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Scientific paper

Assessing 15-year-olds' Understanding of Chemical Concepts in the Context of the Lithosphere and Pedosphere

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Abstract

The aim of this study was to determine the understanding of environmental chemistry content related to lithosphere and pedosphere, such as soil and soil types, soil horizons, rock and rock types, weathering, minerals, coal, and soil erosion, and to investigate misconceptions among 9th grade lower secondary school students. 503 students (254 male and 249 female) from 14 different primary schools and 8 different regions of Slovenia participated in this study. A three-tier achievement test (with 10 three-tier tasks to identify misconceptions) was used to collect the data. The results show that the Slovenian students' knowledge of the lithosphere and pedosphere is adequate. On average, students achieved 55.6% of all possible points. The lowest level of knowledge was found for the topic of soil formation. The number of misconceptions on this topic is low and does not exceed 30% for any task. The highest number of misconceptions was found for the topic of soil formation and pollution.

Keywords: Three-tier diagnostic test, environmental chemistry, environmental education, lithosphere, pedosphere, misconceptions.

1. Introduction

The Slovenian environmental curriculum is interdisciplinary in its structure, i.e., it contains a list of objectives and recommendations. The reason for such a curriculum lies in the complexity of environmental problems, whose explanation and solution lies at the intersection of several sciences.[1] One of the multidisciplinary sciences that is part of environmental education and combines physics, chemistry, biology, etc. is environmental chemistry.[2] Environmental chemistry also includes the topics of soil literacy,[3,4,5] such as the topic of lithosphere[3,6] and pedosphere.[6] These two topics also lend themselves to the integration of physics, chemistry, and mathematics.[7] In Slovenian school system topic of lithosphere and pedosphere is taught in natural science in 6th grade.[8] It is teachers' responsibility to connect this content from science and geography, so that the students acquire broader picture of these content.[9]

People need adequate and quality knowledge about environmental factors to protect the environment, explain environmental problems, and create a healthy environment for future generations.[10] To this end, environmental education must provide students with soil literacy. Soil literacy is a combination of attitudes, behaviours and skills that ultimately contribute to the well-being of the natural environment.[6] Experts believe, that we need a methodological approach if we want to measure the effectiveness of environmental education.[11]

A well-known barrier to science learning are misconceptions.[12] Misconceptions are cognitive structures that are persistent and can become an obstacle when students want to learn more complex concepts. It is very important that we review possible misconceptions before we begin teaching new content.[13,14] Misconceptions formed in school are the result of misleading explanations of concepts where we find oversimplifications and generalization.[15] The study of misconceptions is of interest to researchers. Misconceptions can be uncovered with written tests of knowledge, such as: achievement tests with multiple-choice questions, multiple-tier tests of knowledge, concept maps, interviews, etc.[16] The limiting factor

in diagnostic multiple-choice tests is the high probability of guessing. Therefore, diagnostic tests began to gain baseline knowledge by requiring an explanation for the answer choice in addition to the answer. This form of testing allows for exploration of the reasons for the occurrence of misconceptions.[17] Cetin – Dindar and Geban[18] developed a diagnostic knowledge test with three-tier tasks to determine students' knowledge of acids and bases. This test was used to test how much more accurate it is compared to the two-tier and one-tier diagnostic knowledge test. Reliability was measured using the Cronbach's alpha coefficient. This showed that the reliability of the first part of the knowledge tests (alpha coefficient value) was 0.58, the reliability of the second part was 0.59, and the reliability of the third part was 0.72. According to Milenković et al.[17] 0 to 30% of students indicate a low number of misconceptions, 31 to 60% of students indicate a medium number of misconceptions and more than 61% of students indicate a high number of misconceptions on a given topic.

Research by Borghini et al.[14] and Dove[19] has shown that students have misconceptions about earth science. Misconceptions exists for several topics related to earth science, such as rocks, earthquakes, volcanoes, the structure of the earth, landforms, weathering and erosion, and soil. Borghini et al.[14] cited the short time devoted to earth science, absence of geological background of teachers, difficulty in understanding complex topics, ineffective teaching and learning methods, etc., as reasons for the high number of misconceptions in this area. Francek[20] found a high number of misconceptions in the topic of tectonic plates followed by the topic of weathering/erosion. As Monteiro et al.[21] found, students also have problems with the definitions of minerals. The study found that more than 92% of students have misconceptions about minerals. Given the wide variety of minerals and rocks that can appear, this is to be expected.[19] Study by Putri et al.[22] also showed that type of task can be problematic. Students usually have problems interpreting social problems or mathematical data in graphs.

Misconceptions about the rock cycle often stem from students inability to understand the rock cycle.[20] The problem of understanding the rock cycle among students can address many misconceptions about rocks, but students have trouble connecting the three major rock categories.[23] Rather than seeing a connection between rock classes and the rock cycle, students view the rock cycle as the cause of rock formation.[24] Weathering and erosion are also part of the rock cycle and allow rocks to change from one form to another.[23] Unable to connect different rock types[24] students view erosion and weathering as two unrelated processes and do not connect them to the formation of soil.[20] Rock classification and formation is also problematic because students use observable characteristics such as colour, shape, and size to identify specific rock types. However, these features are not used in rock identification. Therefore, students' perceptions of rocks they know from previous experience are not met and they remain unidentified.[19]

There was confusion among students about what soil is made of and how long it takes to form.[20] The same problem was found among teachers in a study by Hayhoe et al.[25] where teachers had difficulty defining soil as a composition of solid particles with spaces for air and water. Students often believe that soil extends for miles below the surface.[20] This may be due to the difficulty in visualizing cross-sections of soil as soil profiles that are not easily observable.[19] Russel et al.[26] conducted a study that found that upper-level students do not understand the nature of soil and cannot relate to soil composition.

2. Research Problem and Research Questions

The environmental program was introduced in the Slovenian school system in 2008.[1] Part of environmental education is also environmental chemistry,[2] which covers the topics of lithosphere and pedosphere.[3,4,5] To our knowledge, no research has been conducted on the performance of environmental education and students' misconceptions about environmental chemistry topics such as lithosphere and pedosphere. In subject of natural sciences students should be introduced to the key concepts earth science and also reflect on the main causes of soil pollution.[8] However, we do not have enough data to evaluate students' basic understanding of environmental issues.[28]

The aim of the present research is to identify the level of knowledge that 9th grade primary school students possess about the lithosphere and pedosphere. Two research questions were formulated for this purpose:

(1) What is the level of knowledge of 15-year-old students about the lithosphere and pedosphere?
(2) Do students have misconceptions about the lithosphere and pedosphere?

3. Method

A quantitative and cross-sectional research approach was used in this study, non-experimental and descriptive methods were used to determine students' knowledge of the lithosphere and pedosphere.

3. 1. Participants

A total of 503 students (254 males and 249 females, M = 15 years, SD = 6.0 months) attending 14 different elementary schools in 8 different statistical regions of Slovenia participated in the study. This sample represent 2.53% of the entire population of 9th grade students in that year[29]. Participation in the study was voluntary and anonymous.

Prior to implementation, a letter was sent to the school and parents or caregivers of ninth graders informing them of the study. School principals, teachers, students, and their parents or caregivers agreed to participate in the study and informal consents were signed by students' parents or caregivers.

3. 2. Instruments

The data was collected using instrument comprised of two parts: (1) information about the participants (IP), that include general information about the participants (e.g., gender, school, region and grades in biology, chemistry, and physics; (2) diagnostic instrument entitled How Well do I Know Soil and Rocks (HWiKSR), which measured students' knowledge about lithosphere and pedosphere and consist of 10 three-tier multiple-choice tasks, of specific environmental phenomena such as: soil, rocks, soil pollution, rock formation, erosion, soil structure and soil formation.

The content validity of the instruments was confirmed by six independent experts in chemistry and environmental education. The full texts of the instrument can be obtained by request from the corresponding author.

HWiKSR tasks differ in level of complexity and specificity according to Krathwohl[27]. According to Bloom taxonomy each task has been defined in which level it belongs according to this taxonomy. Each tasks topic and Bloom's cognitive level is shown in Table 1. Each task as shown in Figure 1 includes three-tiers: a multiple-choice answer tier (tier 1), a reasoning tier (tier 2) describing an expected reason for the students' answer selected in tier 1 and a six-point confidence scale (tier 3) – the answers obtained in the six-point confidence scale correspond to *"1-just guessing"*, *"2-very unconfident"*, *"3-unconfident"*, *"4-confident"*, *"5-very confident"* and *"6-absolutely confident"* and expresses the students' confidence in giving the answer and the reason for it (tiers 1 and 2). To simplify the discussion, the following answers from the confidence scale were merged as follows: *"Not Sure"*, when students choose "*1*", "*2*" or "*3*" and *"Sure"* when students pick "4", "*5*" or "*6*" on the confidence scale. The overall response possibilities in the HWiKSR (first, second, and third tiers together) resulted in the following categories according to Milenković et al.[17]: *(i)* a combination of correct (tier 1) and correct (tier 2) and sure (tier 3) answers was treated as *knowledge (ii)* a combination of correct (tier 1) and correct (tier 2) and not sure (tier 3) answers was treated as *luck (iii)* a combination of incorrect (tier 1) and correct (tier 2) and not sure (tier 3) answers was treated as *guessing (iv)* a combination of correct (tier 1) and incorrect (tier 2) and not sure (tier 3) answers was treated as g*uessing (v)* a combination of incorrect (tier 1) and incorrect (tier 2) and not sure (tier 3) answers was treated as *lack of knowledge (vi)* a combination of correct (tier 1) and incorrect (tier 2) and sure (tier 3) answers was treated as *misconception (vii)* a combination of incorrect (tier 1) and correct (tier 2) and sure (tier 3) answers was treated as *misconception (vii)* and a combination of incorrect (tier 1) and incorrect (tier 2) and sure (tier 3) answers was treated as *misconception*. The answer to an item was correct if both first and second tiers were correctly answered. The HWiKSR diagnostic instrument not only identifies misconceptions of 15-year-old students, but also differentiates them from their lack of knowledge about the lithosphere and pedosphere. Students could achieve maximum 20 points solving the tasks on HWiKSR (10 for answer tier, 10 for reason tier).

Table 1 Specification table of HWiKSR diagnostic instrument tasks.

Number of task	Topic	Question	Bloom's cognitive level
1.	Soil properties	Soils contain different proportions of water and air. Which soil can be the most breathable and contain the most water?	Understanding
2.	Soil properties	Does soil type increase the biotic diversity of plants?	Understanding
3.	Rocks	What is rock?	Remembering
4.	Soil properties	The figure shows the root system of an oak tree. An adaptation to which environmental factor do roots represent?	Understanding
5.	Pollution	The graph shows the amount of mined lignite in the Velenje coal mine from 1950 to 2018. Assume that all lignite burned, which pollutes the environment. During which period did lignite mining have the greatest environmental impact?	Analyse
6.	Pollution	How does a fuel oil spill affect soil fertility?	Understanding
7.	Rocks	What do we call rocks that form from cooled magma below the surface of the earth?	Remembering
8.	Formation of soil	Erosion is defined as the process of furrowing action of external forces on the surface and removal of material. In what way can we most effectively reduce erosion in nature?	Apply
9.	Soil properties	The picture shows the soil profile. What layers or horizons characterize the soil layer?	Analyse
10.	Formation of soil	Which process of soil formation is shown in the picture?	Analyse

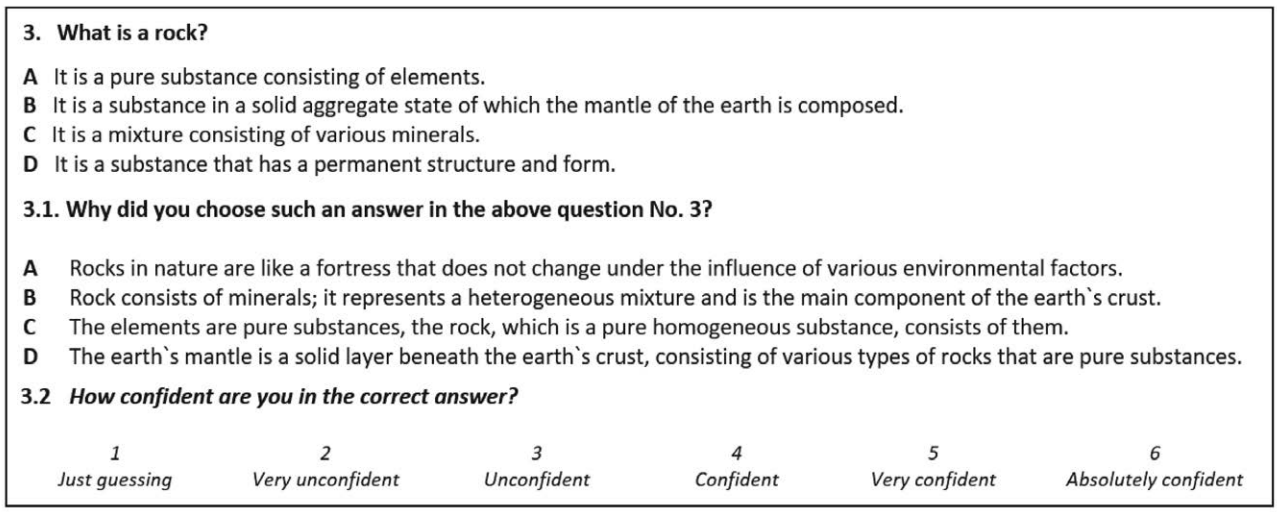

Figure 1. An example of the task no. 3 in HWiKSR; 1st tier (3), 2nd tier (3.1); 3rd tier (3.2.); the correct answer and the correct reason are presented in bold.

3. 3. Research design

Data collection took place between April 5 and April 23, 2021, in elementary schools throughout Slovenia, following the ethical principles of educational research. The IP and HWiKSR were applied anonymously in groups, and all the participants had similar classroom conditions while completing both instruments. They spent an average of 30 minutes completing the two instruments. Participants were informed that the data would be used for research purposes only and the main objective of the study was explained. The research was conducted in accordance with ethical standards for educational research. Data was analysed using descriptive statistics (mean *M*, standard deviations *SD*) to determine the level of students' understanding of the lithosphere and pedosphere and confidence in solving the specific tasks in the HWiKSR; the data were analysed using Excel.

4. Results and Discussion

4. 1. Students' Knowledge About Lithosphere and Pedosphere

The HWiKSR answers and reason responses (i.e., tier 1 and tier 2 responses) indicated low level of student understanding of the lithosphere and pedosphere. According to Milenković et al.[17], Slovenian students' knowledge of the lithosphere and pedosphere is somehow adequate. 31.0% of students did not reach the arbitrary limit of positive evaluation according to rules of evaluation in Slovenian school system.[8] Students scored an average of 55.6% of all possible points on HWiKSR, which is equivalent to 11.2 points. These results are encouraging when compared to the results of the study by Borghini et al.,[14] in which students scored an average of 44.0% of all possible points on the lithosphere and pedosphere achievement test.

Tasks 1., 2., 4. and 9. in the HWiKSR, referred to knowledge of soil properties. The results show that 46.5% of students have knowledge of soil properties. However, 30.1% of the students showed knowledge deficits in these tasks. These results support the idea by Russel et al.[26] who found that students do not understand the composition of soil, these problems may originate from findings by Hayhoe et al.[25] who found that teachers also had difficulties defining soil as composition of solid particles with spaces for air and water. In task 9., only 21.5% of students chose the correct answer in tier 1 and tier 2. A possible explanation for the low level of knowledge could be that, according to Krathwohl[27] this task is at a higher cognitive level of Bloom. In tasks 8. and 10. that referred to soil formation, the results show that 37.8% of students have knowledge. On the other hand, 28.7% of students showed a lack of knowledge of soil formation processes, both tasks being at a higher Bloom's cognitive level according to Krathwohl.[27] In addition, students have difficulty linking the stages of the rock cycle[23], therefore they do not see weathering and erosion as processes of soil formation and have problems linking these two processes. In tasks 3. and 7., that referred to rocks, the students' level of knowledge is very different: 15.5% of the students expressed knowledge in task 3 and 38.6% in task 7. Both tasks were at lower cognitive level according to Bloom's taxonomy[27]. One explanation for the students' low level of knowledge in task 3 could be that the task asked what type of rock is formed from cold lava. Students learn this topic in 6th grade in natural sciences[8] and the participants in the study were 9th graders, so it is possible that they forgot what they learned. A possible explanation could also be that rock classification was defined as problematic due to the type of characteristics we use for classification[19]. Tasks 5. and 6. referred to soil pollution,

and the results show that the students' knowledge level is the lowest for this topic. 21.9% of students answered 1st and 2nd tier of the task correctly. For task 5. alone, only 15.5% of students expressed knowledge. This could be due to the problems that students have in interpreting mathematical and social problems using graphs as stated by Putri et al.[21] The average performance of students to each task is shown in Table 2.

4. 2. Students' Misconceptions About Lithosphere and Pedosphere

The analysis of three-tier tasks on the HWiKSR diagnostic instrument showed that Slovenian students that participated in the study have misconceptions. These results are in line with the findings of Borghini et al.[17] and Dove[19] who also found misconceptions about soil, rock, weathering, and erosion among students in earth sciences. Francek[20] also found that students have misconceptions about weathering and erosion. However, the number of misconceptions in the HWiKSR was below 30.0% for each task, which according to Milenković et al.[17] represents a low number of misconceptions. As shown in Table 2, the highest number of misconceptions was found in task 7 (25.6%), where students had to name the rocks that are formed from cold lava. As mentioned above, one explanation for the high number of misconceptions in this task could be students learn this topic in 6th grade, but this study was conducted with 9th grade students. Monteiro et al.[21] also found that students have misconceptions about minerals and rocks due to the wide variety of minerals and rocks that can occur. Students' inability to understand the rock cycle[20] and to connect different types of rocks[24] could also be an explanation for the higher number of misconceptions in this task. The problem of understanding the rock cycle may address many misconceptions about rocks, as Francek[20] noted. Students' inability to connect different types of rocks and the rock cycle may also explain the high number of misconceptions in task 9 (23.5%), as students often believe that soil extends for miles below the surface[25] and do not understand the composition of soil and its depth.[26] However, according to Dove[19] students also have problems visualizing cross-sections, which could also be an explanation for the high number of misconceptions in task 9. For task 5 (24.5%), the explanation for the higher number of misconceptions could be that students solve social and mathematical problems by reading graphs as Putri et al.[22] found. These types of problems are also more difficult to solve as they are higher on Bloom's cognitive theory level.[28] The number of misconceptions is also higher than 20.0% in task 10. As students are not able to connect different types of rocks to each other, they see weathering and erosion as two unrelated processes and to not connect them to soil formation.[20] Students also have problems seeing erosion and weathering as processes that allow rocks to change from one form to another.[23] In other tasks, the number of misconceptions was below 20.0%. In task 3 19.1% of students showed misconceptions, probably due to the wide variety of rocks and minerals and problems with the definition of minerals.[21]

As mentioned above, the overall number of misconceptions was low according to the literature.[17] However, the main cause of misconceptions arising in the topic of lithosphere and pedosphere is the short time devoted to earth science, as this topic is only covered in 6th grade. Borghini et al.[14] found that the short time devoted to a particular topic is one of the main reasons for the formation of misconceptions. The same applies to the lack of geological knowledge among teachers. The topic of lithosphere and pedosphere is covered in 6th science, and the teachers who teach these topics are not geology or geography teachers.

5. Conclusions

The purpose of this study was to determine whether Slovenian 15-year-old students have sufficient knowledge about the lithosphere and pedosphere, and if they possess any misconceptions about this topic. The three-tier HWiKSR diagnostic instrument was used to obtain

Table 2 The proportion of knowledge, lack of knowledge, guessing, luck and misconceptions according to students' responses on HWiKSR test.

	Knowledge		Lack of knowledge		Guessing		Luck		Misconceptions	
Number of task	***f***	***f%***	***f***	***f%***	***f***	***f%***	***f***	***f%***	***f***	***f%***
1.	86	17.1	184	36.6	26	5.20	154	30.6	53	10.5
2.	154	30.6	119	23.7	36	7.20	172	34.2	21	4.2
3.	78	15.5	146	29.0	91	18.1	92	18.3	96	19.1
4.	126	25.0	108	21.5	45	8.9	147	29.2	77	15.3
5.	78	15.5	177	35.2	68	13.5	57	11.3	123	24.5
6.	142	28.2	91	18.1	54	10.7	195	38.8	21	4.2
7.	194	38.6	53	10.5	60	11.9	67	13.3	129	25.6
8.	134	26.6	153	30.4	57	11.3	116	23.1	43	8.5
9.	59	11.7	196	39.0	84	16.7	45	8.9	118	23.5
10.	81	16.1	136	27.0	134	26.6	49	9.7	103	20.5

information about their understanding of the soil, rocks, weathering and erosion and soil pollution. An additional instrument to gather students' background information was also used. It can be concluded that the students' knowledge of the lithosphere and pedosphere is adequate. However, according to the rules of evaluation in Slovenian school system, the average performance of students is just above the positive evaluation standards of 50.0% of all possible points. 50.0% of all tasks in the HWiKSR were solved correctly by less than 50.0% of the participants. The lowest level of knowledge was found in the tasks on soil formation, where students had to connect weathering and erosion as processes of soil formation and understand the structure of soil. Moreover, 21.1% of students showed knowledge of the properties of soil. The highest level of knowledge was found for the topic of rocks. The highest number of misconceptions appeared in the topic of rocks, soil formation and pollution. The results show that in no task did the number of misconceptions exceed 30.0%, which is a low number of misconceptions.

The present study highlights important issues in the current basic school curricula and points to directions in further research into the content of lithosphere and pedosphere. We must be aware that this topic is part of environmental chemistry and people need this knowledge to explain environmental problems, to protect the environment and to create healthy environment for the future. Therefore, it is essential to include environmental topics about lithosphere and pedosphere in curriculum in the upper grades, which, however, would require a change at the national level. The introduction of such changes may be chaotic at the beginning and thus demand high level of cooperation among all the stakeholders involved.

There are some limitations of this research. The first one can be found in the analysis of the students' responses on all three tiers identifying the proportion of specific misconceptions about lithosphere and pedosphere at the end of the contemporary education in Slovenia. The second limitation lies in the fact that the HWiKSR was applied only at one level of education, and it can be also implemented at the end of secondary education as well as at the beginning or/and at the end of university teacher education. Also, students from all regions should be included in further studies, with a larger sample, in order to be able to generalize the data to the entire population. This data can provide more a detailed picture of students' and teachers' understanding of specific environmental phenomena and help preparing curriculum changes for all levels of education in Slovenia. In this way, a significant impact can be made on improving students' knowledge of the content covered in this article, while at the same time reducing the number of misconceptions about these topics. Considering the limitation of this research some further research on this topic can be conducted. For instance, research should be also conducted at the end of grade 7 when students finish the subject natural science, where these topics are covered. Therefore, we can assume that less knowledge is lost due to forgetting. It is also important to analyse the correlations between answer, reason and confidence tier. The level of teachers' environmental literacy, how they apply environmental issues in their teaching even when the specific curriculum aim is suggested can be studied. More detailed textbooks analysis regarding environmental issues is necessary to interpret the data in more detail. The bottom-up approach of teaching and learning modules development to present science concepts in the environmental context is obligatory and their research-based implementation is necessary.

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Povzetek

Članek predstavlja rezultate raziskave, ki je med slovenskimi devetošolci ugotavljala razumevanje področja litosfere in pedosfere. Raziskava vključuje razvoj tristopenjskega diagnostičnega inštrumenta sestavljenega iz desetih vprašanj z naslovom *Kako dobro poznam prst in kamnine* (HWiKSR). V raziskavi so sodelovali skupno 503 učenci iz osmih različnih regij v Sloveniji, ki so v šolskem letu 2021 obiskovali 9. razred osnovne šole. Podatki pridobljeni s HWiKSR so omogočili proučevanje razumevanja in prepričanosti učencev o prsti in kamninah. Rezultati kažejo, da imajo učenci 9. razredov osnovne šole v Sloveniji ustrezno znanje s področja o litosferi in pedosferi. V povprečju so učenci dosegli 55,6 % vseh točk na HWiKSR. Najnižja raven znanja je bila ugotovljena pri temi nastanka tal. Število napačnih predstav učencev o litosferi in pedosferi je nizko in ne presega 30 % pri nobeni nalogi. Največ napačnih predstav je bilo ugotovljenih pri temi nastanka tal in onesnaževanja.