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**THE RELEVANCE OF RELATIONAL REASONING ABILITY TO
IN-SERVICE BIOLOGY TEACHERS' KNOWLEDGE**

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Abstract

Processing biological content requires cognitive abilities such as creating meaningful relations among pieces of information that link from the macro-level to the micro-level. Cumulative evidence indicates that Relational Reasoning (RR) cognitive ability, comprising the four RR forms - Analogy, Anomaly, Antinomy, and Antithesis, is very relevant for science domains. Findings have shown that acquiring RR forms enables science learners with sufficient knowledge of a specific domain to enhance their understanding of the phenomenon by effectively discerning meaningful relations patterns in the new information. Researchers argue that acquiring RR forms can promote productive learning and academic performance in sciences among students, pre-service teachers, and teachers while teaching, as well as RR forms implantation difficulties. However, due to lack of studies that have investigated in-service teachers, it is unclear how they have acquired RR forms in a specific discipline and how they have coped with challenges to implement RR forms while processing new data. With a focus on the multidimensional structure of RR, this paper illustrates the four RR manifestations within the context of biology. It emphasizes that the implementation of RR skills requires specific knowledge and mental efforts when using cognitive processes of coding, inference, mapping, and application in sequence, in order to process new phenomena efficiently. The importance of this paper lies in the proposal to examine how occupational biology teachers with experience and knowledge in their discipline who will train in RR skills in intervention program research, will be able to process new knowledge effectively and thus improve their teaching.

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1. Introduction

This paper argues that RR forms are relevant to the discipline of biology for in-service teachers, who have experience and knowledge in their discipline. Relying on the literature in the distinction between Relational Thinking (RT) and Relational Reasoning (RR), I will demonstrate examples from the biology content that showing how specific knowledge and cognitive processes, which required mapping high-order relations among identified low-order relations, can promote understanding of a biological phenomenon.

1.1. High-Order Thinking and Relational Reasoning

The cognitive and educational literature presents many different definitions for the concept of 'High-order thinking'. Unifying all the definitions requires applying complex skills in diverse content. Researchers concur that high-order thinking facilitates the creation and development of new knowledge beyond the given knowledge. Applying a critical and analytical thinking approach for the purpose of assessing processed information, leads to the desired product (Bloom, 1984; Costa, 2006; Lewis & Smith, 1993; Resnick, 1987). Simultaneously, this develops the learners' meta-cognitive awareness of the processed information meaning and problem-solving capabilities. The use of higher-order thinking skills can bring about a fundamental change in the knowledge of students and teachers (Zohar, 2006).

Studies of science education have indicated a gap between the flow of information accessible to learners and the latter's ability to use it in a meaningful way in order to build their bodies of knowledge (Alexander, 2016; Jablansky et al., 2019). Efficient use of information for developing an in-depth understanding and for solving problems in the 'real' world, is an essential part of a young adults' 'readiness for life' (OECD, 2019; Pellegrino & Hilton, 2012).

Relational Reasoning (RR) defined a foundational human cognitive ability of discerning meaningful patterns within unconnected information, as well as of deriving overarching patterns from sets of relations (Alexander et al., 2012; Bassok et al., 2012; Goswami, 2013). Indeed, findings have shown that RR as a core capability of processing data is required for most modes of high-order thinking (Alexander, 2017).

1.2. The Relational Reasoning (RR) Skills

Relational Reasoning researchers identified four skills of RR manifestations that frequently appeared in academic contexts: analogy, anomaly, antinomy, and antithesis (Alexander, 2019; Alexander et al., 2012; Alexander et al., 2016a; Alexander et al., 2016b; Dumas et al., 2013). Then, this paper presents the importance of processing each RR skill in a biological context in order to promote building new knowledge, as well as the challenges of implementing the forms in the process of their acquisition and instruction.

1.3. Analogy

Analogical reasoning involves comparing two distinct scenes or events, identifying similarities between them, and using these similarities to transfer what is known about the more familiar target to the less familiar one (Holyoak, 2012). RR facilitates analogical transfer by extracting underlying structures that are applicable across variable contexts with variable surface level features (Kalkstein et al., 2020). Kalkstein et al. (2020) demonstrate an analogous transfer by solving a simple problem of preventing rain from wetting a person by using a newspaper as an umbrella. It serves the same purpose, focusing on imagining relations of role instead of the objects' external appearance (which is considered as lower order relations). Furthermore, the same basic process works in solving more complex problems, such as using a pump as analogous to the understanding and rebuilding a healthy functioning heart. For example: A water pump function of which is to transport seawater through thick and large pipes for cooling a nuclear reactor. A small pipe coming out of the large pipes carries water and cools the water pump itself so that it does not overheat. A blockage in the small pipe due to the accumulation of erosion may accelerate the pump's heating until it stops working. Similarly, the coronary arteries surrounding the heart and branch off from the large and thick aorta, supply the heart muscle with oxygen and energy. The blockage can prevent oxygen from entering the heart, and causing a heart attack that is fatal to the entire body. An analogous transfer is made by understanding the smaller pipes' role that causes the blockage in both pumps, despite the differences.

Success in solving problems with four RR skills requires cognitive processes of coding, inference, mapping, and application. Completion of these processes in sequence results in the establishment of high-order relations from low-order relations that appear among isolated items (Grossnickle et al., 2016). Accordingly, in our analogy, learners should first identify both pumps - heart structure components and their properties (type of pipes, thickness and location, fluid flowing and direction). Next, learners should infer the role' similarity of low-order relations that are not explicit, such as the pump's thick pipes in pumping water to the nuclear reactor or pumping blood with oxygen to the heart, respectively. In the mapping phase, learners should identify a higher-order relations pattern, i.e., the cause for the failure, by mapping higher relations from the lower order relations ('relations on relations'). That is, the identification of the blockage pattern in the pipe caused by the function of the small pipes in relation to the role of thick pipes. The implementation stage, resulting from an analogous transfer, is a reasoned explanation that can promote productive solutions implying. In our analogy, the use of surgical procedures. High-order relations mapping results determine the RR forms represented in the information (Alexander, 2016; Chi & Van Lehn, 2012; Dumas et al., 2013).

Acquisition of relational domain knowledge enables content-specific but potentially rapid improvements in analogical reasoning since aligning relations in an analogy requires some knowledge of those relations (Simms & Richland, 2019). However, transferring this content is not just a matter of having sufficient knowledge of a source domain (Richland et al., 2017). It is also the incorrect information conveyed by the analogy, as well as the learners' ability to debug the incorrect information and reasoning (Schunn, 2017).

1.4. Anomaly

Anomalous reasoning requires the ability to identify discrepancies in a typical pattern and demands additional base knowledge, namely the understanding of a norm that raises challenges in capturing this ability (Trickett et al., 2009). In experts' clinical practice, anomalies occur when medical test results do not match hypotheses derived from previous patients' history (Dumas et al., 2014). For example, diagnosing symptoms of a heart attack caused not as a result of a coronary arteries blockage, as experts are accustomed to predict first, but caused by an unexpected factor. Dealing with anomalies during information processing is critical to the generation of conceptual changes among learners. Nevertheless, anomalies sometimes challenge students' misconceptions in very useful ways, yet sometimes they introduce new 'red herrings' (Schunn, 2017). Thus, students tend to ignore or reject anomalies when they encounter scientific data that do not conform to the theory they have built or when they cannot provide appropriate explanations for their rejection or acceptance (Chinn & Brewer, 1993; Chinn & Malhorta, 2002).

1.5. Antinomy

Antinomian reasoning is to what a class or category, an object, or idea does not or cannot belong, as is commonly required by categorization or classification tasks across different educational settings (Jablansky et al., 2019; Shuwairi et al., 2014). For example, categorical association based on the identification of characteristics unique to the simple heart structure of a class of fish, does not match the more developed heart structure with two blood cycles, according to the characteristics of other classes of animals. Antinomies can be formed with students, or on a different level, as an essential part of scientists' decision-making process, in this case, when they need to decide about placing a new species in the evolutionary tree. Another example of antinomy can occur when experts must decide whether a particular symptom is relevant to heart disease caused by an artery occlusion but it does not belong to another heart disease, when they need to decide on the provision of appropriate treatment.

1.6. Antithesis

Antithesis-based thinking refers to sequences. It is necessary to determine an attribute of an object/phenomenon on a sequence of dimensions the two ends of which are relative opposites of the same attribute or variable (Bianchi et al., 2011). For example, various severity degrees on a scale of an artery occlusion in a person's heart during his or her life, can entail implications for providing appropriate treatment. Or, when biology learners represent a developmental sequence scale that includes opposing trends of the improvement degree in organisms' evolutionary survival with more complex systems and, vice versa, in more superficial system vessels. For example, the development sequence of the heart structure in the fish's heart, oxidized blood mixes with the non-oxidized blood. When we look at reptiles, and other animals, the heart of reptiles and amphibians is developed by having two ascents and part of two blood cycles. When in birds and mammals, complete separation between the ascents and the ventricles and mixing of oxygenated blood and non-oxygenated blood is avoided

In science education research, refutation texts leverage antithetical reasoning in order to improve science learning and conceptual change. For example, common misconception such as, “climate change is a natural phenomenon, not caused by humans” requires learners to present counter-arguments (Danielson & Sinatra, 2017; Dumas & Dong, 2020).

To sum up, RR, as a multidimensional structure, requires high mental involvement. Identifying RR forms for dealing with new data, enables learners to effectively implement and attain an in-depth understanding of the phenomenon being examined (Dumas et al., 2014; Grossnickle et al., 2016).

1.7. Relational Thinking and Relational Reasoning

Alexander and Baggetta, (2014), distinguish between ‘Relational Thinking’ (RT) and ‘Relational Reasoning’ (RR). The first concept can be characterized as more external, relatively effortless and unconscious, and thus considered as lower processing relations. For example, infants identify similarities and differences by recognizing the unique melody of their mother's voice as opposed to other voices. (Mandler, 2008). Identifying direct information relations almost intuitively is an implementation of RT. Conversely, the second concept has a more enduring, representational quality on the human mind. It is considered as a meta-strategy that entails effortful processing of similarities and differences in identifying underlying concepts (Alexander & Baggetta, 2014; Jablansky et al., 2019).

Similarly, Dumas and Dong (2020) describe a terminological distinction that perceives RT as system 1, while RR and critical and analytic thinking, both processing new information, as System 2. RR is most typically described, operationalized, and measured as an effortful system 2 cognitive ability. These researchers argue that learners who have sufficient background knowledge can use RR forms for discerning many of the significant relations in order to critically assess the correctness of a new claim (Dumas & Dong, 2020).

Consequently, in biology, learners with sufficient scientific knowledge, who have been exposed to a new argument, such as 'organism formed from inanimate matter' (the Abiogenesis concept), are able to perceive the claim as having an anomalous nature. Noticing anomalies in the first step is a critical predictor of conceptual change in science (Chinn & Malhorta, 2002). The second step in processing relations is an analogical mapping, for instance, between recent arguments like those from laboratory experiments that succeeded in creating "building blocks" of life, and the common arguments from ancient times, like Aristotle who believed that certain organism were made of "ancient soup". In order to perform the antinomy, learner must assess both claims about the formation of organism or the formation of inanimate matter, using unique characteristics for each of two categories. By refuting the concept of abiogenesis from opposite points of view, learners can choose a persuasive argument. For example, using Pasteur's revolutionary experiment for proving that even simple organism such as bacteria created from bacteria that precede them.

However et al. (2020), pointed out several well-known factors that can explain why an individual cannot always use mental efforts to think critically and to analyze high-order relations while encountering new data to solve new problem, such as: lack of sufficient knowledge; an inability to discern patterns in the information flows; lack of motivation can create believes' conflict (Dumas & Dong, 2020).

1.8. Characteristics of RR with Acquisition Processes

Indeed, prior knowledge of the domain suggested RR ability as a significant factor in fostering the development of academic learning, specifically for analogies. Other internal and external factors affecting the ways RR is used, malleable and teachable are: prior experience with the task at hand and with reasoning; the characteristics of the domain itself; and the context in which reasoning is performed, including collaborative setting (Alexander et al., 2016a; Dumas, 2018; Murphy, Firetto, & Greene, 2017). Researchers who focused on the situated acquisition of the RR ability in a specific domain developed the KReC model, demonstrating how RR can promote knowledge revision while reading (Kendeou et al., 2017). Nevertheless, it has been suggested that training teachers in pedagogies that incorporate RR, analogy in particular, has improved pre-service teachers' teaching performance (Dumas, Alexander, & Grossnickle, 2013).

RR has been studied mainly in the science domain and by different population groups including students, pre-service teachers and in-service teachers while teaching (Dumas, 2018; Gray & Holyoak, 2019). However, no study has examined the ways by which in-service teachers acquire RR, as well as the effect of its acquisition on their disciplinary knowledge.

1.9. Relational Reasoning and The Science Domain

RR ability is highly relevant to the nature of the different science domains and may foster their productive learning. RR may promote conceptualization of science-based of representations and models by meaningful mapping of the many representations of different modalities used in science. RR ability (especially in identifying anomalies and antithesis), may support conceptual change, required due to the alternative theories and students' misconceptions in science. It promotes argument discourse based on evidence, and may bridge the gap between direct experience and phenomena at extreme scales (Alexander, 2017; Dumas et al., 2013; Kendeou et al., 2017; Resnick et al., 2017).

1.10. Relational Reasoning in Biology Instruction

Biology discipline covers a wide range of explanation levels, from the molecular and cellular levels to the entire biosphere level. Biological phenomena are often addressed and investigated from the hierarchy of multiple entities - cells are nested within tissues, and so forth. The complex systems encompass different but related processes on different levels that cannot be captured by any single-level explanation. The challenge to understand such complex systems is rooted in the counterintuitive nature of many emergent phenomena, often non-linear interaction patterns (Kokkonen & Schalk, 2020).

Ecological systems are frequently modeled as complex systems in which different representations capture different levels of explanation. External representations vary in the amount of their perceptual and conceptual information. The more perceptually rich they are, and the more familiar they are to learners, the easier it is to infer the changing attitude of a concept or goal principle (Fyfe & Nathan, 2019; Kokkonen & Schalk 2020). Indeed, representation on the concrete level activates the relevant prior knowledge. Nevertheless, non-tangible schematic representation leads to the construction of knowledge representation that can be more easily applied in new problems (Kokkonen & Schalk, 2020).

Processing biological content requires abilities, such as abstract systematic thinking and establishment of meaningful relationships among pieces of information linking from the macro-level to the micro-level (Harrison & Treagust, 2006). Moreover, learners need a systemic thinking for focusing on some basic components of biology systems directly observed or linked to their prior knowledge, and for making sense of the complex interdependence relations within and across levels (Chi & VanLehn, 2012; Verhoeff et al., 2018).

RR is a multidimensional ability includes four RR skills which relevant to biology when systemic thinking is needed, and can promote abstract thinking and problem solution on a complex level (Alexander, 2019; Kusmaryono et al., 2018). Yet, it is extremely difficult to foster in abstract tasks, even in adults (Simms & Richland, 2019). In the learning of sciences such as biology, teachers aim to improve students' discourse about complex scientific ideas and positively impact students' RR thinking ability (Murphy et al., 2017). Teachers can utilize analogical teaching approaches for the purpose of helping students understand some abstract concepts in biology. However, instruction by analogies does not always improve understanding, and can fail to bring about conceptual change and even mislead students (Resnick et al., 2017).

1.11. Biology Teachers' Knowledge

Some researchers suggest that enhanced 'subject-matter content knowledge' (CK) may offer teachers a wider and more varied repertoire of teaching strategies. On the other hand, limited CK has been conceived as detrimental to 'pedagogical content knowledge' (PCK), limiting the scope of its development (Even, 2011; Kleickmann et al., 2013). Conversely, other studies (Rozenszajn & Yarden, 2014; Zeidler 2002) have shown that an extensive CK in a discipline does not guarantee that teachers use it effectively in their classroom practice. It has been shown that when CK is more under control, chemistry teachers are better able to match the content to the teaching explanations. However, when teachers encounter difficulties in understanding the subject matter, they seem to be less effective in teaching (Childs & McNicholl 2007; Rollnick et al., 2008).

In biology education, possible relations between biology teachers' CK and PCK have been recently measured and found to be low (Juttner et al., 2013). Biology teachers often state that they are very interested in acquiring new CK in biology because they have to stay updated with the continuous flow of new findings in their field (Rozenszajn & Yarden 2014). These researchers have found that in-service biology teachers view CK as a significant component of the knowledge required for teaching biology. However, biology teachers tend to view CK and PCK as separate entities. Unlike novices in their field teachers similar to experts, with an in-depth disciplinary knowledge are able to identify meaningful relations patterns in information, organize it around principles, create complex networks of terms and processes, and efficiently solve problems (Berliner, 2004; Harrison & Treagust, 2006). Nevertheless, teachers lack PCK and 'meta-cognitive declared knowledge' (MDK) about teaching high-order thinking skills (Zohar, 2006). Hence, it is important to know what in-service biology teachers know and what must be understood about their ways of thinking and learning, in order to provide a suitable professional training for their needs.

2. Problem Statement

A gap has been found between the flow of information accessible to students and teachers in the digital era. This includes the ability to organize information and use it in a meaningful way to build their bodies of knowledge (Alexander, 2016; OECD, 2019). Relational Reasoning ability has been studied mainly in science disciplines, doctors diagnosing cases, science and mathematics teachers providing instruction, engineering students designing new products, and different population groups (Alexander, 2019; Dumas, 2018; Gray & Holyoak, 2019). However, no study has examined the ways teachers acquire Relational Reasoning skills, the effect of its acquisition on their disciplinary knowledge and the extent of its appearance in learning materials. The paper will emphasize the importance of processing RR skills to deepen in-service teachers' knowledge in the biology discipline.

3. Research Questions

- This paper refers to the question What is the relevance of acquiring RR skills and their processing by science content teachers in a specific field, in this case, biology, to deepen their knowledge in the area?

4. Purpose of the Study

The purpose of the paper is to illustrate that RR skills implementation requires specific knowledge and mental efforts when using cognitive actions, in order to process new phenomena efficiently. The importance of this paper lies in the proposal to examine how in-service biology teachers with experience and knowledge in their discipline who will train in RR skills in an intervention program, will be able to process knowledge effectively and deepen their knowledge, for improving teaching

5. Research Methods

The paper is a theoretical paper based on various previous studies presented from a recent literature review that discussed the subject of processing knowledge in a specific field with RR skills to advance the knowledge and achievements of learners in the areas of science and biology.

6. Findings

Biology requires students and teachers to efficiently use the information in order to develop an in-depth understanding of schematic representations. This leads to the construction of knowledge representation that can be more easily applied in new problems (Alexander, 2016; Jablansky et al., 2019; Kokkonen & Schalk, 2020; OECD, 2019). Researches have suggested implementing skills for identifying RR forms: Analogy, Anomaly, Antinomy, and Antithesis. These skills allow science learners to merge pieces of information into meaningful units, thoroughly understand this information, and obtain its coherent representations efficiently. Indeed, RR skills may foster productive learning in major scientific

modes of data processing and promote problem solving on a complex level (Alexander 2019; Dumas et al., 2013; Kusmaryono et al., 2018).

RR skills implementation require high-level efforts and mental involvement ('system 2'), (in contrary to RT -'system 1'), for elaborating information by using cognitive processes of coding, inference, mapping, and application in sequence. Learners who have sufficient knowledge can implement RR skills effectively, using those cognitive processes to discern significant relations and solve a new problem. Nevertheless, lack of domain knowledge is a significant factor that can explain why novices have difficulty in mapping high-order relations while facing new data (Alexander, 2017; Dumas et al., 2014; Dumas & Dong, 2020; Grossnickle et al., 2016). Unlike novices in their field, teachers like experts with an in-depth disciplinary knowledge, are expected to identify meaningful relations patterns in the information and efficiently solve problems (Berliner, 2004; Fyfe & Nathan, 2019; Kokkonen & Schalk 2020; Simms & Richland, 2019). However, biology teachers' CK in comparison with PCK was found low (Juttner et al., 2013), and teachers lack PCK and MDK about teaching high-order thinking skills (Zohar, 2006). Nonetheless, biology teachers have stipulated that they are interested in acquiring new CK in biology so that they stay updated in their field (Rozenszajn & Yarden 2014). Consequently, it is essential to know what biology teachers know and what must be understood about their ways of thinking and learning in order to provide a suitable professional RR training adjusted for their needs, emphasizing the promotion of students' knowledge.

Training teachers in pedagogies that incorporate RR have improved pre-service teachers' instruction performance (Dumas et al., 2013). Indeed, RR has been studied mainly in the field of science and among different population groups: students, pre-service teachers, and teachers in classroom interventions (Dumas, 2018; Gray & Holyoak, 2019). However, no study has examined the ways in-service teachers acquire the four RR forms, the effect of its acquisition on their disciplinary knowledge, and the extent of its inclusion in learning materials.

Nevertheless, studies indicate challenges in the process of acquiring RR skills. Indeed, gaining relational domain knowledge facilitates content-specific improvements and transfer (Kalkstein et al., 2020; Simms & Richland, 2019). Yet, analogies demonstrated difficulties in mapping an analogical transfer (Resnick et al., 2017; Schunn, 2019; Simms & Richland, 2019). Anomalies and antithesis may support conceptual change and, with extreme scales, may also promote argument discourse. However, anomalies can be rejected when learners face scientific data that do not conform to their theories (Chinn & Malhorta, 2002). Furthermore, processing biological content requires abstract thinking and meaningful relations between pieces of information that link the macro-level to the micro-level (Harrison & Treagust, 2006) Yet. It is not easy to encourage abstract tasks, even in adults (Simms & Richland, 2019).

RR has been studied mainly in science disciplines, and different population groups (Alexander, 2019; Dumas, 2018; Gray & Holyoak, 2019). However, no study has examined the ways teachers acquire RR skills, the effect of its acquisition on their disciplinary knowledge, and the extent of its appearance in learning materials.

Of all of the RR literature findings which presented above, this paper premise is that biology teachers who have knowledge in their field, required for identifying high-relations in the processing of

RR skills with biological content. Based on the challenges mentioned above, the biology teachers who will participate in the intervention study expected to confront challenges while implementing RR.

7. Conclusion

This paper sheds light on the importance of processing RR skills in complex knowledge as biology. No study has examined the ways teachers acquire RR skills, the effect of its acquisition on their disciplinary knowledge, and the extent of its appearance in learning materials. Therefore, an intervention study will be conducted to examine how in-service biology teachers will train

in RR skills, can enhance their knowledge for enhancing their students' knowledge. Being RR skills relevant for in-service teachers, this paper carries theoretical, pedagogical and practical importance. Theoretically, this paper offers an intervention study which may facilitate in-depth understanding of RR ability in biology content. The data may also advance knowledge about teachers' processes of cognitive skills acquisition and training. Practically, the study will expand knowledge on the effect of RR on teachers' understanding in their disciplinary knowledge, and inform Curriculum developers. The results may contribute to deepening teachers' Meta Strategic Knowledge through professional development to promote meaningful learning by processes of knowledge construction.

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