“ALEXANDRU IOAN CUZA” University of IAȘI
Faculty of Psychology and Educational Sciences
Doctoral School of Psychology and Educational Sciences

The Contribution of a Meta-strategic Training Program to the Development of Relational Reasoning Ability among Biology Teachers

Doctoral supervisor: Prof. Nicoleta Laura Popa

Doctoral student: Vered Alboher Agmon

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Introduction

A primary need of science literacy graduates in an age when knowledge is constantly available and renewed is to understand science. However, there is a gap between the available information flow and learners' (students and teachers) ability to organize and use it effectively to acquire new knowledge for understanding. Specifically, biological processing content and representations challenge learners to create meaningful relations linking between and within levels in complex systems to explain broad scientific principles and concepts (Harrison & Treagust, 2006a, 2006b).

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Relational Reasoning (RR) ability allows learners to efficiently process the information flow and obtain coherent representations in various fields, especially STEM. Being an executive cognitive function, RR is needed for learners to demonstrate greater cognitive flexibility in their field of study when solving problems on a complex level (Kalra & Richland, 2022).

Using RR's ability relates to four main RR skills (RRs): Analogy, Anomaly, Antinomy, and Antithesis (Alexander et al., 2016a, 2016b).

Analogy -finding a similar relations pattern between different representations (such as processes or phenomena).

Antinomy - identifying differences resulting from mismatches of properties, sorting, and classification into categories, as well as what does not belong to a particular category.

Anomaly - detecting deviation from the pattern, abnormal data, or a phenomenon.

Antithesis - finding conflicting values in a graph with continuous variables or contradictory arguments for and against texts about the same phenomenon.

Implementing RRs by identifying their patterns during learning allows the merging of pieces of information into meaningful units. An in-depth understanding of this information has successfully improved learners' use of those skills to gain a deeper understanding.

Indeed, an empirical connection was found between using RRs during acquisition processes, students' academic success, and learning performance, mainly when measured in a specific domain (Alexander, 2019; Dumas, 2018; Gray & Holyoak, 2019).

However, RRs' use, flexibility, and teachability involve difficulties in applying them for problem-solving. Learners including adults struggled to identify meaningful relations between familiar and unfamiliar problems without clues (Hough & Gluck, 2019). Applying RRs is influenced by the prior learner's experience with the specific domain, the reasoning and the nature of the task, and the context in which the thinking is done, for example, collaboration learning (Boshuizen et al., 2020). Furthermore, metacognitive experiences indicated that external factors, including the number of learning attempts, the amount of time, and the overall context, probably cause feelings of difficulty in solving tasks. Repeated exposure to the task during the development of the expertise process produces in the learner higher feelings of familiarity with the task and better analysis and understanding of the task's requirements. As a result, the learner knows how to calibrate his feelings of difficulty better. These feelings stimulate the metacognitive components including meta-cognitive experiences, knowledge, and skills, since they act as a 'regular loop' in monitoring and controlling. Thus, when learners experience embarrassment or failure in a current way, they may seek another way, improve thinking strategies, or help define new ones (Efklides, 2006). Accordingly, this research aims to examine the strategies developed by the participating teachers to overcome difficulties and their feelings experienced in applying RRs to biology tasks.

Moreover, studies consistently show that academic achievements improve as more metacognitive processes occur. A meta-analysis of metacognitive strategy instruction indicates that it has a lasting effect on student academic performance. In the long run, the strategy teaching intervention maintained and even increased student performance after the course ended. As a result, students retain the newly acquired learning skills, signaling that they can regulate their learning autonomously after formal education (De Boer et al., 2018). Accordingly, this research examines the effect of an intervention program for learning RRs for their application on the knowledge and understanding of the teachers' performance in biology.

In addition, explicit instruction dealing explicitly with metacognitive knowledge works with methods emphasizing building knowledge to promote Higher-Order Thinking skills (HOTs) processes, such as data analysis, understanding concepts and effects, and complex variables. Indeed, the accumulation of research indicates a necessity for deliberate explicit training in acquiring complex HOTs for their application. Skills training stages include building Meta Strategic Knowledge (MSK). Thus, explicit instruction was found as one of the effective methods for challenges in learning and teaching analogies in systems with complex interactions. For example, asking learners to find what is common between the items and provide comparisons of similarities and differences after performing the cognitive actions -Encoding, inference, mapping, and implication. (Goel at el., 2011; Lovett & Forbus, 2017).

This research used MSK model explicit instruction in science which was found to improve scientific HOTs in all students, particularly with low achievement (Zohar & Ben David, 2008).

According to Flavell (1979), MSK types of knowledge- declarative, procedural, and conditional knowledge (knowing what, how, when, and why to use the skills) are described as the most effective for developing learners' cognitive and meta-cognitive thinking and achievement promoter. MSK encourage transfer between similar situations by conveying thinking skills and applying them in different contexts to solve problems. Moreover, conceptualizing the relations between the solutions as occurs activating analogical thinking became explicit when learners engaged and shared solutions and their processes. By explaining and generalizing similar situations, they can solve problems more effectively by promoting higher relations using cognitive actions such as inference and mapping. However, transfer depends on how the skill is acquired and how learners adapt between their skills and existing structures combined with a new assignment (Billing, 2007; Pilegard & Mayer, 2018).

Based on the literature, this research assumes that science teachers who explicitly use cognitive actions with meta-strategic knowledge types in writing and discussions promote their performance of the different types of knowledge and the implementation of RRs in biology tasks.

Teachers in science are closely related to scientists in terms of their domain specificity and the amount of immersion experience they require – to advance in complex learning. Like science experts, science teachers require comprehensive knowledge and deep understanding (Shanahan & Bechtel, 2019). Furthermore, in-services teachers with pedagogical content knowledge expertise develop an awareness of thinking strategies and implement ‘pedagogy for understanding’ to prevent fragile knowledge. With in-depth Subject Matter Knowledge (SMK), teachers, like experts, can recognize significant patterns within the information, structure it based on principles, construct intricate networks of terms and processes, and effectively resolve problems. Deepening knowledge and understanding to improve learners' performance influence on previous knowledge. Therefore, the research assumes that teachers with experience in biology required to process RR skills may enhance their performance and deepen their knowledge and understanding.

However, studies showed that science teachers lack Pedagogical Content Knowledge (PCK), Declarative Knowledge (DK), and tools that will present and process their disciplinary knowledge to work to narrow the gap between their knowledge and their students (Zohar, 2006; Zohar & Barzilai, 2013). The effectiveness of teachers in their classrooms is reduced if they lack sufficient comprehension of the subject matter (Rollnick et al., 2008). On the contrary, when teachers participate in content-focused professional development, their student learning is improved (Yang et al., 2020).

Specifically, biology high school in-service teachers need knowledge and skills for effective professional development to improve their capacity to adjust and deal with changes in teaching. Thus, biology teachers should be treated with knowledge beyond facts or concepts and know how to explain their discipline's comprehensive structure and fundamental principles (Rozenszajn & Yarden, 2014a, 2014b). Still, although opportunities for professional development are often given to in-service teachers, these opportunities are usually generally not focused on advancing teachers' understanding to higher levels. There is lacking description of teachers' thinking, which emphasizes what science teachers understand and not what teachers do (Schneider & Plesman, 2011).

Therefore, this research assumes that to determine what in-service teachers know and need to learn, we must understand their knowledge and thinking processes. Thus, the current research offers RRs' professional training that aligns with biology teachers' specific needs to promote their in-depth knowledge and as a result their students' knowledge.

Since the curriculum is essential in promoting teachers 'content knowledge (Arzi & White, 2008), researchers have argued that science textbooks as a key learning material for teachers, can also be part of teachers' professional development and, thus, promote their learning (Roseman et al., 2010). However, promoting teachers' learning through textbooks is contingent on how the texts have been written and their reference to teachers' prior knowledge (Ball & Cohen, 1996). Furthermore, research findings have highlighted the significance of modifying textbooks to align with the demands of a dynamic world and the essential 21st-century skills including HOTs emphasized in current curricula (Bayrak-Ozmutlu, & Yaylak, 2021; Pratama & Retnawati, 2018; Roseman et al., 2010; Rozi et al., 2021; Trisnayanti et al., 2021; Vojíř & Rusek, 2019). Therefore, textbooks that reflect the objectives of the science curriculum emphasizing HOTs are still a primary pedagogical tool, serving teachers and students alike in promoting learning (Sanders & Makotsa, 2016). However, the quality of science textbooks depends on their effectiveness in explicitly using HOTs to provide clear explanations for abstract concepts and various verbal representations so that learners know how to use them.

Based on the accumulation of studies mainly on learning analogies illustrates that applying HOTs is essential for science learning, this research also aims to examine how applying RRs considered HOTs by identifying RRs' expressions in biology textbooks assists in achieving a scientific understanding as required in biology learning.

As said above, many studies deal with the importance of explicit HOTs, analogies promoting learning, and understanding science textbooks' contents. However, no textbook studies examined all four RR skills - except for analogy, including antinomy, anomaly, and antithesis.

In addition, RRs are studied by various demographic groups, such as students, pre-service teachers, and in the classroom, mainly in analogies. However, no research currently investigates how in-service teachers acquire RRs and their impact on their knowledge, specifically enhancing their biology comprehension.

This research expands the literature, examining how in-service biology teachers in Israel explicitly acquire all four RRs and their impacts on their biology knowledge and understanding.

Overviews of the Studies

Regarding the above, the researcher conducted three studies:

Study 1 examines the extent to which RRs appear in the content of different representations included in three middle school life science textbooks with biological content published in Israel. Study 2 Part I (Quantitative) examines the effect of the biology teachers' intervention program on learning RRs, as expressed in their performance in applying types of knowledge and RRs. Study 2 Part II (Qualitative) examines biology teachers' difficulties and strategies in learning RRs for application.

Study 1

Textbooks are supposed to reflect the requirements of the curriculum following the objectives of science education. Accordingly, the updated curriculum in Israel 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 HOTs 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, and building new knowledge is also explicitly addressed (Eisenberg & Selivansky, 2019). However, the gap between the declarative nature of these goals in the curriculum and the content 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).

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

- What are the implicit expressions of the four RR skills in textual or graphical representations from the biology textbooks used in Israeli junior high schools?
- What is the explicit expression of the four RR skills in textual or graphical representations from the biology textbooks used in junior high school?
- What is the distribution of the four RR skills in biology textbooks?
- What is the prevalence of implicit and explicit expressions for RR skills?

The data for this study were collected from three biology textbooks used for eighth grade in junior high school in Israel (Arielli & Yarden, 2013; Bar-Ilan Institute of Integration, 2012; Keynan et al., 2012). All three textbooks are adapted to the updated syllabus and 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.

For this study, four criteria (C1-C4) were used to analyze the content of science textbooks based on criteria in the literature regarding analogies and HOTs (Devetak & Vogrinc, 2013; Orgill, 2013) adapted to the other RR skills. RRs Type (C1) included Analogy; Antinomy; Anomaly; Antithesis. Text Type (C2) included text, question, or activity. Each RR skill's mapping Process (C3) includes three levels from the lowest to the highest level (Implicit mapping, explicit partial mapping, and full mapping). The analog mapping process leads learners from low relations to an analog pattern of high similarity relations (Gentner, 1983; Gentner & Colhoun, 2010). According to the literature, the researcher developed a mapping process for the other three RRs (antinomy, anomaly, and antithesis).

The Use indication of skill (C4) includes explicit instructions 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. The researcher developed an index based on the analysis criteria of the emergence of explicit RR skills and their use in the types of texts. This index cross-referenced the mapping findings (C1), usage (C3), and text type (T1, T2, T3).

Study 1 Summary Findings

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 partially explicit text types (34%) or explicitly expressed in terms of RRs

(14%). There is a high frequency of questions relating to RRs (63%), at all explicit and implicit levels, which appears to be significantly higher than verbal or visual texts (29.5%), or activities (7.5%). From the question-type texts, there is a high frequency of antinomy questions at an implicit level, requiring a low level of thinking (23%). The number of types of texts running a low level of thinking (38%) is slightly higher than those running with a high level of thinking (32%). Activity text types at the highest level of explicit and the high thinking level of using RRs were found with the lowest frequency of all the text types analyzed (less than 2%). Since the success index of biology textbooks is a combination of explicit texts for RRs, i.e., a mapping process for RRs, along with explicit instructions for the learner to use any RR skill, by knowing how to apply a high level of thinking like in problem-solving, therefore, these texts are probably not sufficiently deep to ensure scientific understanding.

The explicit degree of all four RRs in the biology textbook is rather low, compared to the 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 the researcher 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.

Study 2

Science teachers teach biology in junior and high school (grades 7-12), have taught biology for at least three years, and have at least a bachelor's degree (in biology or any scientific field that includes biology studies). The sample included 45 volunteer teachers (N=45) who were randomly assigned to two groups: an intervention group (N=25) and a control group (N=20). Over three months, intervention teachers were trained to use RRs with biology content. Pre- and post-intervention tests were administered before and after the program. At the same time, the teachers of the control group who did not receive the RR intervention program answered two tests in each of the pre-post stages with the same three-month difference.

Study 2 part I aims to examine the effects of the RR intervention program on biology teachers' knowledge and comprehension. Accordingly, the study 2 part I question is: What is the RRs training program's contribution to Biology teachers’ knowledge and understanding?

For study 2, part I tools have used the Test of Relational Reasoning -TORR (Alexander, 2012). Assessing the ability to identify RRs patterns within visuospatial stimuli. In addition to the Test of Biology and RR- TOBARR which was developed by the researcher for applying RRs in biology content and knowledge types of applications-SMK includes conceptual and MSK including procedural, declarative, and conditional knowledge.

The hypotheses (H1-H3) stated that these aspects would increase following the intervention program. H1: The level of generic RR skills application in the intervention group will increase following the intervention compared to the control group (Alexander, 2019). H2: The level of the RR-skills application in the biology content of the intervention group will increase following the intervention compared to the control group (Alexander, 2019). H3: The level of knowledge applications (dimensions) will increase following the intervention compared to the control group (Alexander et al., 2016a, 2016b; Danielson & Sinatra, 2018; Pilegard & Mayer, 2018).

Study 2 Part I Summary Results

The results support the hypothesis that biology teachers' RRs performance -analogy, anomaly, antinomy, and antithesis, in TORR and TOBARR, considerably increased following the intervention program. In comparison, no change occurred in the control group. In addition, biology teachers' RRs' implementation of all types of knowledge - Subject Matter Knowledge (SMK), including conceptual knowledge, and Meta Strategic Knowledge (MSK), including conditional, procedural, and declarative knowledge, significantly increased following the intervention program.

Results of the application of RRs based on intervention teachers' performance in TOBARR indicated that about a third of teachers failed to utilize analogy in the prephase. In the post phase, the highest percentage of teachers applied post-analogy at the highest level and descending order: anomaly by a small margin, antinomy, and antithesis, which was the most difficult to apply for. However, most teachers were unable to apply in very high percentages the other skills in ascending order – an anomaly, antinomy, and antithesis. Compared to the pre-and post-test results, the teachers made significant progress in applying anomaly and antinomy, followed by antithesis, which was applied with less progress.

Study 2 Part II

This study examines the contribution of a training program to developing RR ability among biology teachers on two main questions examined:
What are the teachers' main difficulties in implementing Relational Reasoning skills (RRs) to process scientific content in Biology?
What are teachers' primary coping strategies for these difficulties in implementing Relational Reasoning skills (RRs)?

The intervention was conducted as action research with biology teachers using the explicit MSK instruction model for HOTs (Zohar & Ben David, 2008), adapted for this study for modeling the use of RRs. The researcher modeled how the four RRs are processed with cognitive actions- encoding, inferring, mapping, and implementation- appearing in studies only in the context of application with analogies (Grossnickle et al., 2016). The tools' study used RR task-solving, and reflective discussions using the 'protocol aloud' analysis method (Ericsson, 2017) and open cognitive interview method (Wolcott & Lobczowski, 2021) to reveal important insights about teachers' subjective difficulties during the RRs implementation and their coping strategies while solving tasks. These instruments were performed by recording the teachers' discourses and joint activities with teachers' pairs during the RR intervention teamwork.
Findings related to the first and second questions - Biology teachers’ difficulties and coping strategies in applying RR skills. Four themes and categories are based on Efklides' (2006) metacognition components: Teachers' negative feelings and coping strategies about applying RRs, Teachers' negative attitudes and coping strategies about applying RRs; Teachers' positive feelings and coping strategies about applying RRs; Teachers' positive attitudes and coping strategies about applying RRs.

Study 2, part II summary findings

revealed that all teachers reported difficulties applying RRs, including mapping RRs patterns, and analogical transfer, misunderstanding, and frustration with RRs for using, confusion in RR skills' definitions, confusion in distinguishing the cognitive actions for use, un-confidence, lack of knowledge in a specific subject or field, graphical representations of RRs mainly antithesis, and concerns about expected teaching with RRs.

Study 2 (part I and Part II) conjunction findings

Study 2 findings revealed significant patterns demonstrating how teachers' coping strategies reflect their knowledge level. During the dynamic RRs' learning process, most teachers' feelings and attitudes shifted from negative to positive. It was found that most teachers used ineffective strategies to deal with difficulties applying skills in the early stages of the RRs' learning process. However, 52% of the teachers with lower and medium levels of knowledge performance progress from using ineffective strategies to effective ones. As the study progressed, most of them used aid intervention tools reported as effective strategies (using cognitive actions and collaboration strategies). 32% of the teachers with high knowledge levels performance developed personal effective strategies. 16% of them demonstrated the highest levels of knowledge and RRs applying. In contrast, 16% of teachers who reported difficulty due to insufficient knowledge could not produce strategies to overcome their difficulties. They were almost unchanged in their feelings (such as unconfident and understanding) and performance throughout and following the RRs' intervention process.

Study 2 points out the differences that emerge from teachers' feelings and attitudes expressions regarding their difficulties in implementing RRs and strategies to cope with them depending on their knowledge performance. Accordingly, teachers' responses can be divided into three patterns with the following characteristics: I. Teachers with insufficient knowledge used less precise language in their thinking and focused mainly on their lack of knowledge of scientific phenomena; They struggled with understanding how to use RR skills to explain scientific phenomena; They could not develop strategies to overcome their difficulties in identifying high relations for mapping the skills; They could not provide their students with the expected teaching strategies for learning RRs.

II. Teachers with higher knowledge performance used expressions for their difficulties that showed the language of thinking. As part of the learning process, they suggested appropriate strategies to deal with the main difficulty of mapping skills. However, they could not implement them in the initial phase. As a result, they could have benefited more from the strategy. Therefore, the strategies were ineffective for them; At an advanced stage of the RRs learning process; They expressed positive feelings and attitudes of satisfaction with their progress in overcoming the difficulties of applying the skills by mentioning effective strategies developed independently; Their attitudes revealed a willingness to experience challenges and encouragement for independent study and development of thinking both for themselves and their students; They knew how to explain in detail how they would learn skills with their students (mainly analogies), in future teaching. III. Teachers with intermediate-level knowledge performance asked for instructions with clues to the solution, or examples of correct answers as an effective strategy; They consistently used cognitive actions which was a tool for them that helped them understand the use of skills for their application.

General Conclusion

The intervention program designed for this study significantly improved biology teachers' performance and knowledge applications by implementing RRs. The level of all types of knowledge applications (subject matter knowledge (SMK), including conceptual knowledge and knowledge representation, and meta-strategic knowledge (MSK), including procedural, declarative, and conditional knowledge, increased following the intervention program. As a result, teachers could map higher-order relations between phenomena, better represent relations, better explain how to use RRs, and justify when and how to do so. Thus, using RRs enhanced teachers' knowledge and deepened their understanding.

The application level of the RRs (analogy, anomaly, antinomy, and antithesis) in TORR and TOBARR increased following the intervention program. At the highest level, the analogy was applied, followed by anomaly, antinomy, and antithesis in descending order. Using cognitive actions (coding, inference, mapping, and application) helped teachers identify and map relations from low to high order. Teachers who applied a skill knew how to map the pattern of relations of the skill (relations of similarity and difference or abnormality or inconsistencies or contrasts), identify the problem, and explain the scientific principle behind the phenomenon. Thus, the teachers who applied at least one RR skill in the TOBARR showed an understanding of the phenomenon. Teachers who applied more than one RR skill to the same phenomenon improved their overall score, indicating their level of expertise. Since identifying pattern relations to RR is one of the characteristics of experts, this study indicates a tendency for teachers' expertise to improve.

Learning RRs was difficult for all the teachers. Difficulties characterize the stages of acquiring new skills, such as confusion, frustration, lack of confidence, and lack of understanding of using skills. The main challenge was mapping a pattern of higher relations for each RR skill. In addition, teachers found it harder to map higher-order relations in a scientific principle to explain a phenomenon than to identify those relations in a phenomenon without explanation.

Knowledge was one of the significant factors for success in applying RR skills. A lack of sufficient SMK and MSK characterizes teachers with the lowest performance level. However, most teachers with various knowledge performance levels made significant progress in identifying relations of RRs for application.

Teachers created strategies to deal with difficulties in implementing RRs. Teachers who developed effective strategies to overcome difficulties had high knowledge performance levels. Teachers who developed ineffective strategies or did not use strategies at all had the lowest knowledge performance. As experienced teachers, most teachers developed strategies that effectively overcame the difficulties they encountered during the intervention, including collaborative learning strategies. The teachers with the highest knowledge performance level developed effective strategies with characteristics of independent learning, such as demonstrating intelligent use of knowledge to locate relevant examples; Demonstrating proactive involvement in learning with colleagues, such as striving for different perspectives and disagreements in justifying the identification of the appropriate skill to explain the phenomenon. Teachers with lower knowledge performance levels mostly used more effective external strategies such as mediation, continuously using cognitive actions for mapping, receiving solved answers, and support and feedback from colleagues in collaborative learning. The very few teachers with the lowest knowledge performance levels did not develop strategies or developed ineffective strategies, such as misconceptions. They did not show proactive involvement in collaborative learning and often avoided participating because they feared making mistakes.

Teachers proposed expected teaching strategies corresponding to their experience coping with the difficulties of processing RRs. Thus, teachers who were open to being challenged made a mental effort, were courageous, and were not mentally fixated on the right answer offering appropriate teaching strategies to their students. For example, conducting inquiry emphasizes process or allocating time for students' discussions about meta-strategic thinking focusing on skills. Those teachers explained in detail how they would apply the RRs in their classrooms, except for the antithesis. Conversely, teachers relied more on external help in dealing with uncertainty. By projecting their struggles and strategies onto struggling students, they suggested anchors or adjusting tasks according to their thinking abilities.

The explicit meta-strategic teaching model of RRs contributed significantly to teachers' progress. An explicit meta-strategic guidance model demonstrated to teachers how to use each skill using cognitive actions to map relations and the requirement to transcribe thinking aloud during problem-solving and receive explicit instructions to identify each RR skill by stating its explicit name and explaining its use - how, when, and why. Nevertheless, most teachers had difficulty mapping high relations to RRs. Only half of the teachers could perform analog mapping and, in descending order, the other skills. RR mapping and partially explicit RRs levels in textbooks make it difficult for teachers to understand scientific phenomena in various contexts and to transfer these skills to students.

An interesting conclusion regarding the explicit use of the skills refers to teachers' teaching strategies for learning RRs that did not specify the explicit skill name. The teachers did not connect the skill name and its application. They wanted to avoid confusion in their students' definitions of the different skills. In the textbooks, RRs are presented without explicitly mentioning its name. This issue emphasizes the correlation between explicit skills names missing from textbooks and teachers' attitudes about the importance of explicitly teaching RRs' names.

The level of application of antithesis among the teachers was the lowest compared to the other skills in the TORR and TOBARR- tests. Teachers found it difficult to apply antithesis more than the other skills and by a considerable margin. There was primary difficulty graphically for teachers to identify the cause of inverse relations in the phenomenon on a graph and struggled to use it through variable representation on a continuum. In science textbooks, antithesis appeared more familiar to teachers as rebuttal arguments for and against, with a very low frequency. The textbooks lacked representation of the antithesis skill in its graphical meaning, except for one single graph in one of the three textbooks tested. As learners themselves, teachers must understand the meaning of the concept and application of antithesis if they intend to apply the skill to their students.

There is a high prevalence of antinomies in textbooks, significantly different from the rest of the skills. However, only about a quarter of teachers could map antinomies for their application. The appearance of antinomies with greater frequency in textbooks than in skills indicates the importance of science learning. Most antinomies appear partially explicitly in textbooks. It is imperative that teachers who use textbooks to sort concepts into categories develop antinomic thinking for deep understanding so that they can direct their students to the tasks required for antinomic thinking that indicate deep scientific thinking and understanding.

The research's bottom-line conclusion is that biology teachers have inadequate deep scientific knowledge and understanding. Progress in applying RRs and knowledge types indicates that learning biology with RRs is essential for professional development and updating science materials as textbooks- to advance their processing of complex information for problem-solving. The more teachers deepen their scientific knowledge and understanding they will demonstrate expertise and the more they can help their students build their knowledge.

The research contribution is locally conducted in Israel and examines how learning RR thinking skills affect biology teachers' knowledge and understanding. However, its aspects are also universal. It deals with developing RRs characterizing experts to solve problems researched on students' learning in different countries and cultures; The universal effect of teachers' professional development using a meta-strategic method on types of teachers' knowledge; Using a quantitative research TORR test, one of which is used in worldwide research. The researcher developed the TOBARR test, which deals with disciplinary content in biology and can be translated into any language. The science textbooks examined for this research are approved by the Israeli Ministry of Education and are common in junior high school science teaching. However, they are based on the OECD curriculum. Therefore, the qualitative analysis index developed to analyze the quality of these textbooks from the aspect of thinking development has a universal contribution to analyzing scientific textbooks in different countries and cultures.

Research Theoretical Implications

This research showed progress in learning all four RRs in biology teachers' thinking and understanding, not just analogies. This research responds to the need for in-service biology teachers for professional knowledge and skills to improve knowledge and understanding through acquiring RR skills to explain scientific principles and thus contribute to teachers’ teaching; Examining the effect of biology teachers' knowledge applications in problem-solving based on their performance; Developing strategies to cope with difficulties in learning RR skills for problem-solving.

Research Methodological Implications and Recommendations

This research responds to the need for in-service biology teachers for professional knowledge and skills to improve knowledge and understanding through acquiring RR skills to explain scientific principles and thus contribute to teachers’ teaching. Examining the effect of biology teachers' knowledge applications in problem-solving based on their performance. Developing strategies to cope with difficulties in learning RR skills for problem-solving.

Contribution to Knowledge- A New Model

The researcher developed the model based on qualitative analysis of teachers' reports, attitudes, and feelings about their difficulties and coping strategies during the RRs learning. As well as on their quantitative performance of types of knowledge. Accordingly, this model presents two main variables: A. The knowledge variable includes the types of knowledge - knowledge of scientific content in biology that includes conceptual and meta-strategic knowledge, at two levels - high and low. B. The strategies to deal with difficulties are divided into effective and ineffective strategies.

Thus, the four levels of teachers' knowledge and strategic effectiveness represent four different teacher profiles. Profile A - teachers who demonstrate high knowledge and can develop effective strategies. Profile B- teachers who demonstrate high knowledge and use ineffective strategies. Profile C - teachers who demonstrate low knowledge and can develop effective strategies. Profile D-teachers who demonstrate low knowledge and use ineffective strategies. However, among the teachers examined in this study, there was no characterization of teachers that fit the profile of a high level of knowledge and an ineffective strategy. Based on the research findings, it is likely that most teachers knew how to produce effective strategies due to their experience in combination with providing methods such as collaborative learning and thinking aloud, which enabled the conditions to raise meta-cognitive awareness of negative and positive learning experiences. Therefore, it is more appropriate to represent teachers in scale research at the ends of two contrasting profiles in knowledge and strategic efficiency and a continuum of knowledge and coping strategies with changing tendencies. Nevertheless, the dichotomous division of the model into four types of profiles aims to identify the critical characteristics of each profile. This is to provide appropriate and more accurate guidance and approaches for learners with learning difficulties. Accordingly, a learner with a certain profile can advance to another profile due to the dynamic nature of development in the learning process.

Further Research

The assessment questionnaire was developed based on in-service biology teachers. It can be used for further research within biology teachers' professional development courses or other scientific fields emphasizing problem-solving learning processes through high-thinking skills such as RRs. Additional studies with in-service teachers, beginning teachers, and teaching training students may expand the number and variety of assessment questions and refine the indicator to adapt to specific contexts of complex learning.

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