is very different from the context in which the knowledge and skills are acquired. Far transfer was more demanding, because it also required greater modification to the original knowledge and skills (Hung, 2013). Nevertheless, there is little understanding about the relationship between the context and transfer that is accepted by all researchers, although most claim that transfer is context-related.

Methodology

This study examined student outcomes from a grade 10 and 11 chemistry course include three sub-sections (two on organic chemistry, one on inorganic and one on general chemistry).

Sample. The total number of students in the sample was 2,072, of which 1,129 were 10th grade and 953, 11th grade students. As the sample comprised 10th grade students who had just started gymnasium, their chemistry knowledge was deemed to have been acquired in basic school. (Data were collected in 10th grade in autumn at the beginning of the academic year and in 11th grade in spring at the end of the academic year, after completing the obligatory courses – this is data collection).

Instrument to collect data. The transfer of problem solving skills was measured by results of solving tasks, needed particular skill. The 7-item a paper-and-pencil test was used as an instrument. It was considered that the best context to measure students' problem solving skills is everyday context. The instrument was created, based on solving an everyday problem, related to a sprained ankle and the use of a cold bag to reduce pain and oedema. In answer to the questions posed, students were required to transfer their problem solving skills gained in science lessons to this new context. The 7 item test comprised:

(a) Three items measured the transfer of applying knowledge from chemistry to a chemistry context (seen as near transfer) to interdisciplinary context (seen as far transfer).
(b) Two additional items measured experimental problem solving skills i.e. posing a research question and planning experimentation (in this case, choosing relevant equipment for the investigation).
(c) Two further items focused on measuring scientific explanation skill, one in a chemistry-physics context and the others in a biology-physics context.

Validity and reliability. Validity of the instrument was determined by using expert opinions. The reliability of the instrument was proved using Cronbach alpha (0.734) which value considered to be acceptable.

Procedure. The developed instrument was validated and administered to 10th grade gymnasium students (N=1129) at the beginning of their studies in gymnasium and to 11th grade students having completed four compulsory chemistry courses at the gymnasium level during two academic years.

Data analysis. The first part of the analysis was qualitative. All students' responses were coded and rated analogically on scale 1-3.

I - missing answer, student do not have relevant skill for transfer,
II - partial skill to transfer,
III- maximal transfer

The second part of the data analysis was quantitative. Data was analysed using IBM SPSS Statistics 20 for frequency distribution, Spearman's rho for correlation and Mann-Whitney U-test to analyse nonparametric data, because data do not conform to a normal distribution.

Results and analysis

Table 1 shows results from the test and analyses indicating frequency distributions and differences in transfer, measured by the Mann-Whitney U-test.

Table 1. Grade 10 and 11 frequency distribution and differences in transfer

Skill	Items and context	Grade 10 (***n*** = 1128)			Grade 11 (***n*** = 953)			Difference and significance	
		Responses on Marking %			Responses on Marking %			U	p
		I	II	III	I	II	III		
Applying knowledge	I1 Interd	47.0	3.9	49.1	41.6	4.5	53.9	486746.000	0.019
	I6 Chem	12.7	57.8	29.5	10.0	52.9	37.1	452538.000	0.000
	I2 Interd	73.4	0.3	26.3	71.1	0.5	28.4	451698.000	0.174
Posing RQ	I4 Interd	42.7	33.1	24.2	42.0	32.3	25.7	368045.000	0.262
Plan exp	I5 Interd	46.2	11.3	42.5	42.8	15.1	42.1	492768,000	0.363
Explanation	I3 (Interd ch-ph)	65.2	19.9	14.9	65.0	17.1	17.9	245924.500	0.230
	I7 (Interd bio-ph)	76.4	18.8	4.8	69.5	23.1	7.4	336645.500	0.003

Interdisciplinary – interd; ch-chemistry; bio – biology; ph –physics

Data in table 1 showed that the transfer of problem solving skills in current case is influenced by two factors.

First, the weakness of explanation skill – more than 60 % of students is lacking the corresponding skill. The number of missing and wrong answers clearly showed, that most difficult for students were items (3 and 7), where the need to use explanation skills was expected. Thus, the data suggests that an important skill for successful problem solving in this case is explanation skill and its transfer.

Unfortunately, the data in table 1 show that the improvement of explanation skill is minimal: in a chemistry-physics context (item 3) about 65% of 10th and 11th grade students' did not exhibit mastery of explanation skill. Responses to task 7 (in a biology-physics context) showed a slightly weaker outcome. The data shows that 76,5 % of 10th grade students and 69,5% of 11th grade students did not have mastery of explanation skill in the contexts given. As data showed, in this case by explanation the use of the combination of chemical, biological and physical knowledge is more difficult than combination of knowledge chemistry and physics.

Secondly, the inquiry skills. Answering item 4 was problematic. This item requires skill to pose research question in the context given. Only 24.2% of students in 10th grade and 25, 7% of students in grade 11th indicated mastery level of this skill (in this context). A small improvement may be caused by gymnasium science teachers who do not use open inquiry, through which the corresponding skill would be developed.

Table 2. Results of the correlation analysis (only statistically significant correlations)

Grade	Correlation between		Spearman's rho
10	posing research question (I4)	explanation(ch-ph, I3)	0.451**
	explanation (ch-bio-ph, I7)	explanation(ch-ph, I3)	0.326*
11	applying knowledge, acquired in gymnasium (I6)	explanation(ch-bio-ph, I7)	0.252*
	posing research question (I4)	explanation(ch-ph, I3)	0.475**
	posing research question (I4)	planning investigation	0.481**

Significance on level p=0,05 was noted as *, significance on level 0,001 was noted as **

As indicated above, explanation skill involved applying knowledge. Table 2 showed the difference in explanation: in responses of 10th grade students the relationship between explanation and applying knowledge did not exist. Where comparing with data of PISA tests (Estonian students at a similar development stage as grade 10) what results showed that Estonian students have a good knowledge, but results of current study suggest that they do not apply knowledge by explanation. In responses by11th grade students there was a stronger correlation between applying knowledge and explanation. The body of students' knowledge has grown through two academic years and students in 11th grade can use by explanation more knowledge. That may be one reason for the improved explanation skill and its transfer by grade 11 students.

Discussion

Transfer is only possible in cases where knowledge or skills exist for the transfer. The first finding is related to assessment of students' problem solving skills. Surif and co-authors (2014) reported in their study, that solving open-ended problems in chemistry is less successful than solving algorithmic problems. Such a conclusion can also be reached by analysing the results of the Estonian students' outcomes on the PISA test in 2006 and 2009 (OECD, 2007; 2010). It seems that the level of students' problem solving ability mays not have changed over the last 10 years.

In this study, statistically significant progress was noticeable in the transfer of three skills: applying knowledge (items 1 and 6) and explanation (item 7). The improvement in transfer of these skills might simply be caused by additional academic knowledge e.g. Le Chatelier's principle and its application were taught after testing the grade 10 students, and therefore better understood by 11th grade students. Transference in other problem solving skills did not show significant improvement. The results support the conclusion made by Molnár and co-authors (2013) that improving skills and their transferring depended on the academic knowledge.

Table 1 clearly showed that there were little gains in applying skills of posing research questions and planning investigations (items 4 and 5). This could suggest that little teaching was included in science lessons in these areas and could point to a lack of student involvement in determining experimental work and in gaining problem solving skills.

Results showed that near transfer (into a similar context item 6) was more successful than far transfer item 2, thus agreeing with conclusions made by Johnson (1995) and Hung (2013). The analysis suggested that far transfer is more demanding, because it requires greater modification to the original knowledge.

The transfer of explanation skills through the use of a combination of biological and physical contexts (item 7) was shown to be more difficult than the combination for chemistry and physics in the item 3. This indicated that the skill to use knowledge could be dependent on the context. The inclusion of ethics in the applying knowledge item 2 suggested that decision making skills were not strongly promoted in chemistry teaching.

Conclusions

Students learn chemistry, biology and physics at the basic and gymnasium level. However, the test outcomes indicate that if students dislocate joints during a situation, such as a workout, and use a cold bag to reduce pain and swelling, they do not know which ingredients are needed, how to explain the way the bag "work," etc. The results of current study showed that there is a gap between knowledge and skills needed in this single example of an everyday chemistry problem solving situation, the knowledge and skills, produced and developed through formal education are insufficient. The developing of problem solving skills and its transfer to everyday scientific situations needs more attention in science education.

This study investigated students' progress in the transfer of problem solving skills to an everyday context. Conclusions were:

- progress in the ability to transfer problem solving skills occurred in only three skills which directly associated with the increase of academic knowledge,
- the development of transfer skills is seen as context-related, transfer of the skill into contexts very similar is more successful,
- according to literature, transfer should be involved in the meaningful learning. As showed tables 1 and 2 transfer of problem solving skills and its transfer is poor and their level change may be related to with the addition of one academic year.

The results of this study exposed the need for further investigation, especially related to the effects of the combination of knowledge from different subjects.

Limitation

The students tested in grades 10 and 11 were not the same, although they were from the same schools and taught by the same teachers. The number of test items, per transfer types, were small and may not fully reflect student achievements when tested on a wider scale.

Acknowledgements

This study has been supported by European Social Fund programme EDUKO grant LoTeGüm and Estonian Science Foundation grant GLOLO8219.

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