EDUCATIONAL TOOLS TO ASSESS STUDENTS' THINKING SKILLS

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Abstract

Knowledge can be regarded as the sum of skills and information gathered by a student.

Thinking skills and reasoning processes are considered a critical element in the process of teaching science subjects. Those skills could be grouped in a number of main blocks: focusing skills, information gathering skills, remembering skills, organizing skills, analyzing skills, generating skills, integrating and evaluating skills [1]. In 2008 the Polish educational system underwent a major reform, which consisted of introducing a new Science Curriculum. The Curriculum emphasizes the role of experiments and observations in development of complex student skills. One of the research activities of the authors of the present paper was to develop novel assessment tools for students' knowledge in chemistry. In order to check the quality of the tools, both large scale tests and cognitive labs in Polish schools were performed. The exact results of this test for two exercises and selected exemplary tools are presented.

Keywords: complex skills, assessment, school curriculum, educational tool, cognitive laboratory.

1 INTRODUCTION

In the year 2008 a major reform of the Polish educational system was carried out, which meant the introduction of a new Science Curriculum. The Curriculum emphasizes the role of experiment and observations in development of complex student skills. In Poland physics, chemistry, biology and geography are taught as separate subjects.

The article contains an example of an exercise aimed at checking practical skills in laboratory work together with qualitative and quantitative research results showing how it was tackled by students and what kind of problems they met. It also indicates problems one has to deal with when constructing such exercises.

1.1 Complex skills in teaching chemistry at ISCED 2 stage

To fulfil the requirements of the Curriculum for chemistry, twenty five exercises have been pointed out as obligatory to perform during chemistry lessons at ISCED 2 stage (in Polish nomenclature – *gimnazjum*, comparable to *middle school* in GB or *junior high school* in the US) [1]. Teachers should carry out laboratory experiments; however, they tend to focus on preparing students to external examinations, which are highly theoretical and not practical. Therefore they habitually skip experiments altogether.

One of the experiments which are obligatory to execute in class is the preparation of insoluble salts. The exemplary exercise presented below was designed to check if this experiment was actually carried out during chemistry lessons.

1.2 Exemplary tools used to assess students

This tool was prepared in two different versions to assess the same students' complex skills. *Multiple choice version (MCQ)* means that a student has only to choose one or more correct answers from those listed in the exercise. In the *open question version* student has to give the answer to two questions using his own words in a short written form. The following two paragraphs (1.2.1 and 1.2.2) show the text of the tool used.

1.2.1 Multiple choice question version

Explanatory note: tasks 1 and 2.

During the lesson dedicated to salts students perform an experiment described as follows.

Students fill a glass dish with water and subsequently pour a small amount of calcium nitrate $Ca(NO_3)_2$ powder on one of its endings and a small amount of potassium carbonate K_2CO_3 powder in another ending. After a while a white line can be observed to appear in the solution. The experiment effect is depicted in Figure 1.

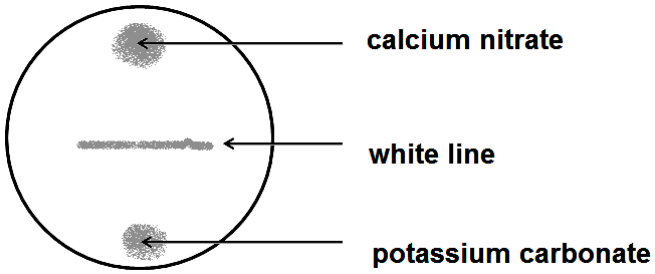

Fig. 1: Results obtained during the experiment.

Task 1

What could be reason why a white line appears in the experiment?

a) Contamination of salts with some other chemical substances.

b) Scratches in the glass which appeared in the presence of water.

c) An insoluble salt was created during the process.

d) The dish was put on a slanted surface.

Task 2

Choose which processes took place during the experiment.

a) Dissolution

b) Sublimation

c) Diffusion

d) Melting

e) Dissociation

1.2.2 Open version

Explanatory note for tasks 1 and 2:

Students fill a glass dish with water and subsequently pour small amount of calcium nitrate $Ca(NO_3)_2$ powder on one of its endings and small amount of potassium carbonate K_2CO_3 powder in another ending. After a while a white line can be observed to appear in the solution. The experiment effect is depicted in Figure 2.

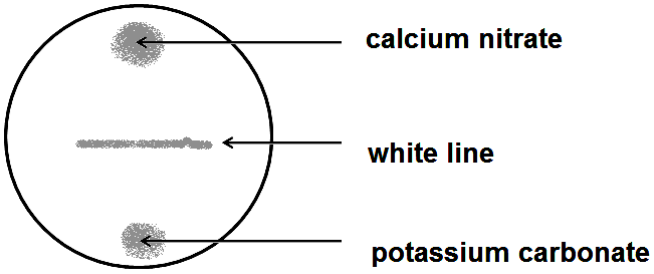

Fig. 2: Results obtained during the experiment.

Task 1

What could be reason why white line appears in the experiment?

Task 2

Name the phenomena that took place during this experiment.

1.3 Detailed task discussion

The tool described above measures complex skills acquired by students. Preparation of an insoluble salt is apparently a simple experiment. Mixing two chemical substances, for example two different soluble salts, may lead to obtaining a precipitate of insoluble salt, as it takes place in the case in question. One might say that the first task in this exercise is sufficient to assess if students have sufficient skills to understand the phenomena occurring in this case. This is true only to a certain extent because there are four possible answers so the probability of guessing the correct one is 25 percent. To eliminate this doubt, the author designed the second task, which is much more complicated in comparison with the first one. This time the students have to choose three correct answers from the five given in the exercise. Not only is the knowledge about insoluble salts precipitation assessed, but also the reasoning process is checked. To give the correct answer, one has to comprehend all the phenomena which occur during the reaction, which are: dissolution, dissociation and chemical reaction and know what melting and sublimation phenomena are. The intent put behind this experimental set was also to make certain that students are able to surmise the diffusion process present and involved in white line formation.

If the answer in the first task is correct, we may surmise that student remembers the schema of reaction: salt1 + salt2 → salt3 + salt4, so he or she has the necessary information but one cannot be sure about the actual cognition of the problem. Both tasks should be done correctly to prove real understanding of the experimental set.

2 FIELD WORK ASSESMENT

The Field Work Assessment was performed in 120 ISCED-3-stage schools in Poland of which 60 were *liceum* (comprehensive high school, comparable to *grammar schools* in GB, preparing for entering university), 30 were *technikum* (a kind of senior vocational high school, providing professional qualifications, yet making it possible to enter university after graduation) and 30 were *zasadnicza szkoła zawodowa* (junior vocational high school, vocational middle school, providing basic professional qualifications for manual workers, being not enough to enter university after graduation) in which students were on their first year of education. 1290 students and 581 teachers took part in the assessment. Within this paper we present results obtained by students completing exercises presented in paragraph 1.2 and opinions were given about those exercises by teachers.

2.1 Results of the Field Work Assessments – students' results

Results acquired by students completing the exercise in *MCQ* version (presented in paragraph *1.2.1*) are given in Table 2 (for the first task) and in the table 3 (for the second task):

ANSWER	CORRECT ANSWER	PERCENT OF CORRECT ANSWERS
a) Contamination of salts with some other chemical substances		14.4 %
b) Scratches in the glass which appeared under the presence of water		10.6 %
c) An insoluble salt was created during the process		69.2 %
d) The dish was put on a slanted surface		3.3 %

Table 2: Results acquired by students completing the first task of the exercise in *MCQ* version. 2.5 % of students gave no answer to that question. Correct answer is highlighted by the grey rectangle.

ANSWER	CORRECT ANSWER	PERCENT OF CORRECT ANSWERS
a) Dissolution		28 %
b) Sublimation		19.8 %
c) Diffusion		20 %
d) Melting		3.9 %
e) Dissociation		18.1 %

Table 3: Results acquired by students completing the second task of the exercise in *MCQ* version. 10.2 % of students gave no answer to that question. Correct answer is indicated by a grey rectangle.

As far as the first task is concerned, the number of questions omitted is significantly smaller as compared to the second task.

It may be a prerequisite about the difficulty level of the tasks for students. As it has been pointed in 1.3, the first task may be easier to answer correctly by students not only because there is one correct answer, but also because of that this task is mainly scoped on the students' knowledge. As one can see the last distractor was chose only by 3,3 % of students which means that this answer should be replaced by a different one. Trudel and Métioui [2] showed that in exercises constructed similarly to the first task, a good distractor is one that has the 15 % probability of being chosen as the correct answer by students and this probability should be lower for good students and higher for weaker ones. One of the possibilities that should be considered is that students do not associate chemical changes with the types of apparatus used during the experiment, especially the exact structure of the experimental setting. It might have had an important role: had the dish been placed on a slanted surface, the precipitate would not have formed a straight line but a U-shaped curve.

Results acquired in the second task seem to be preponderant for the assessment of the whole exercise. The mark is constructed in a way that both two tasks have to be completed correctly to obtain the good grade in his exercise. As it can be seen, students have significant problems with reasoning concerning all the phenomena which take place during the experiment. The author of the exercise assumed that the answer "c" would be the most difficult one to predict from all the answers given in the exercise. The results, though, showed that it the answer "e" was actually the least common one from the appointive from the correct ones. The results of the second task reveal the information about the reasoning process which took place during the choice of the correct answer in the first and it the second task. The scores acquired for the point "b" of the second task show that a significant part of students have problems understanding the phenomena discussed in the task. It is coherent with the results received in the cognitive laboratory assessment given in section 3.

Experimental exercises are a rare practice in Polish schools and are merely exceptionally present in the final exam after ISCED-2-stage school. It may also be one of the reasons for such low scores obtained in this exercise.

It is noteworthy that if the students had chosen the answer totally at random, the probability for each answer would theoretically be 50%. Yet, it is much less. This may be due to the fact that students did not know how many answers should be chosen; thus some of them marked one answer only, while others may have marked two or more.

2.2 Results of the Field Work Assessments – questionnaire filled by teachers

Almost 600 teachers filled a questionnaire concerning discussed exercises. The aim was to get their opinion about those tools. The results are given in table 4.

task number	innovativeness of the task content criterion	attractiveness of the task content criterion	pertinence of the skills assessed criterion	mistakes contained
1	2.64	2.79	2.64	0
2	2.14	2.15	2.69	0

Tab. 4 Results of the questionnaire filled by teachers. The maximum number of points which teachers could give in each section was 3.

It can be seen that the first task was found more interesting by teachers. They also pointed out that this task was also more creative and interesting for students than the second task. All of the teachers did not find any mistakes or misunderstandings in the exercise content. One can also find that second task had higher score in the meaning of assessing students' skills and knowledge which is connected with the information given by authors in 1.3.

3 COGNITIVE LABORATORY ASSESSMENT

In order to check what was the reason for the difficulty the students had solving tasks and investigate on possible constructional failures, cognitive laboratory assessment has been performed.

The presented results are a part of a bigger research project where ten different exercises were used both in open question and in *MCQ* versions. Cognitive laboratory assessment was performed with the participation of twelve students from four different schools, whereof two are *gimnazjum* (ISCED 2), where students were in the last term of their education, and two are *liceum* (ISCED 3) schools in which students were on the first year of study in each school (comparable to *Year 9/11 in GB* or *8^{th}/10^{th} Grade in the US*). From each class taking part in the project three students were chosen, one of whom was very gifted and not diligent, another one was averagely gifted and diligent, and the last one was not gifted but diligent. The choice was made by the chemistry teacher. The assessment was performed in two steps. During the first one students completed the tasks. The second step was an interview with students. During this step students were given questions that were designed to check their reasoning concerning the problem. The questions are listed below.

To the first task:

1. Do you understand the introduction to the exercise and all the given tasks?
2. Describe what is going on in the dish when the experiment is being performed.
3. Based on what you understand, what could you say about this experiment?
4. Is this a physical phenomenon or a chemical reaction?
5. Do you know how to use the solubility table?
6. Why did you choose those answers?

To the second task:

1. Which substances dissolve? How do you know that?
2. Which substances sublime? How do you know that?
3. Which substances diffuse? How do you know that?
4. Which substances melt? How do you know that?
5. Which substances dissociate? How do you know that?

3.1 Results of Cognitive Laboratory Assessment

The assessment was performed using both – *multiple choice questions* (for all students) and *open questions* (students numbered from 7 to 12) tool versions. Results are given in Table 1. Information given in columns 2 to 4 is students' own opinion.

Student's number	Difficulty level (1-5)	Time consumption (1-5)	Attractiveness (1-5)	Number of points acquired	Is this exercise dedicated to ISCED 2?	Did you need the table of solubility?
1	3	1	3	1/0	yes	no
2	3	2	3	1/1	yes	no
3	-	-	-	-	-	-
4	3-4	1	3	1/0	yes	no
5	3	3	2	1/0	yes	no
6	4	2	3	1/0	yes	no
7	3	3	3	0/0	yes	no
	4	3	3	1/0	yes	no
8	-	-	-	1/0	yes	no
	-	-	-	1/0	yes	no
9	3	1	5	1/0	yes	no
	3	1	5	0/0	yes	no
10	4	3	3	0/0	-	no
	4	3	2	1/0	-	no
11	5	3	4	1/0	-	no
	5	2	4	0/0	-	no
12	3	4	4	1/0	-	no
	3	4	4	0/0	-	no

Tab.1: Results acquired by twelve students in the cognitive laboratory. As for rows from 7 to 12 the rows are divided in two sections. In the first section one can find the number of points acquired by students in *MCQ* type of exercise, while in the second one in the *open* one. The result */** (for example 1/0) means that student acquired * points in the first and ** points in the second task. Student signed with number 3 did not fill in any question. For columns from 2 to 4: 1 meant the lowest value whereas 5 meant the highest value.

The general observations and conclusions that can be drawn are listed below.

1. Numbers of points acquired by students from the ISCED 2 and ISCED 3 stages were comparable.

2. The average difficulty level marked by the students was about 3.6 in 1-5 scale. However, only one of them answered correctly in both tasks.

3. Most of students had problems defining the difficulty level of the exercise; they were not sure whether or not the task was easy.

4. It was problematical for students to describe what processes and reactions exactly took place during the experiment but most of them gave the correct answer in the first task. This may lead to the assumption that the distractors designed for the first task are not equal. Students tried to guess the experiment results without using the solubility table, the use of which should be essential for the correct answer. All the students said they knew how to use the solubility table.

5. In the second task students tried to find an answer which could confirm the answer they had given in the first one.

6. Students had problems explaining the phenomena given in the second task (*MCQ* version).

7. All assessed students from the first stage of high school (*liceum*) said that the knowledge acquired during the ISCED 2 stage was sufficient to give the correct answer in both tasks.

8. There are no significant differences between results acquired by students in the open and in the MCQ version of the exercise.

The interview with students also revealed that they had not performed any experiments beforehand; thus they had basic problems with the names of the laboratory equipment used in the exercise. Therefore they tried to recall the name of the dish and got stuck at this point. Even though they knew the

laboratory stuff, they did not know how and when to use it. Another problem which students indicated was the form of the salt that usually is a precipitate in a test tube and in the exercise in question forms a white line.

Cognitive laboratory assessment showed that the construction of the first task in the exercise was not entirely appropriate in the sense that students chose the correct answer not because they understood it was correct but because all the other answers “looked like they were not in fact related to chemistry”, they “did not seem chemical enough”. Some of the students when asked to justify their choice said that they could not explain it.

It should be noted that the probability of providing a good answer in task 1 equals 1/4, while in task 2 it equals 1/32.

4 SUMMARY

Complex skills can be defined as those that are connected with critical reasoning processes or with some abstraction elements, with thinking in the category of the phenomenon, strategy or correlation between the system elements or a phenomenon [3].

The construction of a tool assessing complex skills is a multifaceted process. Such an exercise has to meet many requirements: not only does it have to conform to the School Curriculum and to have a well-defined complex skill to be assessed, but it also has to be attention-grabbing for students and developed in such a way that minimizes the probability of guessing the correct answer. All the distracters should be equally chosen by students. The last feature along with the difficulty level of the exercise can only be found after a preliminary research having been performed.

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