Age-Dependent Conceptual Structure in Primary School Science Textbook Definitions *

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Abstract

This paper examines variation in textbook definitions of scientific concepts in Croatian primary education from a terminological perspective. A qualitative comparative analysis was conducted on definitions and definitional explanations of six core science concepts extracted from textbooks for Grades 3–8. The results show that intensional definitions are relatively infrequent and that definitional strategies exhibit conceptual enrichment, progressing from context-dependent and functional explanations toward more abstract formulations. These findings highlight the need for adaptive, learner-oriented digital terminological resources that support the gradual acquisition of scientific knowledge.

Keywords

concepts, concept characteristics, definitions, education, terminology, textbooks

1. Introduction

Already in the first grades of primary education, children encounter abstract and complex concepts, many of which cannot be well captured by conventionally formulated definitions. Developmental research has long suggested that children's reasoning abilities undergo significant changes during middle childhood. In Piagetian theory, the transition to the stage of concrete operations (approximately between 7 and 12 years of age) is associated with the emergence of logical reasoning tied to concrete objects and situations, whereas abstract, propositional reasoning becomes more stable only later [1]. Consequently, younger learners may struggle with understanding abstract concepts like *energy*, *community*, or *climate*. Although the strict age boundaries and stage-like nature of this model have been challenged, its central insight — that children's ability to process abstraction is constrained by cognitive development and contextual support — remains influential in educational research.

Contemporary studies have further shown that children's ability to engage with scientific and abstract concepts is closely linked to the form in which these concepts are presented, including sentence structure, vocabulary choice, and the degree of contextual support provided [2, 3]. Moreover, differences in children's linguistic expression should not be treated the same as differences in conceptual understanding, as children may demonstrate conceptual competence through less formal or less structured language that does not align with adult categorical models [4]. Research on concept acquisition further suggests that abstract concepts are acquired gradually and are initially grounded in emotionally relevant experiences and situations, particularly in early school years, age 6 to 9 [5]. This contextual dependency is especially pronounced for abstract concepts, which tend to elicit thematic and situational information rather than stable object properties [5].

These findings have already had direct impact on the design of contemporary educational resources for children, notably primary school textbooks, in which new content must be introduced using linguistic and conceptually appropriate strategies. In the domain of science education, where the interdisciplinarity of school curricula is particularly evident, new concepts are commonly defined

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within conceptual networks, and conceptual complexity increases systematically across grade levels, reflecting both curricular progression and learners' cognitive development [6].

However, comparatively little attention has been paid to how this curricular progression is realized at the level of textbook definitions themselves, particularly from a terminological perspective. Addressing this gap, this paper examines grade-dependent variation in textbook definitions of scientific concepts with the aim of identifying concept characteristics and relations that support gradual development of conceptual complexity. The findings will be used in future research for developing definitional patterns to be used in creating an adaptive, learner-oriented online terminological dictionary.

2. Aim and methodology

The aim of this study is to examine the conceptual structure of definitions in primary school science textbooks and to assess their suitability for presenting scientific concepts to young learners. The study is based on the hypothesis that conventionally formulated intensional terminological definitions are relatively infrequent in this educational context, as they often do not align with children's developing linguistic and reasoning abilities. This does not imply that intensional definitions cannot be apt for defining certain basic concepts, often representing concrete objects, e.g., *laboratory*: *A laboratory is a workplace in which different investigations are conducted using special equipment and devices* (Naš svijet 3). However, textbook definitional strategies are usually adapted to learners' cognitive and linguistic development, resorting to context-based explanations at earlier stages and more abstract, structured definitions introduced progressively in higher grades.

This paper analyses a small dataset of definitions and definitional explanations extracted from Croatian textbooks for the subjects *Nature and Society* (Grades 3 and 4), *Nature* (Grades 5 and 6), and *Biology* (Grades 7 and 8), with the objective of identifying salient concept characteristics and concept relations in these definitions. The focus of the analysis is limited to Croatian-language textbooks; however, the methodological framework is language-independent and can be applied to comparable educational materials in other languages. The study is intended as a preliminary step toward the development of a digitally adaptive, learner-oriented science terminology resource for primary education.

2.1. Data

In the Croatian education system, primary education comprises eight grades and typically covers learners aged 7 to 14. As a result, Grades 7 and 8 in Croatia, although comparable in content to lower secondary education elsewhere in Europe, are formally part of primary education and are therefore included in the present analysis. Science content is distributed across several school subjects (see Table 1). In the first four grades (ages 7–10), the curriculum is covered by the subject *Nature and Society*, which integrates topics related to living beings, living conditions, ecosystems, energy, and the human body with basic scientific, geographical, and historical content. In Grades 5 and 6 (ages 11–12), the curriculum is divided into separate subjects: *Nature*, *History*, and *Geography*. In Grades 7 and 8 (ages 13–14), *Nature* is replaced by *Biology*, while *Chemistry* and *Physics* are introduced as additional STEM subjects. A similar subject-based organization continues in secondary education, although the latter falls outside the scope of this study.

The definitions analysed in this study form part of a larger dataset currently being developed for the purpose of creating an online, learner-oriented dictionary of scientific concepts. The dataset contains key terms extracted from each textbook together with their definitions and/or explanatory statements. Each term represents an entry that is annotated for the presence of a superordinate concept (where stated), salient concept characteristics, and concept relations expressed in the text.

Table 1
Structure of the analysed dataset

Grade	Age	Subject(s)	Scientific content
3	8–9	Nature and Society	Integrated science (basic biology, environment, energy, human body); basic geography (spatial orientation and local environment); basic historical concepts (timeline and sequencing of events, family)
4	9–10	Nature and Society	Integrated science (ecosystems, living conditions, materials, energy and basic processes, human body); geography (regions of Croatia, the climate; economy); history (local and national history)
5	10–11	Nature	Introductory natural sciences (living beings, environment, matter)
6	11–12	Nature	Expanded natural sciences (ecosystems, energy, human biology)
7	12–13	Biology (+ Chemistry, Physics)	Biological systems, human body, ecological relations
8	13–14	Biology (+ Chemistry, Physics)	Advanced biological concepts and systems

All textbooks included in the analysis are officially approved and widely used in Croatian primary education. The current dataset, on which this study is based, comprises 618 entries with definitions and/or explanations extracted from textbooks published by *Školska knjiga* and *Alfa*. As *Školska knjiga* publishes two different textbook series for the subject *Nature and Society* (Grades 1–4), both series have been included in the dataset. The full dataset will ultimately include textbook material from all approved publishers, including *Profil Klett*.

From each textbook, definitions of concepts highlighted in bold font were manually extracted. If no explicit definition was provided, the sentence in which the concept was explained was selected for analysis; such instances were labeled as explanations in the dataset. As graphical presentation varies across textbooks, some textbooks contained relatively few concepts highlighted in bold. In those cases, definitions or explanations of concepts introduced within individual textbook sections were extracted for analysis.

As previously mentioned, the current dataset comprises 618 entries with definitions and/or explanations. From this dataset, a smaller analytical subset was selected for detailed examination, consisting of definitions and explanations for six representative concepts that recur across multiple grade levels. The concepts selected for analysis in this paper represent different conceptual types — namely substance, process, and system — thus allowing for a comparative examination of age-dependent definitional strategies:

- energija ‘energy’
- voda ‘water’
- organizam ‘organism’
- hranidbeni lanac ‘food chain’

- razlagači ‘decomposers’
- životna zajednica ‘life community’.

These concepts were chosen because they (a) appear in at least three different grade levels and (b) allow for the observation of age-dependent variation in conceptualization, abstraction, and linguistic realization. For each concept, all explicit definitions and definitional explanations occurring in the selected textbooks were extracted. The resulting analytical subset consists of 45 definitions and 21 explanations presented in 59 entries. Croatian original formulations have been retained, while English translations of all examples were prepared by authors for analytical and presentation purposes.[1]

2.2. Annotation and analysis method

The analysis adopts a comparative qualitative methodology grounded in terminology research. Definitions of the same concept were compared vertically across grade levels in order to identify systematic differences related to learners’ cognitive development and curricular progression. Rather than evaluating definitional correctness, the analysis focuses on how concepts are presented to different age groups. Particular attention is paid to changes in: concept characteristics foregrounded in the definition, the degree of abstraction, as well as explicitness of relations to other concepts. The study proceeds from the assumption that conventionally formulated intensional terminological definitions [7, 8] are relatively infrequent in primary school science textbooks. Instead, it is assumed that definitions and explanatory structures are constructed in ways that support the contextualization of newly introduced concepts and facilitate conceptual understanding at different educational stages.

To ensure consistency and comparability, an annotation scheme was developed and applied to all extracted definitions and explanations. The annotation focused on the following analytical categories: (a) the presence of a superordinate concept, where explicitly stated; (b) concept characteristics mentioned; and (c) concept relations linking the defined concept to related concepts. All data were independently annotated by two annotators, who subsequently compared their results and reached a joint decision for each example. In cases where no explicit definition was available for a given concept, the corresponding explanation was annotated instead. Although inter-annotator agreement was not formally measured using a statistical coefficient, simple descriptive counts are reported in the Results section to provide transparency regarding the degree of convergence between annotators. These counts are not intended as a quantitative measure of reliability, but rather as an exploratory indication of how consistently particular analytical categories could be identified in the dataset. A formal agreement measure was not considered appropriate at this stage, given the relatively small sample size, the exploratory nature of the study, and the use of open annotation categories that allow for multiple valid interpretations. The primary purpose of the annotation was therefore not to establish statistical reliability, but to test the applicability and sensitivity of the annotation scheme for capturing definitional variation. After the annotation had been completed, the annotators compared their results and reached a joint decision for each example, and these final annotations are presented in the published version of the subset.

3. Results and discussion

The annotation results indicate that the definitions and explanations of the six selected concepts exhibit conceptual and structural development across grade levels. As previously stated, 59 definitional entries include both explicit definitions and explanations. In 23 out of 59 entries, both annotators identified the same superordinate concept. There were no explicitly signalled superordinate concepts in the remaining 36 entries. This high level of agreement is expected, as the superordinate concept, or *genus proximum*, is relatively easy to identify when explicitly stated in a

[1] The subset is available in the spreadsheet format here: https://sef.jezik.hr/?page_id=150.

definition. Alignment between annotators was somewhat lower with regard to the identification of concept characteristics: in 48 out of 59 cases, both annotators selected the same salient characteristics. This lower level of convergence can largely be attributed to the fact that the set of characteristics was not predefined or closed, and that individual definitions often encode more than one characteristic. In several cases, differences arose from the interpretation of a characteristic as referring either to *purpose* or to *function*, with both labels being applicable. Based on these observations, a more constrained and systematically defined set of concept characteristics will be developed for future annotation, in order to improve consistency and facilitate comparability across annotators.

With respect to the identification of concept relations expressed in definitions and explanations, alignment was reached in 44 out of 59 cases. As with characteristics, discrepancies were primarily due to differences in determining which relation was most salient when more than one relation could be identified. For example, a single definition may simultaneously encode a generic relation between the defined concept and its superordinate concept, as well as an associative relation referring to its function, as illustrated by the Grade 3 definition of *razlagači*: *Organisms that decompose dead organisms are called decomposers* (Eureka 3).

Next, we describe those concepts whose definitions show the most pronounced changes in conceptual depth and level of abstraction across grade levels.

3.1. Core science concepts: *energy*, *water*, *organism*

The first group comprises *energy*, *water*, and *organism*, which are core scientific concepts not only in the sense that they play a central role in multiple scientific disciplines, but also because they are introduced very early in primary education. *Energy* (hr. *energija*) is part of the curriculum as early as the second grade. It is the most abstract of all the concepts analysed and also the most difficult to capture by means of a conventionally formulated definition.

Of the six textbooks examined for Grades 3 and 4, only one provides a relatively standard definition of energy: *This is why we say that energy is the ability of a certain body or matter to perform work* (Alfa 5). Very similar definitions appear in some, but not all, textbooks for Grades 5 and 6, for example: *Energy is the ability of a certain body or matter to perform work* (Alfa 5); *Energy is the ability of a body to perform work* (ŠK 6). In all other textbooks, no explicit definition of the concept is provided. Instead, energy is introduced through explanatory statements focusing on its purpose and function in everyday life, its sources, and different types of energy, as illustrated in the following example: *All living beings need energy in order to live. We obtain it from nutrients. In humans and animals, these are produced by the breakdown of food taken into the body. In everyday life, energy is used to operate many devices, to prepare food, to heat rooms, to power vehicles, etc.* (Eureka 3). In comparison, there is a definition of *organism* in 9 out of the 14 textbooks analysed.

Both annotators agreed that the explanations provided in Grades 3 and 4 primarily describe the concept of energy through its source, origin, and application. In the Grade 4 explanation found in Eureka 4, neither annotator was able to identify a salient delimiting characteristic, as the explanation focuses on a general principle rather than on defining characteristics: *Energy cannot be created or destroyed in nature; it only changes its form. For example, the Sun's light energy is converted into electrical energy in special devices. Electrical energy in a light bulb is transformed into light and thermal energy* (Eureka 4).

In this case, the annotators may have focused on the mention of light energy and electrical energy as types of energy, although the aim of the annotation was to identify the most salient characteristic of the concept defined or explained in the entry. The only point of disagreement concerned the interpretation of another Grade 4 definition: *This is why we say that energy is the ability of a certain body or matter to perform work* (Alfa 4). One annotator classified the highlighted characteristic as referring to *purpose*, while the other interpreted it as referring to *function*. This discrepancy can be attributed to the fact that no predefined or closed set of concept characteristics had been established prior to the annotation process.

The concept of water is the only one in the annotation grid for which there was full agreement between the two annotators across all analytical categories. *Water* (hr. *voda*) is a concrete concept with a definition that is both common and widely accepted. In four out of six textbooks for Grades 3 and 4, a variant of the prototypical definition appears: *Water is a liquid without colour, taste, or smell.* All six textbooks refer to the states of water, either within the definition itself or in accompanying explanations, as illustrated by the following Grade 3 example: *In nature, water occurs in all three states: as a liquid (liquid state), as ice (solid state), and as water vapour (gaseous state)* (Eureka 3).

Water is defined using either *matter* or *liquid* as the superordinate concept, with state identified as the salient characteristic. Other prominent characteristics include purpose and application. In textbooks for higher grades, the definitions reflect the required conceptual enrichment, as additional characteristics are progressively introduced. In Grade 5, students learn that *Water is a good solvent for gases and mineral substances* (ŠK 5), and the previously used term *stanje* 'state' is replaced by the more precise *agregatno stanje* 'state of matter'. The Grade 7 explanation further expands the concept by contextualizing it within human physiological processes: *Water has no energy value, but it is essential for the course of chemical processes in cells; it participates in the regulation of body temperature, forms the liquid component of blood and cytoplasm, and serves as a medium in which harmful substances dissolve and are excreted through sweating and urination, etc.* (ŠK 7).

Organism (hr. *organizam*) denotes another concrete concept, referring to a biological unit or an individual living being. In eight out of nine definitions collected, the concept is defined using the superordinate concept *cjelina* 'whole', whereas in the Grade 7 definition it is defined as *jedinka* 'single individual'. Furthermore, the organism as a unit is described using a range of modifiers that emphasize internal coherence, including *usklađena cjelina* 'coordinated whole' (Grade 3), *jedinstvena cjelina* 'unified whole' (Grade 4), *skladna cjelina* 'harmonious whole' (Grades 4 and 7), and *nedjeljiva cjelina* 'indivisible whole' (Grade 6).

As expected, composition is the most salient conceptual characteristic across all definitions, while the remaining concepts mentioned are related to the defined concept through partitive concept relations, referring to organs, systems, or body parts.

3.2. Process- and system-based concepts: *decomposers, food chain,* and *life community*

Unlike *energy*, *water*, and *organism*, the concepts of *decomposers*, *food chain*, and *life community* are inherently relational and system-based, as they cannot be adequately described without reference to other living beings or ecological processes. Consequently, their definitions and explanations show a stronger reliance on relations, processes, and contextual embedding already in lower grades, with increasing explicitness in higher grades.

The concept of *decomposers* (hr. *razlagači*) is introduced in Grade 3 and recurs consistently in subsequent grades. In the lowest grades, it is defined through a simple functional relation to other organisms, most commonly by means of a relative clause: *Organisms that decompose dead organisms are called decomposers* (Eureka 3). This type of definition relies on function as the salient characteristic and uses the superordinate concept *organisms*, without specifying subclasses or mechanisms. In Grade 4, the concept is conceptually enriched by the introduction of typical representatives, such as *fungi* and *microorganisms*, and by an implicit reference to reuse of matter by plants. From Grade 6 onwards, explanations shift towards a more scientific and process-oriented perspective, explicitly mentioning biochemical outcomes (carbon dioxide, water, mineral substances) and the role of decomposers within ecological systems. The Grade 7 definition further extends the concept by linking decomposers to the cycling of matter (hr. *kruženje tvari*), thereby situating the concept within a broader ecological framework. Both annotators agreed that definitions show a function-based identification of these organisms.

The concept of *food chain* (hr. *hranidbeni lanac*) exhibits a similar development, although its relational nature is emphasized from the outset. In lower grades, food chain is typically introduced through linear sequences of organisms connected by feeding relations, often accompanied by

concrete examples. In higher grades, the concept is increasingly abstracted and contextualized within ecological systems, with explicit references to producers, consumers, and decomposers, as well as to the transfer of energy and matter. While early explanations focus on observable relations, later definitions integrate causal and systemic aspects, which allows the concept to function as an explanatory tool rather than merely a descriptive sequence. There was some disagreement between annotators in the identification of concept characteristics. In one case, one annotator did not identify the location of the process, while the other classified the conceptual relation as *generic* rather than *partitive* in the following definitions: *The feeding relationships, from producers through a series of consumers all the way to decomposers, are called a food chain* (Alfa 6); *The feeding relationships, from producers through various consumers, are called a food chain* (ŠK 6).

Given that nearly identical wording appears in both definitions (in textbooks from different publishers), this way of defining the food chain appears to be common. In the discussion following the annotation procedure, the annotators agreed that the partitive relation, expressed through the listing of the members of the food chain, should be considered the more salient concept characteristic in the definition. Additionally, it is worth noting that the description of the food chain in all textbooks relies heavily on illustrations and graphical representations, which is to be expected for a process such as the food chain.

The concept of *life community* (hr. *životna zajednica*) represents the most explicitly systemic concept among those analysed. In lower grades, it is typically described as a group of living beings that live together in the same area, with emphasis on coexistence rather than interaction. In higher grades the term *living beings* is replaced with *population*. The superordinate concept is usually implicit, and the defining strategy relies on spatial and situational context. Untypically, all definitions of this concept are quite similar in all grades, placing the concept in relation to other concepts by means of partitive relations and highlighting location as a concept characteristic.

Taken together, the analysis of *decomposers*, *food chain*, and *life community* points to the conclusion that process- and system-based concepts are introduced at earlier educational stages in a relational but conceptually reduced form, and gradually acquire depth through the explicit articulation of processes, roles, and interdependencies. The observed progression in conceptual complexity across the analysed concepts reflects the multidimensional nature of conceptual systems [9, 10] and highlights the need for context-sensitive, flexible definitions [11] that support learners' cognitive development and adequately represent scientific concepts across educational levels. From this perspective, digital terminology resources based on textbook data should either provide multiple, level-specific definitions for each concept or allow for age-based adaptability of definitions. Such adaptability should encompass not only variation in conceptual content, but also adjustments in vocabulary choice and syntactic structure in order to meet the needs of learners at different stages of cognitive and linguistic development.

4. Conclusions and future work

This study presents a preliminary analysis of definitional practices in Croatian primary school textbooks for the subjects *Nature and Society*, *Nature*, and *Biology*. A comprehensive analysis of the full dataset will be conducted once additional textbooks are incorporated. Even at this stage, the annotation of the analytical subset revealed certain challenges in identifying the aspects of the defined concepts. While the annotators had no difficulty identifying the superordinate concept when it was explicitly stated in the definition, there was some lack of alignment in the annotation of delimiting concept characteristics and concept relations most prominent in definitions and definitional explanations. To address this in future annotation of the remaining data, a more constrained set of concept characteristics was developed based on these results, e.g., categories such as *origin*, *location*, *form*, *purpose*, *function*, *result*, etc.

Beyond confirming the initial hypothesis that the use of conventionally formulated intensional terminological definitions is limited, the analysis also demonstrates that definitional strategies in primary school science textbooks show a gradual shift towards conceptual complexity. Across grade

levels, the same concept is typically introduced through context-dependent explanations, functional descriptions, and everyday examples in lower grades, while formulations in higher grades increase in abstraction, introduce additional delimiting characteristics, and make concept relations more explicit.

The observed variation present in most analysed concepts provides empirical support for the view that a single definition cannot adequately represent how scientific concepts are introduced and progressively re-conceptualized in school education. These findings reinforce the need for adaptive digital resources that can offer multiple, aligned representations of the same concept depending on educational level and conceptual complexity. Such resources would help improve terminological coherence across curricular stages and support learners' gradual transition from experiential and thematic knowledge toward systematic scientific conceptual networks.

The results of this study will be used in several lines of future work. A prototype of an online, learner-oriented science dictionary will be developed, in which individual concepts can be represented by multiple definitions dynamically selected according to educational level and conceptual depth. In parallel, field-based research is already being conducted in two primary schools, where students are asked to explain selected scientific concepts in their own words. These learner-generated explanations will be analysed in relation to textbook definitions in order to assess conceptual alignment. Finally, the proposed framework is intended to support the future development of digital resources that integrate specialized knowledge into educational resources and general-language dictionaries.

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Declaration on Generative AI

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