10.24193/ed21.2023.24.01

Explicit Relational Reasoning Skills: An Index for Fostering Thinking in Biology Textbooks

Vered Alboher Agmon, Nicoleta Laura Popa

Educatia 21 Journal, (24) 2023, Art. 01
doi: 10.24193/ed21.2023.24.01
Research article

Explicit Relational Reasoning Skills: An Index for Fostering Thinking in Biology Textbooks

Vered Alboher Agmon [a*], **Nicoleta Laura Popa** [b]

[a,b] *"Alexandru Ioan Cuza" University, Toma Cozma Street, No. 3, Iasi, 700554, Romania*

*Corresponding author: *veralboher@gmail.com*

Abstract

Even in the 21st century, textbooks can play a significant role in fostering higher-order thinking skills (HOTs) for effective learning and understanding. Still, HOTs like analogies used in biology textbooks may miss their purpose in promoting in-depth understanding. Since most analogies are presented implicitly or partially explicitly, they lack an explicit mapping to explain the analogical pattern between the source and the target. This study examines the degree to which implicit and explicit expressions of four Relational Reasoning skills (RRs): Analogy, Antinomy, Anomaly, and Antithesis, appear in three biology textbooks taught in Israel's junior high school. Qualitative content analysis crosses four predetermined criteria (C1-C4): RRs' type, texts' type (T1, T2, T3), 'mapping process', and 'use-skill indication'. The quantification of the findings provided information on the RRs' distribution and prevalence. The study's findings indicate that only 14% of texts appear with explicit expressions for RRs, mainly in antinomies questions (T2). Although about 32% of the various texts in biology include instructions for learners to activate HOT by using RRs, they are presented at a partially explicit level. Moreover, less than 2% of activities (T3) explicitly enable HOT by using RRs to solve problems. This study expands the theoretical knowledge of analogies to all four RRs. Methodologically, the study presents explicit mapping processes developed for antinomies, anomalies, and antitheses. The implications of the RRs' degree of explicitness are discussed as an effective index of learners' scientific understanding

Keywords:
Biology textbooks; Relational Reasoning skills; Analogy; Antinomy; Anomaly; Antithesis; Higher-order thinking skills.

Zusammenfassung

Auch im 21. Jahrhundert können Lehrbücher eine wichtige Rolle bei der Förderung von Denkfähigkeiten höherer Ordnung (HOTs) für effektives Lernen und Verstehen spielen. Dennoch können HOTs wie Analogien, die in Biologielehrbüchern verwendet werden, ihren Zweck verfehlen, ein tiefes Verständnis zu fördern. Da die meisten Analogien implizit oder teilweise explizit präsentiert werden, fehlt ihnen eine explizite Abbildung, um das analoge Muster zwischen Quelle und Ziel zu erklären. Diese Studie untersucht, inwieweit implizite und explizite Ausdrücke von vier Fähigkeiten des relationalen Denkens (RRs): Analogie, Antinomie, Anomalie und Antithese in drei Biologielehrbüchern vorkommen, die an Israels Junior High School gelehrt werden. Die qualitative Inhaltsanalyse kreuzt vier vorgegebene Kriterien (C1-C4): RRs-Typ, Texttyp (T1, T2, T3), "Mapping-Prozess" und "Use-Skill-Indikation ". Die Quantifizierung der Befunde gab Aufschluss über die Verbreitung und Prävalenz der RRs. Die Ergebnisse der Studie zeigen, dass nur 14 % der Texte mit expliziten Ausdrücken für RRs erscheinen, hauptsächlich in Antinomiefragen (T2). Obwohl etwa 32 % der verschiedenen Texte in Biologie Anweisungen für Lernende enthalten, HOT durch die Verwendung von RRs zu aktivieren, werden sie teilweise explizit dargestellt. Darüber hinaus aktivieren weniger als 2 % der Aktivitäten (T3) explizit HOT, indem sie RRs verwenden, um Probleme zu lösen. Diese Studie erweitert das theoretische Wissen um Analogien zu allen vier RRs. Methodisch stellt die Studie explizite Kartierungsverfahren vor, die für Antinomien, Anomalien und Antithesen entwickelt wurden. Die Implikationen des Grads der Explizitheit der RRs werden als effektiver Index des naturwissenschaftlichen Verständnisses der Lernenden diskutiert

Schlüsselworte:
Lehrbücher der Biologie; Fähigkeit zum relationalen Denken; Analogie; Antinomie; Anomalie; Antithese; Denkfähigkeiten höherer Ordnung.

1. Introduction

Science textbooks are still a common learning tool for students and teaching tool for teachers. Therefore, their role in fostering High Thinking Skills (HOTs) is necessary to achieve the in-depth understanding required for science literate in the 21st century. In biology, the importance of presenting connections between abstract concepts is essential for learners' understanding, to generate new ideas and to solve problems. However, biology textbooks were found in previous research ineffective in promoting HOTs, in the aspect of lack explicitness, meaning without providing explicit explanations to the connections, i.e., for the relations between the scientific concepts presented. To effectively process scientific data, Relational Reasoning ability is crucial in identifying significant patterns of relations such as similarity and difference, contrast, inconsistencies, and anomalies which are necessary for many high-thinking situations to acquire new knowledge. Thus, it is essential to incorporate processing textual information with Relations Reasoning skills (RRs) - Analogy, Antinomy, Anomaly, and Antithesis, into curricula and school learning materials (Alexander, 2017). Still, the limited previous work conducted on textbooks analyzed focused on analogies, and indicated that analog mapping process was neither fully explicit, nor partially explicit. Since the degree of explicitness is essential to minimize misconceptions in scientific explanations, analogies may not be effective to fulfill their role for achieving scientific understanding (Orgill, 2013). Accordingly, the present study aims to examine implicit and explicit RRs expressions by determine mapping -criteria, not only for analogies, but for the all four RRs. Three biology textbooks taught in junior high school for 8th grade in Israel were analyzed. The implications of RRs explicitness on the development of HOTs for understanding in the biology textbooks will be discussed.

2. Theoretical foundation

Many previous studies have examined the development of HOTs in science textbooks (e.g., Devetak & Vogrinc, 2013; Irez, 2009; Pratama & Retnawati, 2018; Roseman et al., 2010; Sanders & Makotsa, 2016; Vojíř & Rusek, 2019). Many studies have dealt with analogies in teaching and learning processes (e.g., Holyoak & Thagard, 1989; Thiele & Treagust, 1995), but only a few engaged with the development of criteria for analyzing analogies in the content of science textbooks (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Orgill, 2013). Nevertheless, no study has examined the extent to which all four RRs other than analogy, namely antinomy, anomaly, and antithesis, appear in textbooks.

Being common learning materials for students (Williams & Agosto, 2012), science textbooks must conform to the requirements of the updated 21st century skills curriculum such as HOTs for understanding (Bayrak-Ozmutlu, & Yaylak, 2021). Pratama & Retnawati (2018) suggested that teachers' practicability to train students for high thinking would increase as more HOTs are engaged in textbooks. Therefore, the content included in science textbooks should involve high thinking (Bayrak-Ozmutlu, & Yaylak, 2021).

2.1. What do the findings say about HOTs in biology textbooks?

Some analyses conducted on biology textbooks are based on three high levels of thinking following Bloom's updated taxonomy - analysis, synthesis, and evaluation (Anderson & Krathwohl, 2001), and they indicated a mixed but insufficient trend in developing HOTs. For example, developing HOTs in biology textbooks for a vocational school has been declared as a failure (Rozi et al., 2021). On the other hand, a study in Indonesia suggested that about two-thirds of biology items are at the analysis level. However, at the level of creativity, problem-solving activities were found to cover less than 3% of contents and activities (Trisnayanti & Masykuri, 2021; Bayrak-Ozmutlu & Yaylak, 2021), although science textbooks should include activities that enable students to perform HOTs by using cognitive actions, such as, to relate concepts to other concepts, to classify, generalize, and apply them in finding new solutions (Trisnayanti & Masykuri, 2021). Following, the present study examined the prevalence of activities that require HOTs by application of RRs.

Several researchers measured the quality of science textbooks by their effectiveness in presenting connections as relations between representations of scientific ideas and concepts (Devetak & Vogrinc, 2013; Roseman et al., 2010). Effectiveness in biology textbooks is necessary for students to achieve scientific understanding through externalizing relations between the representations and models of theories and concepts (Stern & Roseman, 2004). However, scientific concepts can appear in textbooks imprecisely and may cause misconceptions (Irez, 2009). Although science textbooks should support students by presenting the relations between scientific ideas, it is rare to found biology textbooks with textual representations presenting explanations explicitly. Therefore, biology textbooks may not constitute support and effective learning factors as required (Roseman et al., 2010). Although this study did not directly examine the effectiveness of textbooks, the explicitness degree of RRs in biology textbooks could indicate on their effectiveness in promoting thinking and understanding.

2.2. Relational Reasoning skills (RRs) promote scientific understanding

In an age where information streams accessible and dynamic, the need for scientific understanding is essential for students to acquire scientific literacy

(Roseman et al., 2010). Scientific understanding occurs when new connections are made (Brunner, 1960), and transferred to new contexts (Perkins & Solomon, 1992). Experts in their field of knowledge, compared to novices, students should make meaningful connections between components of complex information, to implement their knowledge and to transfer it to various contexts in solving new problems (Roseman, et al., 2010). Students who are characterized as novices in their science level, need to apply HOTs to organize pieces of information by identifying differences or contrast relations, and make a critical assessment of the data with meta-cognitive awareness (Afandi et al., 2018; Rozi et al., 2021). Accumulation of studies on academic development with RR indicates on RRs' success on fostering understanding and expanding knowledge (Jablansky et al., 2020). This is due to RRs' role in processing scientific data by identifying significant patterns of similarity and different relations between abstract concepts, phenomena, systems, etc. (Alexander, 2017). Biology, like all sciences, is based on abstract representations and models that require the application of RR, in order to map the representations of different modes used, and to build the meaning of the relations. Learning with RR can promote learners' conceptualization of science. For example, Danielson and Sinatra (2017) demonstrated how coupling representations such as texts to images, could encourage learners to notice significant RR relations, that deepen their understanding (Danielson & Sinatra, 2017). The four RR skills (RRs) defined in the literature are (Alexander, Jablansky, Singer, & Dumas, 2016): a) analogy (i.e., identifies a pattern of similarity between different items of data items); b) anomaly (i.e., detects an unusual pattern of significant relations between data items); c) antinomy (i.e., detects discrepancies in the pattern of relations between data items by identifying relations of characteristics that do not belong to a particular category); d) antithesis (i.e., identifies inverse relations of the same trait to create a contrasting pattern).

Using all RRs in learning is necessary for students to activate the highest levels of thinking according to Bloom's taxonomy: analysis, evaluation and synthesis. For example, while acquiring knowledge process, students' analytical ability is measured by breaking down the problem into its components, identifying the essential features of the new problem, rearranging the elements, and identifying patterns. Moreover, Dumas & Dong (2020) suggested that critical and creative thinking activated in creating hypothetical arguments about a scientific phenomenon also involves using RRs. Following this line of reasoning, the application of the four RRs can help students understand abstract concepts and ideas, to the depth required in biology. Consequently, it is essential to examine the contents of science/biology textbooks concerning their engagement with RRs.

2.3. The updated science curriculum for high junior schools in Israel

Textbooks are supposed to reflect the requirements of the curriculum following the objectives of science education. Accordingly, the updated curriculum in Israel (2014) emphasizes the aspiration to train its graduates to successfully face the future challenges of a dynamic and knowledge-rich society by cultivating 21st-century skills. The higher-order thinking skills required for the graduates' profiles are explicitly mentioned: comparison, arguing for individual inference, and research orientation. Information skills such as identifying and organizing information, processing information while critically examining it, building new knowledge (Ministry of Education, 2014, pp. 1-9) are also explicitly addressed. However, the gap between the declarative nature of these goals in the curriculum and the contents in the textbooks sharpens the need to analyze science textbooks and assess their quality (Devetak & Vogrinc, 2013). Researchers have called for the assimilation of RRs into curricula and the design of learning and teaching materials accordingly, due to their importance for deep learning (Alexander, 2017; Alexander et al., 2016).

Given this specific framework, the present qualitative study attempts to answer the following research questions:

1)What are the implicit expressions of the four RR skills in textual or graphical representations from the biology textbooks used in Israeli junior high school?

2)What are the explicit expression of the four RR skills in textual or graphical representations from the biology textbooks used in junior high school?

3) What is the distribution of the four RR skills in biology textbooks?

4) What is the prevalence of implicit and explicit expressions for RR skills?

3. Research methodology

3.1. Textbooks and Selection

The data for this study were collected from three biology textbooks used for eighth-grade in junior high school in Israel (Table 1). All three textbooks are adapted to the updated syllabus, included in the latest science and technology curriculum of the Israeli Ministry of Education. These textbooks are approved for use by the Ministry of Education, and are recommended and commonly used after the selection process at the school level. Specifically, the following topics for eighth grades were examined: cells, the reproductive and communication systems, and ecosystems. They were selected because they are mandatory topics in this age group's curriculum, so they have been assessed.

Table 1. Study data

No. Name of the textbook	Name of authors and year	Name of publisher
1 'Nature of Reproduction'	Bar-Ilan Institute of Integration, 2012	Worldwide, Bar-Ilan Institute of Integration
2 'Life Sciences'	Keynan et al., 2012	The Centre for Educational Technology
3 'Investigating life systems'	Ben hur, Arielli & Yarden, 2013	Weizmann Institute of Science. Ministry of Education

3.2. Data analysis

For this study, textual content analysis according to the mixed methods paradigm was appropriate was selected (Chu, 2017). To examine how qualitative data can sometimes be "quantified" for statistical analysis (Saldaña, 2021). The qualitative content analysis was performed to distinguish between explicit and implicit statements in textbooks' content, with the purpose to produce meanings and assumptions (Calado et al., 2015), as a deliberate approach (Hsieh & Shannon, 2005), by using pre-developed categories based on relevant literature findings. The quantitative content analysis is designed to uncover the occurrence of each of the analyzed units (Bengtsson, 2016). Specific, we highlight the frequency of RRs expressions in the textbooks examined.

For this study, four criteria (C1-C4) were used to analyze the content of science textbooks based on criteria in the literature regarding thinking skills and analogies, and adapted to the other RR skills, as follows:

C1. RRs Type: Analogy; Antinomy; Anomaly; Antithesis; (Alexander et al., 2016; Jablansky et al., 2020).

C2. Text Type: T1 - literal or visual text (graphic, etc.); T2 - Question (can be accompanied by visual or verbal text); T3 - Activity (experiment, observation, project, and more). The use of the skill is examined at three levels: Passive-0- The text type does not show instructions or keywords to activate the skill. Activity 1- There is a requirement for the learner (using instructions or keywords) to practice the RR skill using a basic or low thinking level. Activity 2 - There is a requirement for the learner (using instructions or keywords) to practice the RR skill using a high level of thinking.

C3. Mapping Process: Implicit Mapping - The appearance of the skill is not explicit at all lowest level-0; Explicit partial - There is a partial explanation for the skill process and only one or two steps from the complete cognitive process required for relations mapping appear, Mapping-1; Explicit Mapping- a full description of the skill process -all stages of the cognitive process for mapping RR relations appear - highest level-2 (Orgill, 2013).

(I) *Analogical mapping* - A. Identify similar or different characteristics between the source analog and the target analog; B. Initial inference of similarity (visible), between the source and target; C. Identification of similar relations of a high order of thinking between the source analog and the target analog; and D. Application- Full explanation of the mapping process.

(II) *Antimonial mapping* - A. Identify similar or different characteristics; B. Sort into categories based on finding the similarities at an earlier stage; C. Identify a pattern of category mismatch based on finding differences between properties at an earlier stage; and D. Inclusion by classifying the unsuitable attribute into another existing category or a new category.

(III) *Anomalous mapping* - A. Identify an existing pattern by identifying properties that belong to a given pattern or category; B. Detection of an anomaly from an existing pattern; and C. Raising hypotheses for anomalies or explaining an anomaly.

(IV) Antithetical mapping for verbal representation A. Identify arguments contrary to the same phenomenon; B. Express a position regarding a counter-position but lacking well-founded arguments; C. Expressing a position and a counter-position and base them on at least one reasoning; D. Express your position and counter-position and substantiate them with several arguments.

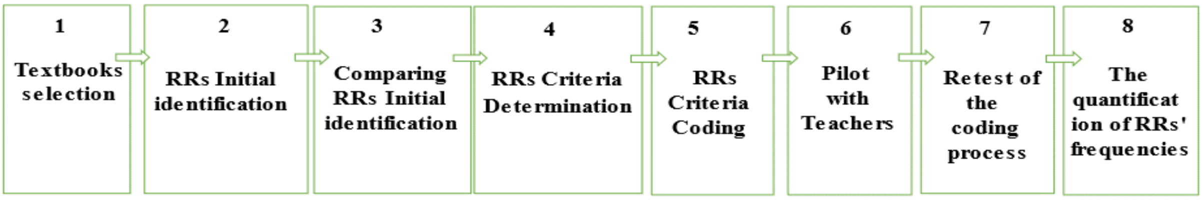
(V) Antithetical mapping for a graphical representation (like a system of axes) -A. Identify the inverse relationships between continuous variables from the exact cause of the phenomenon; B. Provide a detailed explanation (verbal and graphical) of the opposing relationships between the variables.

C4. Use: Indication of skill use by explicit statements, such as instructions or keywords displayed in different types of texts, enable learners to use RR skills, such as: Compare, Characterize, Sort, Match, Difference Between, Resist, Support, Explain the exception. The instructions are for the learner so that he can know how to use the RR skill. The instructions can be a low order of thinking (Active LOT) when using RR or high order of thinking (Active HOT) when using RR skills (Devetak & Vogrinc, 2013).

3.3. The procedure

The steps followed in order to select and analyze the data, as well as their sequencing, are presented below.

Figure 1. The procedure steps



Step 1 - Three biology textbooks were selected for the 8th grade.

Step 2 - RRs in four types, analogy, antinomy, anomaly and antithesis were identified based on their definition in the literature (Appendix No 1).

Step 3 - Two coders, the researcher and a colleague, a professor emeritus who is an expert in systemic thinking in biology, performed an initial comparative analysis, of 100 pages from the textbook 'Nature of Reproduction' simultaneously but separately. Comparing the results and discussed them helped us to make agreed-upon decisions to identify the RRs according to the literature' definitions and achieved a consensus to prevent the coder's bias.

Step 4 - Four criteria were determined for examining the explicitness of RRs (C1, C2, C3, C4) (Appendix No. 2).

Step 5 - The four criteria (C1, C2, C3, C4) coded in three levels for each criterion 0-2. In sampling the developed criteria following the literature, a strategy of extracting all the texts that matched specific criteria was used (Paton, 2015). Respectively, I extracted the RRs expressions that appeared in 3 types of texts (in different representations) (T1, T2, T3). My colleague and I applied for a critical-analytical position in associating the expressions to RR for each criterion. In the few cases where there were disagreements about other meanings of presenting the expressions to RRs, we debated together until we reached an agreement.

Step 6 - A pilot with two independent teams of 7 biology teachers from two large schools were identified the RRs' criteria. The pilot is designed to teach RR skills in ten 30-hour academic training sessions in exchange for a reward. The teachers had an M.A. in science, and only two had a B.A. in science. During four out of ten sessions, teachers were asked to identify each of the four RRs in selected content from the 'Life Sciences' textbook they teach (one of the three textbooks analyzed). In the first step, each teacher was asked to analyze expressions for each RR skill mentioned independently. In the chapter, according to the following guidelines: a) "Does a text (verbal or visual representation) appear in an expression of a particular RR skill (e.g., analogy)?"; B) "How did you identify an indication of this skill in the text (such as by keywords that match the definition of the skill learned)?"; C) "Does the text imply the skill?" E) "Does the skill appear explicitly in the text?": F) "By what did you determine this?". The second stage was implemented in the plenum when each teacher shared the examples he was debating. Teachers' access to as many examples as possible from the textbooks helped teachers refine the nuances between the levels of each criterion (C1, C2, C3, C4) and ultimately reach an agreement on identifying a specific RR skill.

Step 7 - Three rounds of retests of reading, testing, and comparison were performed by the researcher.

Step 8 - For the quantification of RRs' frequencies, data analysis arrived at a matrix that triangulated all four criteria to four variables. Thus, the first phase was to triangulate RRs type (C1) with Text type(C2), the output of which was 12 categories:

1) Analogy – text (RR1-T1)
2) Analogy – question (RR1-T2)
3) Analogy – activity (RR1-T3)
4) Antinomy – text (RR2-T1)
5) Antinomy – question (RR2-T2)
6) Antinomy – activity (RR2-T3)
7) Anomaly – text (RR3-T1)
8) Anomaly – question (RR3-T2)
9) Anomaly – activity (RR3-T3)
10) Antithesis – text (RR4-T1)
11) Antithesis – question (RR4-T2)
12) Antithesis – activity (RR4-T3)

The second phase was to triangulate the variables that were assessed –Mapping(C3) and Use-skill (C4). The output of this was 9 categories:

1) Implicit mapping + passive use (M-0, U-0).
2) Implicit mapping + active lower-order use (M-0, U-1).
3) Implicit mapping + active higher-order use (M-0, U-2).
4) Partially explicit mapping + passive use (M-1, U-0).
5) Partially explicit mapping + active lower-order use (M-1, U-1).
6) Partially explicit mapping + active higher-order use (M-1, U-2).
7) Fully explicit mapping + passive use (M-2, U-0).
8) Fully explicit mapping + active lower-order use (M-2, U-1).
9) Fully explicit mapping + active higher-order use (M-2, U-2).

The final phase was to triangulate the 12 categories from step 1 with the 9 categories from step 2. The output of this was 108 categories, which can be seen in Figure no. 5 in the findings chapter.

3.4. Reliability

In analyzing and coding the content units for RR skills, several strategies were used:

(1) Coding of three textbooks from the same age group enables the coding consistency of RRs tested to be maintained, preventing the coders' bias in the analysis.

(2) Experts' validity– two coders, the researcher and a colleague, a professor emeritus who is an expert in the field of thinking in biology. In addition, two coding teams - 7 teachers in each team – were trained in learning RR skills separately and independently. They constituted an additional strengthening reliability for coding the RR skills.

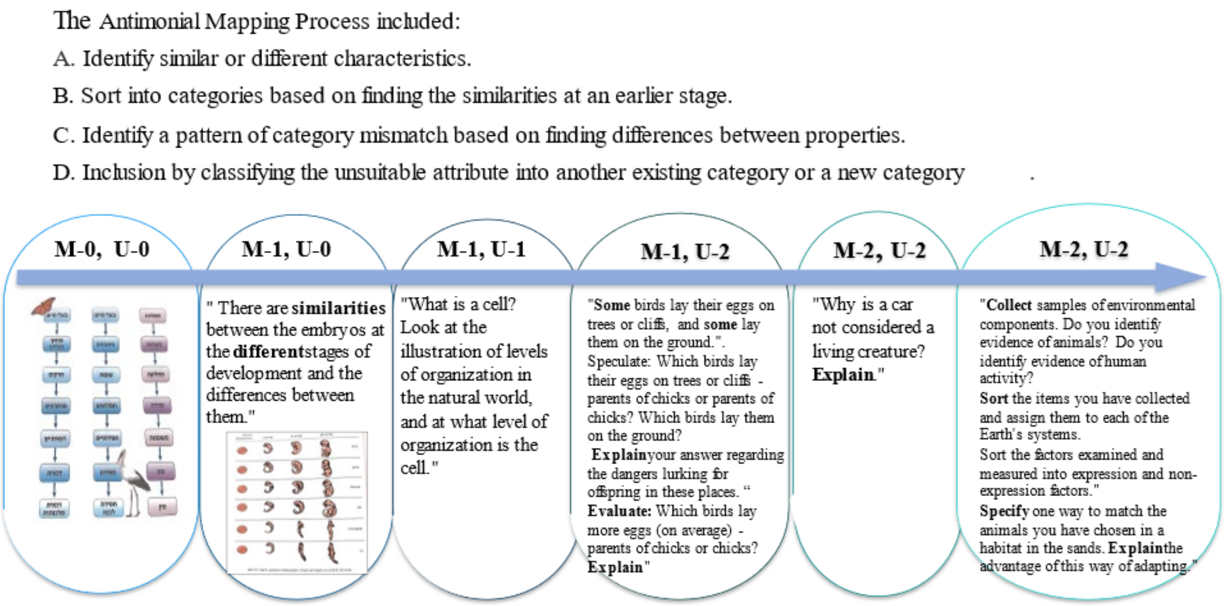
(3) Repeating analysis included reading, testing, and comparison in three rounds, in all three textbooks following the pilot study and, thus, strengthened the reliability of the coding.

4. Results

The findings of the quantitative and qualitative analysis refer to the research questions and appear in four figures (Figures 2-5), respectively. The qualitative findings relating to the first two research questions regarding the appearance of implicit and explicit expressions for RRs in various texts in biology appear in Figure 2, which shows examples for the antinomy skill in each text type (T1 – T3).

The degree of explicitness of antinomy was explored using the mapping process criterion that includes the cognitive actions required to identify an antinomy pattern at three levels (M0-M2). Implied text means a text that does not demonstrate any of the cognitive actions needed for an antinomy mapping process, whereas explicit text means that the whole mapping process is described in the text, including the antinomy pattern, whose identification is required for a high cognitive level. The criterion for the use of antinomy appears in three levels (passive text without instructions in the text to use of skill, active text that includes instructions for the learner to use the skill while exercising low thinking order, and active text that contains instructions for using skill while operating high thinking order (U0-U2). The arrow direction in figure 3 indicates an upward trend starting from the text's lowest effectiveness index (M-0, U-0), to the highest effectiveness index (M-2, U-2), as for example, the leftmost taxonomy between two species belonging to two different classes. Apart from the picture, no description explains the relations between the species and a lack of instructions for the learner to identify the antinomy pattern, the category of the particular species in this picture, based on similarities and differences between the two categories. Thus, this particular example characterized by implicit expressions of antinomy and passivity, i.e., without instructions for antinomy skill use at low or high level of thinking. The second text describes a picture that deals with the embryonic development of different species. The level of explicitness for antinomy is partial (M-1). Because the learner must pay attention to the similarities and differences between the categories of development in each creature and between the animals. However, there are no explicit instructions for the student to use the antinomy (U-0). The two middle texts are rated at the same level of partial explicitness but differ in the level of thinking about the use of antinomy. The text that deals with organizational levels activate the student to a low level of thinking by using antinomy in matching the cell to a certain level of organization (M-1 U-1). On the other hand, the following example explains to the student the categorical distinction between parents and chicks and chicks. Still, it raises antinomy thinking to a high level by requiring the student to exercise an evaluation and explanation that indicates his scientific understanding (M-1, U-2). The last two texts are at the highest explicitness and skill use. The difference between them is in the type of text. The penultimate example asks the student to explain the antinomian pattern of mapping by explain the particular characteristic that is not belong to the living being's category but to another category. The rightmost example is the index of success (M-2, U-2) of activity-type text (T3) that activates the learner to use explicit high-thinking antinomy when deciding on the type of organism to the habitat and explaining its benefit. These kind of activity deals with a problem and requires from the student to construct new knowledge when organizes it into a new scientific category.

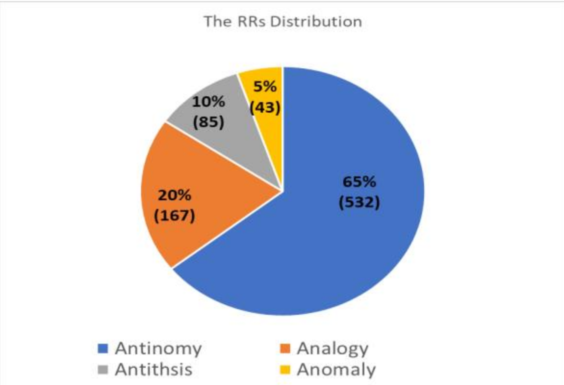
Figure 2. Qualitative Textual analysis an Antimonial example



The distribution of RR skills, referring to study question 3 as demonstrated in Figure 3. According to the findings, the distribution of RR skills is heterogeneous. Compared to other RR skills, antinomy expressions are significantly more prevalent. These findings are in contrast with previous work, emphasizing the popularity of analogies in science teaching (Lovett & Forbus, 2017). In the textbooks we analyzed antinomies appeared in a larger ratio among other RR skills.

The results obtained from crossing the two pairs of criteria refers to research questions 4 about the prevalence of the four RRs in all three textbooks examined as shown in Figure 4. Two cross-pairs of variables representing the four qualitative criteria were coded quantitatively for calculating frequencies. The Horizontal title bar indicates the type of RR skill (RR1-RR4) in the crossover with the text type (T1-T3). The left column shows the mapping for explicit (M1-M3) crossing with the use of skill (U1-U3), according to the level of thinking. The appearance of the variables in descending order (shown in the top-down column), from the level of implicit cross-mapping with a no use indication of RR skills (M-0, U-0), to the highest level of explicit mapping cross with the highest level of thinking (M-2, U-2).

Figure 3. The distribution of RR skills



Prominent findings from 827 types of texts, reflect that the number of passive RRs text types is smaller (U-0 = 29%) than the number of RRs texts that use a high or low level of thinking, while the number of the types of texts running low level of thinking (U-1 = 38%) is slightly higher than the number of texts running with high level of thinking (U-2 = 32%), with an insignificant gap of 5% between them. In a horizontal line indicating the cross variables M - O, U - 1, the highest number in the total 197 (about 24%), implied texts use low-thinking RRs. Some of relevant research findings are the following: 129 Questions included expressions for antinomy; 26 questions included expressions for analogy; 23 questions included expressions for antithesis; and five questions had expressions for an anomaly. Hence, the highest number of assignments in the textbooks contain instructions for the learner to exercise implicit antinomies at a low level of thinking. Another notable finding, in a horizontal row (M-1, U-2), refers to the 109 texts to activate RRs that appear in them semi-explicitly but require their use at a high level of thinking: 70 questions for the learner to activate antinomies at a high level of thinking; 17 questions for the learner to apply analogies at a high level of thinking; 13 questions for the learner to activate antitheses at a high level of thinking, and only one question for a learner to activate an anomaly for a high level of thinking. With a similar frequency and small difference, 99 semi-explicit texts were found for low-thinking RRs (M-1, U-1). Compared to the other findings, a small number of all texts' type (about 7%) appear for explicit RRs and require the learner to activate them at a high level of thinking (horizontal line M-2, U-2). An interesting finding highlights that only 13 activity tasks (T3), and less than 2%, containing explicit RRs' expressions with high level demanding, of them, nine analogs, four antinomies, two antitheses and without any activity task of anomaly.

Figure 4. Summary of the prevalence of RRs results in a crossover with mapping, usage, and text type

	RR1-T1 Analogy-Text	RR1-T2 Analogy-Question	RR1-T3 Analogy-Activity	RR2-T1 Antinomy-Text	RR2-T2 Antinomy-Question	RR2-T3 Antinomy-Activity	RR3-T1 Anomaly-Text	RR3-T2 Anomaly-Question	RR3-T3 Anomaly-Activity	RR4-T1 Antithesis-Text	RR4-T2 Antithesis-Question	RR4-T3 Antithesis-Activity	TOTALS
M-0, U-0	22	0	0	88	0	0	9	0	0	4	0	0	123
M-0, U-1	0	26	8	0	129	6	0	5	0	0	23	0	197
M-0, U-2	0	18	9	0	52	7	0	1	1	0	13	1	102
M-1, U-0	11	0	0	56	0	0	12	0	0	0	0	0	79
M-1, U-1	0	17	1	0	68	2	0	3	0	0	7	1	99
M-1, U-2	0	17	2	0	70	6	0	1	0	0	13	0	109
M-2, U-0	14	0	0	15	0	0	6	0	0	3	0	0	38
M-2, U-1	0	3	3	0	8	2	0	4	0	0	4	0	24
M-2, U-2	0	9	7	0	19	4	0	1	0	0	14	2	56
TOTALS	47	90	30	159	346	27	27	15	1	7	74	4	827
												827	

The cross-frequency data for RRs are visually represented in pie charts as a matrix, in two elements, color, and size, as shown in figure 5. The chart makes it possible to represent different but complements the significant trends of the findings in the table. Thus, a different color for each segment in the pie represents the pairing of the skill type with the text type. In comparison, the gray color represents the pie segments representing the distribution of the findings of the other categories that are not relevant to the type of text represented in each line. The pie size varies according to the number of passive or active texts in the degree of use of RRs according to levels of thinking, in cross-reference with the explicit level of these skills. Significant trends are emerging from the matrix of the pie charts :

- The pie size is getting smaller, indicating a small number of text types in which the level of explicit mapping to RRs and the degree of active use of skills for high-level thinking is increasing. And vice versa. The increasing pie size indicates many passive text types in which the allusive or partially explicit level of RR expressions includes their use at a basic level.

- The giant pie on the left side in the horizontal middle row illustrates the highest number of tasks (24%) with implicit RR expressions and low activation of thinking order, mainly questions that referred to antinomy expressions. In the other hand, the number of RR expressions for the anomaly in all types of texts and at all explicit levels and the use of thinking appears with the lowest frequency, as represented by the size of the smallest pie segment.

- The size of the left pie in the top horizontal row of the matrix represents the most significant number of implicit and passive texts found for RRs, with the highest frequency for the antinomy phrases compared to other RRs. In contrast, the rightmost pie in the lower horizontal row in the matrix indicates a small number of texts of all types (7%) found at an explicit level for RRs and a level of using them with a requirement for high thinking. Of these, a minority of task-type texts (in pie segments painted in a different color than gray) included the use of explicit analogy, antinomy, and antithesis expressions to activate students at a high level of thinking.

- In summary, from Figures 4-5 the results indicate several trends:

- RRs expressions (Analogy, Antinomy, Anomaly, and Antithesis), appeared in all types of texts but in a heterogenic distribution

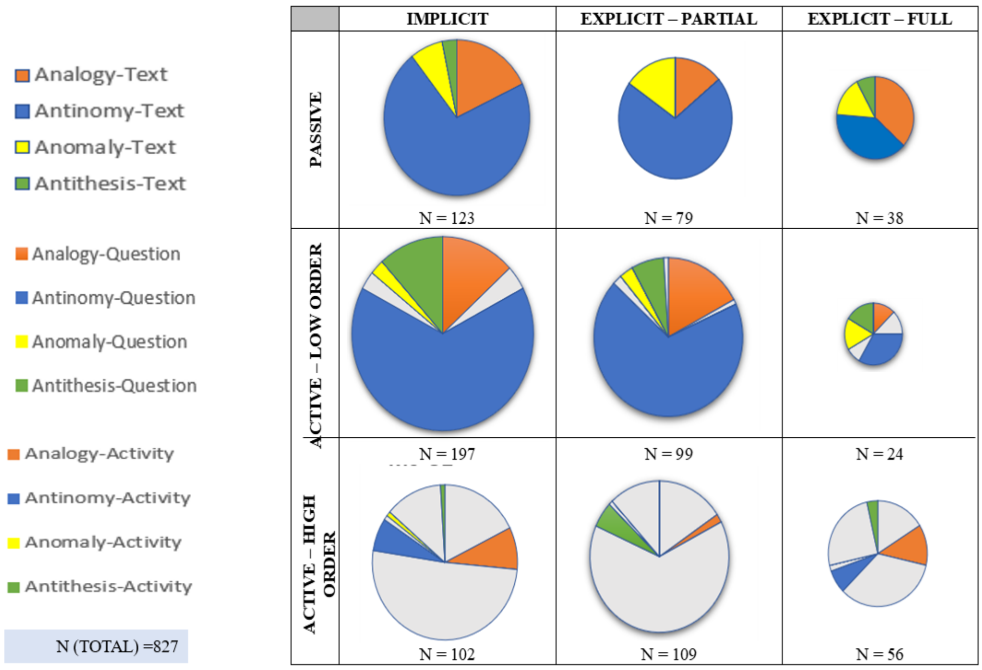
- The number of all types of texts with implicit RRs, in different thinking levels of the used skill, is significantly higher (51%) than the number of the texts types that are partially explicit (34%) or explicitly expressed in terms of RRs (14%).

- There is a high frequency of questions relating to RRs (T2- 63%), at all explicit and implicit levels, appears to be significantly higher than verbal or visual texts (T1-29.5%), or activities (T3 -7.5%). From the question-type texts, there is a high frequency of antinomy questions at an implicit level, with the requirement for a low level of thinking (23%).

- The number of types of texts running low level of thinking (U-1- 38%) is slightly higher than the number of texts running with high level of thinking (U-2 -32%).

- Activity text type (T3) at the highest level of explicitly and the high thinking level of using RRs were found with the lowest frequency of all the texts types analyzed (less than 2%).

Figure 5. The Prevalence of RRs results



In this study, combining a text containing explicit requirements for learners to apply RRs at high levels of thinking and an explicit mapping to RR skills may indicate the success index of biology textbooks for developing high thinking skills. From the pie chart and table trends, this measure of success has not been realized sufficiently.

5. Discussions

The findings suggest that the distribution of RRs is heterogeneous: antinomy appears most frequently in all three types of texts, and in descending order are expressions of analogy, antithesis, and anomaly. These results raise a question, as analogies are more common in scientific teaching and learning processes, due to their ability to mediate abstract concepts (Goel et al., 2011; Lovett & Forbus, 2017), as suggested in the wide range of studies on analogies (Dikmenli, 2010; Irez, 2009; Seyihoglu & Ozgurbuz, 2015). Still, understanding scientific phenomena by explaining its complex relations and concepts requires abstract abilities (Chi & Van Lehn, 2012). Accordingly, antinomic thinking ability is designed to process complex content by categorizing or taxonomically classifying and diagnosing what does not fit the category definition (Alexander et al., 2016). Since every concept and taxonomy appearing in biology textbooks may be considered as a category, it makes sense that high prevalence of antinomies appears in biology textbooks.

The present analysis shows that the degree of explicitness of all texts for RRs is insufficient. Thus, the frequency of expressions for RR at an implicit level is higher (51%) than the expressions for RRs at a partially explicit level (34%). Only 14% of all text types were interpreted as RRs for activation at different levels of thinking. Even if there is an explicit RR level it appears in a small percentage that is not satisfactory. The RR findings in this study are consistent with the previous reports of a lack of explicit analogies or unexplained or partially explicit analogies presented in science and biology textbooks that may create misconceptions (Orgill, 2013). Moreover, previous analyses of science textbooks have rarely explained connections between scientific ideas (Rosman et al., 2010).

The findings indicated a slight difference between activating texts based on the question or activity type that required high-thinking (32%), and texts that required low-thinking (38%). Nearly a third of the texts were passive, i.e., they did not require instructions for using RR skills. The findings are interesting because they contradict previous analyses of analogies, showing that none of the scientific and biology textbooks reviewed included a general statement regarding the use of analogies, or how students should use analogies to learn (e.g., Orgill & Bodner, 2006; Orgill, 2013). Instead, there is no consistency between the current findings and the literature regarding how students should use HOTs to learn science. (e.g., Orgill & Bodner, 2006; Orgill, 2013). Furthermore, even if there is a reference to high-level thinking with RRs in the examined texts, in light of the previous contradictory findings, the findings do not indicate consistency. On the one hand, it is argued that science textbooks are not an adequate source for HOT development (Rozi et al., 2021). On the other hand, there is evidence that science textbooks in Indonesia appear to contain over two-thirds of items requiring high-level reasoning (Trisnayanti et al., 2021).

Since the analyzed textbooks reflect the updated science curriculum for junior high school that explicitly encourages high thinking skills, we can assume that this explains the trend of over a third of items for RRs found in a high order of thinking. However, it is essential to emphasize that there is insufficient development of high thinking with RR in activities. For example, when the instructions for the activity with the playing cards in the textbook include antinomic thinking from the students due to the requirement to sort the reproductive characteristics of living creatures and assign them to certain traits, this is done without explicit reference to explain the sorting methods used to create the new categories. The analysis on RRs indicates that the percentage of activities dealing with problem-solving that implies further information processing is minimal (less than 2%). This finding is consistent with the accumulation of findings and researchers' claims about the ineffectiveness of scientific textbooks expressed in the absence of problem-solving activities, designed to create patterns and build new knowledge of personal significance to them (Kabapınar, 2007; Bayrak-Ozmutlu & Yaylak, 2021).

The success index of biology textbooks is a combination of explicit texts for RRs i.e., mapping process for RRs, along with explicit instructions for the learner to use any RR skills, by knowing how to apply a high level of thinking like in problem-solving.

In the textbooks analyzed in this study, only 7% of activity-type texts were found, and these are most probably insufficient deep to ensure scientific understanding.

6. Conclusions

The explicit degree of all four RRs is the biology textbook is rather low, compared to high prevalence of the implicit RRs. Expressions of RRs (Analogy, Antinomy, Anomaly, and Antithesis) appeared in all types of texts but in a heterogenic distribution, and antinomies seem to have a higher frequency. The biology textbooks mostly feature question-type texts that guide learners on using RRs at different levels of thinking, (high and low), with an almost similar frequency. Only a small and limited percentage of the texts are activities requiring HOTs when using RRs expressions. Although we aimed to develop an index for mapping biology textbooks for RR skills, the process is still at the beginning. Criteria used for data analysis should be further refined and better circumscribed.

At the theoretical level, the findings extend the previous knowledge that referred only to the analogy, and rather neglected of the other three RR skills (Antinomy, Anomaly, and Antithesis). At the methodological level, the research offers qualitative content analysis according to pre-known categories and the qualitative findings were quantified to contribute to their in-depth understanding. At the practical level, the research contributes to applied knowledge related to learning and understanding at a high order thinking level in biology textbooks, and can be successfully transferred to other cultures and educational systems.

It is necessary to develop science textbooks adapted to the curriculum that emphasizes explicit meta-strategic knowledge on the characteristics of RRs and when, why, and how to use them. This can be done by mentioning the explicit name of the RR skill (analogy, antinomy, etc.); by mentioning 'what' – through explicitly detailing the process of mapping RRs; by mentioning 'how' to use it, and by mentioning 'why'- through presenting the purpose of the skill and when used. Further research to examine the texts in which RR skills appear, intended for the use in teaching and learning biology, is certainly highly recommendable.

Appendix 1

The RR skills expressions in textbooks

Analogy expressions - To find the common principle is comparing similarities and differences between different processes, in different systems, in various representations (where each representation is an analogy).

Antinomy expressions - To identify differences resulting from mismatches of characteristics, sorting and classification into categories, as well as what does not belong to a particular category or the definition of a concept.

Anomaly expressions - To detect deviation from the norm, abnormal phenomenon, abnormal behavior.

Antithesis expressions - To find conflicting values in a graph with continuous variables, or contradictory arguments for and against texts, for the same given phenomenon.

Authors note:

Vered Alboher Agmon is a doctoral student in education researching the effects of Relational Reasoning skills on teachers' knowledge. As an instructor at the Israeli Ministry of Education, she was a part of a team promoting the assimilation of higher-order thinking skills (HOTs) for all ages and disciplines. She was the coordinator of Ohalo College's pedagogical development programs up to 2020 and a lecturer specializing in meta-cognition and meta-strategic knowledge in explicit instruction. She is also a biology teacher and instructor for science teachers. Her Master's thesis at the Hebrew University of Jerusalem dealt with the views of science teachers on the Israeli 2009-2012 reform and its effects on teaching. Her paper was presented at the 2017 NARST Annual International Conference in San Antonio, TX, on "Increasing test scores versus teaching higher order thinking (HOT)". Another paper on the topic was published in Research Science & Technological Education in 2018.

Nicoleta Laura Popa is a Professor at the Department of Education Sciences, within the Faculty of Psychology and Education Sciences of the Alexandru Ioan Cuza University of Iasi, Romania. Her research and teaching interest cover migration and inclusion in education, intercultural education, educational policies, and teacher education. She is

involved in several R&I European projects, and coordinates the Research Centre in Education Sciences.

References

Afandi, A., Sajidan, S., Akhyar, M., & Suryani, N. (2018). Pre-service science teachers' perception about high order thinking skills (HOTS) in the 21st century. *International Journal of Pedagogy and Teacher Education*, *2*(1), 107-114.

Alexander, P. (2017). Relational reasoning in STEM domains: A foundation for academic development. *Educational Psychology Review*, *29*, 1-10.

Alexander, P. A., Jablansky, S., Singer, L. M., & Dumas, D. (2016). Relational reasoning: what we know and why it matters. *Policy insights from the behavioral and brain sciences*, *3*(1), 36-44.

Anderson, L. W., & Krathwohl, D. R. (2001). A Taxonomy for learning, teaching, and assessing. A revision of bloom's taxonomy of educational objectives. Longman: New York.

Bar-Ilan Institute of Integration (2012). *Nature of reproduction – From the living cell to the ecological system.* Olamot – World of Science and Technology for Junior High School. [Hebrew]

Bayrak-Ozmutlu, E., & Yaylak, E. (2021). Analysis of Thinking Skills Targeted for Development by Activities in Life Science Textbooks. *International Online Journal of Educational Sciences*, *13*(2).

Bengtsson, M. (2016). How to plan and perform a qualitative study using content analysis. *Nursing Plus open*, *2*, 8-14.

Ben Hur. y., Arielle. M., & Yarden, A. (2013). *Investigating life systems - B.* Weizmann Institute of Science. Ministry of education. [Hebrew]

Bruner, J. S. (1960). On learning mathematics. *The Mathematics Teacher*, *53*(8), 610-619.

Calado, F. M., Scharfenberg, F. J., & Bogner, F. X. (2015). To what extent do biology textbooks contribute to scientific literacy? Criteria for analyzing science-technology-society-environment issues. *Education Sciences*, *5*(4), 255-280.

Chi, M. T., & Van Lehn, K. A. (2012). Seeing deep structure from the interactions of surface features. *Educational Psychologist*, *47*(3), 177-188.

Chu, Y. (2017). Twenty Years of Social Studies Textbook Content Analysis: Still "Decidedly Disappointing". *The Social Studies*, *108*(6), 229-241.

Curtis, R. V., & Reigeluth, C. M. (1984). The use of analogies in written text. *Instructional Science*, *13*(2), 99-117.

Danielson, R. W., & Sinatra, G. M. (2017). A relational reasoning approach to text-graphic processing. *Educational Psychology Review*, *29*, 55-72.

Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational researcher*, *34*(3), 3-14.

Devetak, I., & Vogrinc, J. (2013). The criteria for evaluating the quality of the science textbooks. In Critical analysis of science textbooks (pp. 3-15). Springer.

Dikmenli, M. (2015). A study on analogies used in new ninth grade biology textbook. In *Asia-Pacific Forum on Science Learning and Teaching* (Vol. 16, No. 1, pp. 1-20). The Education University of Hong Kong, Department of Science and Environmental Studies.

Dumas, D., & Dong, Y. (2020). Focusing the Relational Lens on Critical Thinking: How Can Relational Reasoning Support Critical and Analytic Thinking? *Critical Thinking and Reasoning* (pp. 47-63). Brill.

Goel, A. K., Bras, B., Helms, M., Rugaber, S., Tovey, C., Vattam, S., & Yen, J. (2011). Design patterns and cross-domain analogies in biologically inspired sustainable design. *2011 AAAI Spring Symposium Series*.

Holyoak, K. J., & Thagard, P. (1989). Analogical mapping by constraint satisfaction. *Cognitive science*, *13*(3), 295-355.

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative health research*, *15*(9), 1277-1288.

Irez, S. (2009). Nature of science as depicted in Turkish biology textbooks. *Science Education*, *93*(3), 422-447.

Jablansky, S., Alexander, P. A., Dumas, D., & Compton, V. (2020). The development of relational reasoning in primary and secondary school students: a longitudinal investigation in technology education. *International journal of technology and design education*, *30*(5), 973-993.

Kabapınar, Y. (2007). The image of "others" and tolerance in Turkish history and social studies textbooks: "not us", "the other is to blame". *Teaching for tolerance in Muslim majority societies*, 33-50.

Keynan, N., Tumani-Minis, S., Kashtan, Y., Reisfeld, S., Gavrieli, Y. (2012). *Life sciences for the 8^th^-grade: Development and writing.* The Center for Educational Technology. [Hebrew]

Lovett, A., & Forbus, K. (2017). Modeling visual problem solving as analogical reasoning. *Psychological review*, *124*(1), 60.

Ministry of Education (2014). *Science and technology curriculum for junior high School*. https://pop.education.gov.il/tchumey_daat/mada-tehnologia/chativat- beynayim/mada-technologia-pedagogia/curriculum [Hebrew]

Orgill, M. (2003). *Playing with a double-edged sword: Analogies in biochemistry*. Doctoral dissertation, Purdue University.

Orgill, M. (2013). How Effective Is the Use of Analogies in Science Textbooks? In *Critical analysis of science textbooks* (pp. 79-99). Springer.

Orgill, M., & Bodner, G. M. (2006). An analysis of the effectiveness of analogy use in college-level biochemistry textbooks. *Journal of Research in Science Teaching*, *43*(10), 1040-1060.

Perkins, D. N., & Salomon, G. (1992). Transfer of learning. *International encyclopedia of education*, *2*, 6452-6457.

Pratama, G. S., & Retnawati, H. (2018). Urgency of higher order thinking skills (HOTS) content analysis in mathematics textbook. *Journal of Physics: Conference Series* (Vol. 1097, No. 1, p. 012147). IOP Publishing.

Roseman, J. E., Stern, L., & Koppal, M. (2010). A method for analyzing the coherence of high school biology textbooks. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *47*(1), 47-70.

Rozi, A., Khoiri, A., Farida, R. D. M., Sunarsi, D., & Iswadi, U. (2021). The fullness of Higher Order Thinking Skills (HOTs) in applied science textbooks of vocational schools. In *Journal of Physics: Conference Series* (Vol. 1764, No. 1, p. 012143). IOP Publishing.

Saldaña, J. (2021). *The coding manual for qualitative researchers*. Sage.

Sanders, M., & Makotsa, D. (2016). The possible influence of curriculum statements and textbooks on misconceptions: The case of evolution. *Education as Change*, *20*(1), 1-23.

Seyihoglu, A., & Ozgurbuz, I. (2015). Analysis of analogies in geography textbooks. *Egitim Ve Bilim-Education and Science*, *40*(179).

Shepardson, D. P., & Pizzini, E. L. (1991). Questioning levels of junior high school science textbooks and their implications for learning textual information. *Science Education*.

Stern, L., & Roseman, J. E. (2004). Can middle-school science textbooks help students learn important ideas? Findings from Project 2061's curriculum evaluation study: Life science. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *41*(6), 538-568.

Thiele, R. B., & Treagust, D. F. (1995). Analogies in chemistry textbooks. *International Journal of Science Education*, *17*(6), 783-795.

Trisnayanti, Y., & Masykuri, M. (2021). Profile of Junior High School Science Textbooks: Fulfillment of the Higher-order Thinking Skills component. In *Journal of Physics: Conference Series* (Vol. 1842, No. 1, p. 012053). IOP Publishing.

Vojíř, K., & Rusek, M. (2019). Science education textbook research trends: A systematic literature review. *International Journal of Science Education*, *41*(11), 1496-1516.

Williams, R., & Agosto, V. (2012). Missing and shrinking voices: A critical analysis of the Florida textbook adoption policy. In *The New Politics of the Textbook* (pp. 17-39). Brill Sense.