JOURNAL OF BALTIC SCIENCE EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

THE CHANGES OF SECONDARY SCHOOL STUDENTS' CONCEPTIONS OF SCIENCE CONCEPTS

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Abstract. *Contemporary secondary science education is characterised by a greater inclination towards the constructivist paradigm of education and the development of inquiry-oriented teaching. The basic principle of this paradigm is the dynamic modification of preconceptions towards the desired level given by the school curriculum. This places particular importance on identifying the level of students' preconceptions and on uncovering any misconceptions. Since preconceptions are an individual characteristic of the learner, preconceptions can also be expected to be modified over time due to societal changes. The research is based on a semi-longitudinal study to find out what changes in the level of learners' preconceptions occurred between 2003 and 2023. The level of preconceptions was monitored in three basic dimensions: cognitive, affective, and the dimension of structuring. A total of 10 concepts from the field of science education in secondary school were selected. The research study involved 103 respondents in 2003 and 104 respondents in 2023, all 12–13 years old. The results show substantial increases in the level of preconceptions in all three dimensions studied. This reflects both societal changes in recent years and a change in attitudes towards science education.*

Keywords: *preconceptions structure, secondary science education, science preconceptions, semi-longitudinal research,*

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Introduction

Since approximately the late 1970s, science education in Europe has changed significantly. The original concepts, based on the scientistic paradigm and using behavioural models of learning, are compared to the reform movement taking place internationally. The original scientistic paradigm based, for example, on Zankov's theory of developmental learning, was characterised by a high degree of mathematisation, abstraction, and a one-sided preference for theoretical knowledge in teaching (Guseva & Solomonovich, 2012). This ultimately led to the low popularity of science subjects and the diminished ability of students to apply the acquired theoretical knowledge to problem solving and its use in practice (Cēdere et al., 2018). The aforementioned reform movement significantly changed both the paradigm of science education itself and specific educational practices (DeBoer, 2019). Achieving scientific literacy has become the main goal of science education. In particular, this goal requires students to take an active approach to science inquiry, to be able to use observation and experimentation, and to analyse and critically evaluate the information they acquired (McFarlane, 2013). These basic principles are based on the theory of pedagogical constructivism and were used to derive various models for managing students' learning activities such as problem-based learning, heuristic teaching, inquiry-based teaching, and other analogous approaches that use active construction of knowledge by the learner (Singh & Yaduvanshi, 2015). A common element of constructivist-oriented educational conceptions is active work with preconceptions. From an epistemological point of view, they emerge as spontaneous concepts based on individual experiences and on the learner's comparisons with the surrounding world (Olteanu et al., 2016). Rai and Kumar (2020) argued that the terms preconception and misconception fall under the category of research for which a norm determines the value of a particular concept and lends it a certain legitimacy. In such a view, a preconception is found to be immature or incomplete in relation to the accepted norm, while a misconception is identified as a concept that is wrong with respect to the same norm (Vlckova et al., 2016). It should be noted, however, that although children's misconceptions were found to be incompatible with the scientific model, they are always legitimate for the child and

https://doi.org/10.33225/jbse/24.23.1164

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

are part of the knowledge created by the child (Fragkiadaki & Ravanis, 2015). However, the role of preconceptions in the cognitive process is more complicated. These are complex decoding structures that give individual meaning to incoming information. They are also the receiving structures that enable the incorporation of new facts into the learner's existing internal conceptual system. They therefore play the role of mediator between knowledge and the individual's thinking structures – the learner elaborates their knowledge in the interaction between these preconceptions and the information they can acquire from them (Vosniadou, 2012). Preconceptions are thus neither the foundations nor the outcomes of knowledge. They are the very tools of this activity. They are constantly being rebuilt, and the new knowledge must be incorporated into the pre-existing structures available to the learner. Over the course of human life, preconceptions gradually evolve; their system expands and becomes more complex, and the conception of the whole and its parts and their relations differentiate. Based on these theoretical premises, learning can be characterised as a dynamic modification of the learner's existing preconceptions towards a certain norm; this can be the current state of knowledge in a given scientific field, or the construction of a usable model as required by 'school science' and as defined in curriculum documents (Duit et al., 2013). According to Piaget (1978), dynamic modification occurs through the processes of assimilation and accommodation. If the incoming knowledge is consistent with the learner's internal conceptual system, it is organically incorporated and assimilated into existing knowledge structures, which it expands and enriches. If the new knowledge is inconsistent with the learner's existing conceptual system, cognitive conflict occurs. Based on this, the internal conceptual system is then rebuilt and acculturated so as to achieve harmony between this system and the newly acquired knowledge (Rutherford, 2011). The learner is thus an active agent of their learning, using their preconceptions as unique and original cognitive tools at their disposal (Mitchell, 1992). Preconceptions are shaped by all the previous influences and experiences that have been exerted on the learner throughout their previous life. These are both school and extracurricular influences, and the degree to which they operate depends on the age level of the learner and their ability to process all previous experiences. Exogenous factors in the formation of pre-concepts include social, economic, cultural, religious, ethnic, and other influences. The endogenous factors then include influences based on each individual's psychological and biological characteristics or dispositions. The process of developing preconceptions ensures that each person's internal conceptual system is entirely original and unique, shaped by a distinctive combination of various influences (Vosniadou, 2019). This has serious educational implications. If one accepts the thesis that preconceptions are both encoding and decoding structures of the cognitive process, then the notion of information transmission from teacher to learner used by the traditional behavioural model of learning appears to be highly distorted (Dahlin et al., 2009). It is not possible to effectively teach students collectively through one single teaching method. The individual specificities of cognitive structures in students also make it problematic to achieve the intended learning goals in the classroom for all students. Given the diverse range of influences involved in the formation of preconceptions, it is not possible to consider them only in cognitive terms. A preconception, then, does not have the nature of knowledge, or rather of mere knowledge, but is structured in a much more complex way (Anderson & Lindsay, 1998). Its placement in the structures of the learner's internal conceptual system also plays an important role. At the theoretical level, there are no unified approaches to the structuring of preconceptions. The most frequently cited components (dimensions) of preconceptions are cognitive and affective dimensions (Azizah & Mudzakir, 2016). Some authors add a conative component (Sainafat et al., 2020). For research purposes, the structure of preconceptions has been defined using three dimensions: cognitive, affective, and structured. The cognitive dimension of a preconception is characterised by its content and scope. Thus, a learner has a certain detectable cognitive level of a given preconception, defined by the quality and quantity of information contained in the preconception. They are able, for example, to pronounce an individually valid definition, to distinguish essential from non-essential properties, to define a concept from other concepts in terms of information, to give its characteristics, to list its properties, etc. The cognitive dimension of a preconception is created by means of knowledge that the learner constructs on the basis of their own experience or by confrontation with perceived reality. Similarly, it can be constructed on the basis of social interactions within a particular discourse. It is formed both intentionally and spontaneously. The affective dimension of a preconception arises as a person's emotional reaction upon initial acquaintance with a certain knowledge. It is usually formed on the basis of the associations that the new (and therefore previously unknown) knowledge evokes in a person. This emotional content creates the affective dimension of the preconception, i.e., what attitude the individual has towards it (Anggoro et al., 2017). Of course, it is also possible that the emotional reaction to the new knowledge is neutral (e.g., indifference), but this can only be interpreted as a special case of this reaction. The cognitive and affective dimensions of preconceptions mutually interact (Thompson & Mintzes, 2002). For example, the affective dimension may induce the development of the cognitive dimension of the preconception and may be a determi-

https://doi.org/10.33225/jbse/24.23.1164

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

nant for this development. Negative emotion, for example, leads to a preference for information that is consistent with an individual's attitude toward a given fact or knowledge. On the other hand, a fear of something may trigger a desire to learn as much as possible about the subject matter. To some extent, structuring in this thesis represents the conative component of the preconception. It is understood as the ability to actively use a given preconception (e.g., in context), be it in a correct or incorrect sense. The correctness or incorrectness of the use of a preconception is closely related to how it is situated in the conceptual structure of a given individual. These conceptual structures can be interpreted as mental maps where individual preconceptions are plugged into specific conceptual networks and where they form clusters based on unique associative links (Syar, 2022). It is then clear that any misconceptions are not only generated on the basis of the cognitive dimension but may also be due to the misclassification (structuring) of a preconception in the learner's knowledge structure. Therefore, this dimension also needs to be addressed in empirical research. Knowledge of learners' preconceptions and their internal structuring is the basis for an effective learning process that is based on conceptual change (Vosniadou, 2007). In this process, the learner's original preconceptions are dynamically modified in confrontation with information brought by sources of knowledge towards concepts that are desirable in terms of a given level of learning (Sobah et al., 2019).

This study is based on the theory of conceptual change (Clement, 2008; Chi, 2008; diSessa, 2008). In order to understand advanced scientific concepts in various disciplines, students cannot rely on simple memorization of facts. They must learn how to restructure their naive, intuitive theories based on everyday experience and lay culture. In other words, they must undergo a profound conceptual change. This type of conceptual change cannot be achieved without systematic instruction that takes into account both individual, constructivist, and sociocultural factors (Vosniadou, 2007). The term "conceptual change" was first introduced by Thomas Kuhn (1962) to suggest that concepts embedded in scientific theory change their meaning when the theory (paradigm) changes. Posner et al. (1982) were instrumental in making the theory of conceptual change appropriate for teaching science and transforming student misconceptions. They described an analogy between Piaget's (1978) concepts of assimilation and accommodation and the development of concepts of scientific knowledge (Özdemir & Clark, 2007). From this analogy, they derived a theory of science teaching based on accommodation. According to Posner et al. (1982), there are four basic conditions that must be met before conceptual change can occur: (1) there must be dissatisfaction with existing conceptions, (2) there must be a new conception that is comprehensible to the learner, (3) the new conception must be plausible, and (4) the new conception should contain the potential for meaningful learning.

Linn and Songer (1991) reported that conceptual changes occur during adolescence, both because students assimilate knowledge about previously unexplored phenomena and because their original ideas are replaced by more predictive, abstract, or robust concepts. The study examines cognitive change by focusing on how conceptual change occurs, specifically looking at both the increase in understanding and the process of replacing one concept with another. Of particular importance is the strong influence of the social context in which learning occurs. The social context becomes more important during adolescence in conjunction with increased awareness of social relationships and social influences. Given the very significant social changes that have taken place over the last 20 years, particularly in the countries of the former Soviet bloc, it seems necessary to examine the influence of these social changes on the formation of preconceptions in science education. These profound changes are not only related to societal changes, but are also reflected in a radical change in educational paradigms and the content of education itself. Thus, inquiry-based approaches grounded in the theory of conceptual change, which underpins the process of didactic reconstruction, are being increasingly implemented in education (Kattmann et al., 1997). This research is aimed at reflecting on these changes, which should also be reflected in the formation of student preconcepts.

Research Problem and Research Question

The research problem of this study is based on the fact that over the last 20 years, there have been significant changes in the natural sciences, science education, and in the societal evaluation of some natural phenomena. These include:

1. New scientific discoveries (e.g., vaccines and pharmaceuticals in the context of the covid-19 pandemic).
2. The massive development of technologies that enable the use of new energy sources that reduce dependence on fossil fuels.
3. Increased emphasis on environmental aspects of the development of modern society (sustainable development, Green Deal, waste sorting, environmental burden of microplastics).
4. Significant strengthening of innovative approaches in science education based on theoretical concepts

https://doi.org/10.33225/jbse/24.23.1164

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

of pedagogical constructivism (inquiry-based science education, problem-based teaching). These concepts purposefully work with students' preconceptions and individual experiences as the basic tools of the didactic reconstruction process.

5. Increased emphasis on the development of science literacy competences, which are also directed towards the development of the affective component of students' personality.
6. Development and accessibility of artificial intelligence and its use in the broadest spheres of human society, including the educational process.

These facts provide a starting point for research into the genesis of preconcepts that should reflect these significant changes. Since preconcepts are also tools of cognition and decoding structures through which students receive and evaluate new knowledge and information, they need to be intensively investigated in the educational process. Therefore, the aim of the presented research study was to explore the influence of these changes on the formation of selected preconcepts. A comprehensive understanding of the changes in students' preconcepts in relation to the formation of science literacy is a prerequisite for effective curriculum reform, which is currently being intensively discussed in the Czech Republic.

The basic research question addressed in the research study presented here was formulated as follows:

- What changes in the descriptive categories of science preconceptions have occurred due to changes in science education over the past 20 years?

This research question is causal in nature so as to capture the semi-longitudinal changes that occurred between 2003 and 2023.

Hypotheses

The following substantive hypotheses were formulated to answer the research questions:

The level of the cognitive dimension of selected science preconceptions of secondary school students in 2003 differs from the level of the cognitive dimension of preconceptions in 2023.

The level of the affective dimension of selected science preconceptions of secondary school students in 2003 differs from the level of affective dimension of preconceptions in 2023.

The level of the structuring dimension of selected science preconceptions of secondary school students in 2003 differs from the level of the structured dimension of preconceptions in 2023.

Research Methodology

General Background

The research is based on the assumption that preconcepts are not rigid structures, not only from an ontogenetic but also from a phylogenetic perspective. Therefore, changes in the level of preconcepts in students can be expected due to changes in science education, social changes and the development of digital technologies. A large number of these changes have occurred over the last 20 years; hence the research is also aimed at finding out the level of preconcepts in the specified dimensions in the years under study, 2003 and 2023.

Sample

The research was conducted in 2003 and repeated again 20 years later in 2023. In both cases, the research sample consisted of students in year 7 of secondary school (aged 12 to 13) – i.e. students who had not yet started chemistry education but had already completed education in primary science, and partly in science and physics. Traditionally, chemistry education in the Czech education system begins in the 8th grade of secondary school. As this was research on preconceptions for concepts which, by their nature, fall within science education and the emphasis is also placed on them in chemistry, the students could not have a chemistry-targeted school education. The research was carried out on students in four randomly selected secondary schools in the Ústí nad Labem Region in the Czech Republic. It is a structurally disadvantaged region with a high unemployment rate (5.9%), a low level of education in the population (only 11.2% with a university degree) and a low level of qualification of science teachers (the proportion of unqualified teachers was 28%). The region has a total of 315 primary schools with 79 657 students, of which 49.8% in secondary classes. Schools were selected by lot for the survey in 2003, and were approached again in 2023 and agreed to participate in the survey. Schools selected for the research

https://doi.org/10.33225/jbse/24.23.1164

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

were secondary schools (with Framework Educational Programme for Basic Education) that are not specialised in science education. The research was conducted in both 2003 and 2023 in the same four secondary schools. In 2003, the research sample consisted of a total of 103 students in year 7 of secondary school, and in 2023 of 104 students in the same year.

Selection of Preconceptions for Research and Criteria for their Selection

The selection of the preconceptions on which research was conducted in 2003 and 2023 was not random but was guided by certain criteria in order to respect the intrinsic diversity and variety of preconceptions as much as possible. However, the specific demands of the envisaged research had to be taken into account.

The following criteria were used to select the individual concepts to be researched for their preconceptions:

1. The selected concepts should be from the field of science education on which our research is focused. Moreover, we believe that concepts from this area allow us to reflect a wide range of influences involved in the formation of the preconceptions of these concepts.
2. The selected concepts should be the subject of teaching in the curriculum of science subjects in secondary school in the Czech Republic.
3. The selected concepts should be universally known. Since we are also interested in the early stages of the development of preconceptions, it is necessary for students to have encountered the selected concepts before these concepts are included in the content of chemistry education.
4. The selected concepts should respect the principle of diversity and variety. It can be assumed that the preconception of a concept denoting a real three-dimensional object or substance will be formed differently from the preconception of a concept denoting a property, process, state, etc.
5. The selected concepts should allow for a quantifiable characterisation. They must therefore be concepts that allow the use of all descriptive categories, be clearly specified, and be definable in an exact way even at the secondary school level. We have therefore chosen concrete concepts with a clearly definable content and scope for the research, rather than abstract concepts. For the purpose of the research on science concepts, ten concepts were selected. They represent:
   (a) specific objects or substances (acid, plastic, lime, air),
   (b) characteristics of substances (energy, density),
   (c) processes (combustion, radioactivity),
   (d) 'socially accented concepts' (drug, poison).

In the final selection of terms, they also included the 'socially accented terms' drug and poison. These are related to science education, but they also touch on civic and environmental education. It is expected to see very different affective attitudes among students and to observe their development; this is significant both from a societal point of view and from the point of view of students' basic attitudes to life.

Instruments

The cognitive dimension

When a preconception is told about, it is important to note that its cognitive level is usually not only the result of targeted instruction with objective feedback and objective verification, but rather the result of 'self-learning', or the random, spontaneous intake of information verified by the student only subjectively at the level of the preconception's involvement in the preexisting structures of the cognitive map (Kalhous & Obst, 2002). This subjective verification is also determined by how the learner uses the concept, in what contexts, and in what situations. An apparent discrepancy between the use of a concept and objective reality may (or may not) trigger a learner's correction in the cognitive dimension of the preconception of the concept. Thus, the cognitive level of a preconception is usually not verified by confronting it with objective theoretical or empirical data, but only with the student's own perspective and the level of their own knowledge and understanding so far. The consequence of this is that the cognitive dimension of the preconception may also contain explicitly erroneous and mistaken information that does not correspond to objective reality or the current state of scientific knowledge (here called misconceptions, cf. e.g. Doulík & Škoda, 2008), which would otherwise be eliminated in the case of targeted teaching with feedback. The research instrument must therefore be able to capture these misconceptions as well.

In developing a suitable instrument for research on the cognitive dimension of preconceptions, which is referred to here as the 'cognitive test', the test is based on the following criteria:

https://doi.org/10.33225/jbse/24.23.1164

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

a) the time-saving nature of the test,
b) the simplicity and comprehensibility of the text (also for students in lower grades),
c) the possibility of objective evaluation of the data obtained,
d) the ability to measure the level of misconception, and
e) the unambiguity of the solution or evaluation.

Due to time constraints, the preconception of each concept is measured by only one item of the cognitive test. From a theoretical point of view, it would be advisable to design a cognitive test with open-ended test items, as they better allow capturing the student's own idea of the concept. However, for practical reasons, with some exceptions (drug), it was chosen a cognitive test with closed-ended items.

The items of the cognitive test were designed as preconception elicitation items for each concept of the application task. For mathematical reasons, their scores were converted to a standard interval, which was conventionally defined as <-2;2> (see more in Doulik, 2005). This interval was chosen uniformly for expressing the results of the cognitive dimension and the affective dimension levels. The uniform interval of these mentioned descriptive categories was chosen because of the possibility to compare the level of each preconception. As an example, there is presented the item of the cognitive test for the preconception of 'density': The students are presented with 10 equal-sized cubes made of different materials known to them (wood, cork, water, iron, petrol, air, honey, aluminium, stone, sand). The students' task is to mark the lightest cube by writing the number '1', etc. up to the heaviest cube by writing the number '10'. (In the original, the task is visualised by drawing ten identical cubes, which are clearly marked with the material they are made of.) The task also has an 'I don't know, can't answer' box, which students select when they cannot even partially solve the task, thus expressing their 'zero' level of the preconception (this option is present for all preconceptions examined so that respondents do not try to guess the correct answer).

The affective dimension

The affective dimension of a preconception characterises the attitude that an individual holds towards a given phenomenon. It is considered that his attitude can be expressed both at the level of the relationship, i.e. the learner's emotional reaction to the concept, and at the level of the meaning (in terms of importance) that the learner attributes to the concept. In this paper, it is investigated this dimension using a tool based on the principles of the scaling method. Respondents first express their attitude towards the concept on five scales: bad-good, fear-trust, dislike-like, unfavoured-favourite, dangerous-safe, each scale is a 5-point ranging from negative emotion (item 1) to positive emotion (item 5). Students then characterise the meaning they attach to the concept, again on five scales: harmful-useful, unknown-familiar, meaningless-meaningful, useless-necessary, outdated-modern, with each scale again having five points. All scales include the symbol 'N', which can be chosen if the student cannot or does not want to comment on the item. If the student selected the symbol 'N' as their answer, this statement was not included in the overall statistical evaluation.

In the actual evaluation and processing of the data obtained, the data from the scales used in the research instruments, which are within the interval <1;5>, are transformed again into standard scales within the interval <-2;2> allowing further mathematical operations on the data obtained from the survey of each descriptive category.

The structure

The aim of this descriptive category of preconception is to capture the links of the preconception under investigation with other preconceptions or concepts that are included in the student's individual cognitive map. For the purpose of this research, an instrument consisting of six so-called 'structuring schemes' was created for each phenomenon under study. Of these, five represent differently organised models of cognitive maps, while the sixth scheme is the 'null' scheme, which students choose if they have not heard anything about the concept and thus have not yet formed their individual preconception. In creating the structuring schemes, it was proceeded from the assumption, verified by the results of the conducted preliminary research, that in the course of preconception genesis, the preconception is first included in the structure of affective and primarily cognitive ('non-scientific') terms, and only later does the preconception form a greater degree of association with primarily cognitive ones, and still later increasingly with secondary cognitive ('scientific') terms, with complementarily weaker links to terms from the affective dimension. By affective terms, we mean those that describe the relationship of an individual to a preconception or the meaning they attribute to it (e.g. in relation to the preconception of acid; these are caution, danger, or pain). Primarily cognitive ('non-scientific') terms are those that relate to an individual's knowledge of a given preconception, but are acquired mostly outside of school, by the family, and are in a sort of 'lay' sense (in the case of acid, e.g., lemon, vinegar, soda). Finally, the secondary cognitive ('scientific') terms are mostly the

https://doi.org/10.33225/jbse/24.23.1164

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

content of targeted schooling in a given subject and grade (for the aforementioned acid, we chose e.g. neutralisation, hydroxide, salt).

This trend is also captured in the offered structuring schemes from which students choose. It should also be taken into account that as the representation of concepts from the cognitive dimension increases, the cognitive map produces qualitatively higher, more organised structures. The proposed structuring schemes take this into account and progress from a more primitive radial structure to a higher hierarchical structure with the definition of superordinate, coordinate and subordinate terms. The developed structuring schemes always contain, in addition to the identified preconception, seven terms with which the preconception is related in some way depending on the degree of organisation of the scheme. The same number of terms in each structuring scheme was deliberately chosen to guide probands in selecting which scheme to use by increasing the degree of its organisation, which could be highly biased and confusing for students if different numbers of terms were used. The individual concepts in the structuring schemes for each of the preconceptions were generated according to this uniform key.

The described research tool was created by the authors of the paper and, in the first phase, was optimized on a sample of 50 respondents aged 13 years. Based on this, the tool was optimized, and its final form was created. The validity of the part of the research instrument that determines the level of the cognitive dimension was verified by analysing the educational content (content validity). The reliability of this part of the research instrument, expressed by Cronbach's alpha value, is equal to .693. This means that the reliability can be considered acceptable. In the remaining parts of the research instrument (affective dimensions, structuration), concurrent validity based on expert judgment of the instrument was used. The expert assessment was carried out by a team consisting of an educator, a psychologist, a chemistry didactician and a chemistry teacher. The reliability of the part of the research instrument measuring the level of the affective dimension expressed by Cronbach's alpha was .733, and for structuring, this value was .795. Thus, these values can be considered satisfactory. The external validity of the whole research is limited by the sample selection, which was not random, and also by its limited scope. In contrast, internal validity was maintained and allowed for unambiguous interpretation of the results.

The questionnaire survey was conducted in accordance with the ethical principles of the research organisation (J. E. Purkyne Univesity in Usti nad Labem) and after the informed consent of the legal representatives. Full versions of research tools in original form (Czech language) are available at authors.

Data Analysis

The research instruments for detecting the level of cognitive and affective dimensions of the preconceptions provide data at the level of interval measurement in the standardised range <-2;2>. For the semi-longitudinal comparison of these data, the Fisher-Snedecor *F*-test was first used to test for the skewness of the data, followed by the appropriate type of *t*-test (for matched or unmatched variances). Both of these analyses were performed at a significance level of $\alpha = .05$.

The data for detecting the level of dimensionality of structuring are at the ordinal measurement level. For semi-longitudinal comparisons of these data, the non-parametric Mann-Whitney *U*-test was used, again at the $\alpha = .05$ significance level.

For this statistical analysis of the data, the null hypotheses of no difference between the levels of each descriptive category of preconception in the years of interest were set:

$H_0$1: The level of the cognitive dimension of preconceptions in 2003 is the same as the level of the cognitive dimension of preconceptions in 2023.

$H_0$2: The level of the affective dimension of preconceptions in 2003 is the same as the level of the affective dimension of preconceptions in 2023.

$H_0$3: The level of the structured dimension of preconceptions in 2003 is the same as the level of the preconception structuring dimension in 2023.

For all statistical analyses performed, a level of substantive significance (Cohen's d) was calculated in addition to the level of statistical significance (*p*). The subsequent interpretation of the results is then based on these values.

https://doi.org/10.33225/jbse/24.23.1164

Journal of Baltic Science Education, Vol. 23, No. 6, 2024
ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Research Results

The tables capture the basic statistical data for each dimension of the preconcepts, which were essential for establishing their level, including statistical and substantive significance.

The following values are given in the tables: *M* (2003) - arithmetic mean of the results from 2003, *M* (2023) - arithmetic mean of the results from 2023, *t* of the test criterion, *p* - observed significance level, *d*Cohen - Cohen's d (effect size), *Mdn* (2003) - median of the results from 2003, *Mdn* (2023) - median of the results from 2023, *U*-test criterion of the Mann-Whitney test.

In the cognitive dimension, there was a statistically significant difference (increase in level) given by the p-value for the following terms: energy, burning, density, poison, plastic, radioactivity and air. The largest shift at all occurred for the concept of radioactivity ($p < .001$). In terms of effect size, the highest effect size was achieved for radioactivity, and medium effect sizes for energy and poison. For the other terms, the effect size was small or none.

Table 1
Changes of Cognitive Dimension

Preconcept	*M* (2003)	*M* (2023)	*t*	*p*	d_{Cohen}	Effect
Drug	1.23	1.34	-1.483	.139	0.214	small
Energy	0.783	1.179	-4.826	< .001	0.674	intermediate
Burning	0.569	0.727	-2.065	.040	0.285	small
Density	0.579	0.801	-2.941	.004	0.408	small
Poison	0.809	1.109	-4.474	< .001	0.622	intermediate
Acid	0.781	0.802	-0.377	.707	0.052	no effect
Plastic	0.779	0.920	-2.469	.014	0.345	small
Radioactivity	0.796	1.238	-6.092	< .001	0.848	large
Lime	0.752	0.870	-0.118	.344	0.132	no effect
Air	0.897	1.061	-3.024	.003	0.419	small

In the affective dimension, there was a statistically significant difference (increase in level) given by the p-value for the following concepts: drug, energy, burning, density, poison and acid. The largest shift at all occurred for the concept burning ($p < .001$). In terms of effect size, the highest effect size was achieved for burning and density. For the other terms, this effect size was small or none. In the case of the concept of lime, it was the only concept that showed a decrease in the level of the affective dimension, but this decrease was not statistically significant and showed only a small size effect.

Table 2
Changes of Affective Dimension

Preconcept	*M* (2003)	*M* (2023)	*t*	*p*	d_{Cohen}	Effect
Drug	-0.973	-0.674	-3.016	.003	0.420	small
Energy	1.000	1.211	-2.473	.014	0.351	small
Burning	-0.093	0.398	-4.615	< .001	0.641	intermediate
Density	0.323	0.649	-3.662	.003	0.553	intermediate
Poison	-0.955	-0.615	-3.157	.002	0.438	small
Acid	-0.112	0.139	-2.553	.011	0.356	small
Plastic	0.501	0.592	-1.723	.086	0.114	no effect
Radioactivity	-0.483	-0.372	-1.053	.292	0.146	no effect
Lime	0.616	0.462	1.629	.105	0.227	small
Air	1.262	1.346	-0.906	.366	0.126	no effect

https://doi.org/10.33225/jbse/24.23.1164

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

In the affective dimension, there was a statistically significant difference (increase in level) given by the p-value for the following concepts: drug, energy, burning, density, poison and acid. The largest shift at all occurred for the concept burning ($p < .001$). In terms of effect size, the highest effect size was achieved for burning and density. For the other terms, this effect size was small or none. In the case of the concept of lime, it was the only concept that showed a decrease in the level of the affective dimension, but this decrease was not statistically significant and showed only a small size effect.

As for the structuring dimension, there was a statistically significant difference (increase in level) given by the p-value for the following concepts: drug, energy, burning, density, radioactivity, lime and air. The largest shift at all occurred for the concept of air ($p < .001$). In terms of effect size, the highest effect size was achieved for air and energy. Medium effect sizes were for drug, burning, density and radioactivity. For the other terms, the size effect was small or non-existent.

Table 3
Changes of Dimension Structuring

Preconcept	*Mdn* (2003)	*Mdn* (2023)	*U*	*p*	d_{Cohen}	Effect
Drug	2.0	3.0	7136.0	< .001	0.599	intermediate
Energy	2.0	4.0	7725.0	< .001	0.827	large
Burning	2.0	3.0	7365.5	< .001	0.685	intermediate
Density	3.0	4.0	7008.5	< .001	0.553	intermediate
Poison	4.0	4.0	5543.5	.556	0.061	no effect
Acid	3.0	3.0	6101.5	.078	0.242	small
Plastic	2.0	2.0	5712.5	.397	0.115	no effect
Radioactivity	3.0	3.0	6924.0	< .001	0.523	intermediate
Lime	3.0	4.0	6228.0	.033	0.284	small
Air	2.0	3.0	8437.0	< .001	1.145	large

Discussion

The Cognitive Dimension

In terms of substantive and statistical significance, there was no change in the level of the cognitive dimension for the preconceptions of lime and acid. As for the concept of lime, this is typically a school concept. Although lime is widely used in practical life, it is currently in the form of pre-made and commercially sold mixtures. Their composition may not be obvious, and they usually do not even contain the term lime in their name. Another term without significant change is acid. This is a traditional term, both a school term and a term used in everyday life (acid rain, vitamins, digestion). This preconception is therefore formed on the basis of individual experiences in which students encounter acid, for example, in the family or in lower education. Therefore, no significant changes can be expected in the last 20 years (Liu & Lesnak, 2006).

Little substantive significance is shown by the results for the preconceptions of drug, combustion, density, plastic, and air. The level of the cognitive dimension of the preconceptions of combustion, density, plastic, and air is statistically significantly higher for the 2023 group of respondents. In the case of drug, no statistically significant difference is confirmed, and even the substantive significance reaches borderline values. All of these preconceptions are from a domain characteristic of students' everyday lives and are accessible to their individual experiences, even in the case of density, where the task was empirical in nature and did not require school knowledge (cf. e.g. Costa & Machado, 2014). Minimal changes in the level of the preconceptions of combustion, density, and air are expected, as the use of these concepts has not undergone significant changes in the last 20 years. In contrast, larger differences were expected for the preconceptions of drug and plastic; when compared to 2003, these concepts are now much more emphasised from a societal perspective, including an ecological perspective for plastic and an addiction perspective for drug (Britchi, 2022; Nicholson et al. 2013). It seems interesting that the change in

https://doi.org/10.33225/jbse/24.23.1164

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

the level of cognitive dimension for these two preconceptions reaches very little substantive significance. All the preconceptions in this group are already part of education at the primary level and are thus emphasised before the actual teaching of chemistry.

The next group is preconceptions that show a moderate increase in the level of the cognitive dimension between 2003 and 2023. These are the preconceptions of energy and poison. These concepts are now far more the subject of intense social and political debate than they were 20 years ago. In the case of energy, this is the use of renewable energy sources, emission-free production, green deal, etc., whereas in the case of poison, it is the pollution of the environment with toxic substances. Thus, the awareness built by students' individual experiences of these concepts increases significantly as these social discussions are reflected in school education in different areas (Delegkos & Koliopoulos, 2020).

The largest increase in the level of the cognitive dimension was observed for the preconception of radioactivity. Here the difference in the results of the 2003 and 2023 respondents is at the highest level of substantive significance. As with energy, radioactivity is a concept that is currently being discussed in different contexts (Morales López & Tuzón Marco, 2022). Examples include emission-free energy sources, the construction of new nuclear power plant units, and the quest for independence from fossil fuels. In the context of the Russian-Ukrainian conflict, the misuse of nuclear weapons based on the principles of radioactivity is also discussed more.

The changes in the level of the cognitive dimension of all the preconceptions examined are very similar, there is no decrease in any of them between 2003 and 2023; on the contrary, in terms of arithmetic averages, an increase can be observed everywhere, but in some cases, it is not statistically significant. This can also be explained by the increasing emphasis on the development of science literacy in Czech education in recent years.

The Affective Dimension

In developing the research instruments for the study conducted in 2003, it was found meaningful to think about the affective dimension on two levels, namely the relational and the semantic levels (Doulík & Škoda, 2003). The relational level is formed on the basis of an individual's spontaneous (and usually extracurricular) reaction, thereby forming a certain relationship to the concept. The meaning level tends to be the result of an intentional learning process. Since both levels interact, in this comparative study we work with the affective dimension as a whole.

The only concept that shows a decline in the level of the affective dimension after 20 years is the concept of lime. In this case, it is a fairly neutral affective concept. In both examined years, the level of the affective dimension reaches positive values. The decline expressed by the small substantive significance is due to the fact that the students' awareness of lime as a building material is generally decreasing. This is also evident at the level of the cognitive dimension, as discussed above.

The largest positive change in the level of the affective dimension was observed for the concepts of combustion and density. We believe that the reason for this increase is the relatively high attention given to these essentially abstract concepts in constructivist and inquiry-based teaching approaches, already at the level of primary science education (Costa & Machado, 2014; Van Uum et al., 2016). And it is these approaches that have been strongly emphasised in Czech education in recent years. It is thus evident that they not only lead to the development of knowledge (i.e. the cognitive dimension), but the affective dimension is influenced as well.

In contrast, no substantive significance was observed for the preconceptions of air, radioactivity, and plastic. In the case of air and radioactivity, this is a steady state, and no significant change is expected in these preconceptions. This is due to the fact that the importance attributed to air has been at a high level for a long time. For radioactivity, it is actually the other way around. It is a bit of a paradox that there has been no significant change in the level of the affective dimension in the case of the preconception of plastic. This is despite the fact that the current era is referred to as the plastic age and students encounter plastic issues on a daily basis, e.g. environmental contamination by microplastics, waste sorting and recycling, and the long life of plastics in nature (Raab & Bogner, 2020).

The Dimension Structuring

The greatest increase in the level of dimension structuring is seen in the preconceptions of energy and air. Both of these concepts are interdisciplinary in nature and are already part of the curriculum of primary science education at primary school (1st – 5th class). In the case of the concept of energy, its social connotations (discussion of possible alternative sources of energy) are also emphasised in school education, thus expanding the scope of the preconception (Won et al., 2017). This leads to a reflection of the broader context of these preconceptions,

https://doi.org/10.33225/jbse/24.23.1164

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

which is reflected in the qualitatively higher structure of the concept maps that are represented by the structuring schemes used in the research tool. The situation is similar in the case of the preconception of air.

No or little substantive significance was found for the change in the level of dimensionality of the structuring of the preconceptions of poison, acid, plastic, and lime. In all cases, these are concepts that are typical of chemistry education, but which have not yet been implemented in any of the groups studied. A certain exception is the preconception of poison, which shows a qualitatively high level of dimension structuring in both years studied. This is due to the fact that the concept of poison is commonly encountered by students in the extracurricular environment, and the influence of the media, for example, is evident.

In summary, students in both 2003 and 2023 were more likely to choose structuring schemes built on concrete concepts with a structure that is not very rich in the interrelationships of concepts. On the contrary, the relations are closely related only to the studied preconception.

Gilbert et al. (2011) stated that current science education faces a lack of clarity of purpose, content overload, incoherent student learning, lack of relevance to students, and lack of transfer of learning to new contexts. They conclude that only a model based on context as social circumstance leads to conceptual development, contextual understanding, and student science literacy development. The social context of learning is also an essential element of conceptual change itself. The conceptual change induced by this context is also manifested in the nature of the student's mind maps, leading to a better understanding of the context to effectively use the knowledge of concepts in life. This was also reflected in the results of the presented research, where a significant conceptual shift occurred for most concepts, which was reflected not only in the cognitive and affective dimensions, but also in the choice of schemas representing more complex and elaborate mental maps. These shifts are also documented by the gradual changes in the paradigm of science education. The original conception of isolated knowledge is being replaced by a conception of science literacy that is based on the active construction of knowledge and the applicability of acquired complex knowledge not only in schooling but also in practical life, cf. knowledge-as-theory perspectives and knowledge-as-elements perspectives (Özdemir & Clark, 2007).

Conclusions and Implications

The research study described changes in the level of preconceptions of science concepts among 12–13-year-old students in the Czech Republic over 20 years (2003–2023). The study shows that the current social changes and the change in the paradigm of science education are significantly reflected in the increase in the level of preconceptions in all three studied dimensions. The greatest changes occur in the dimension of structuring, where most of the preconceptions under study undergo a qualitative change in the structuring of their conceptual maps. This indicates that students are able to understand concepts in a broader context and not only in science, which leads to meaningful learning. This also brings the prerequisite of a more successful formation of science literacy competences.

Thus, the use of constructivist and inquiry-based elements instead of traditional transmission teaching appears as a possible pathway to a more significant development of science literacy and a more effective formation of science concepts. This is also reflected in the results of the PISA survey, where in 2022 Czech students scored an average of 498 points in science literacy, making the Czech Republic one of the countries with a statistically significantly better result than the average of OECD countries and the average of the European Union countries. Confirmation of this trend may come from PISA testing in 2025, in which science literacy will be the main testing domain.

There are no or very few changes in the affective dimension of the preconceptions studied. Thus, there is no significant change in students' attitude towards science concepts or in the meaning they attribute to them. This indicates that the current Czech education system focuses only marginally on the targeted formation of the attitudinal and value component of the learning individual. It would therefore be advisable for teachers to focus more on setting and fulfilling affective educational goals. Social constructivist approaches to education which, in contrast to research-oriented teaching (based on individual constructivism) also develop social competence within cultural discourse, could help to achieve this.

The results of the study of changes in the level of preconcepts of selected science concepts show how significantly current social issues and changes in the concept of science education at basic school reflect in their structure. Specifically, the following factors are involved in the change of preconcepts:

- The development of information technology and artificial intelligence makes it easier for pupils to access information and thus enriches their knowledge base.
- Emphasis is placed on developing scientific literacy competences instead of mere rote learning.

https://doi.org/10.33225/jbse/24.23.1164

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

- A move towards application and practical use of knowledge instead of interpretation of facts for understanding.
- The application of a didactic reconstruction approach that considers preconcepts as central tools and works with them in a significant way. This trend reinforces the importance of diagnosis and research in the field of preconcepts.
- Socially accentuated themes such as the emphasis on sustainable development, the use of alternative energy sources, environmental protection and building environmental literacy are reflected in the form of preconcepts.

As a result, the importance of science education in the primary school curriculum is increased and elements of innovative educational practices, such as inquiry-based learning, are applied. This is also reflected in the innovative nature of textbooks and other teaching materials.

The results presented should be viewed through the prism of the limitations of a quantitatively oriented research study:

- The relatively small number of respondents, which is due to the considerable time required to process the complete battery of research instruments for all the preconceptions examined.
- The influence of intervening variables that cannot be effectively eliminated (influence of teachers, curricular changes, methodological materials, modern didactic means).
- The availability of the research population, where the students were from one region of the Czech Republic, which is related, among other things, to the willingness of schools to engage in pedagogical research.
- The quantitative design of the research study, which allows for statistical comparison of the groups studied but does not provide detailed information about the nature of the preconceptions studied. Here, it would seem appropriate to use a mixed research design and supplement the research with an additional study based on qualitative research methods (interviews, drawing analysis, etc.).

It has been shown that monitoring the level of preconceptions as the individual characteristics of students is a suitable strategy for monitoring the progress of science education. This can broaden the spectrum of insight into the level of science education provided by, for example, didactic testing in the context of the PISA project.

Declaration of Interest

The authors declare no competing interest.

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Received: *September 04, 2024* Revised: *November 08, 2024* Accepted: *December 04, 2024*

Cite as: Doulik, P., Škoda, J., Bilek, M., & Procházková, Z. (2024). The changes of secondary school students' conceptions of science concepts. *Journal of Baltic Science Education*, *23*(6), 1164–1177. https://doi.org/10.33225/jbse/24.23.1164

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