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METHODOLOGICAL APPROACHES TO THE STUDY OF INQUIRY-BASED LEARNING IN NATURAL SCIENCE EDUCATION

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Abstract

Previous research of inquiry-based learning in natural science education indicates that there are different methodological trends and paradigms in the study of these issues. The aim of this research has been to analyze the selected relevant studies on inquiry-based learning in natural science education in order to assess their scope and limitations in the light of educational changes and reform initiatives. Directions of analysis of the relevant studies include considerations of the following: 1) Theoretical starting points and specific conceptual solutions, 2) Methodological design (research questions / problems, methods, techniques, and procedures), as well as 3) (Re)interpretation of the most significant findings. It could be stated that studies on inquiry-based learning in the field of natural sciences are rather insufficient, very diverse and heterogeneous, differing from each other both in terms of theory and conceptual solutions, research problems, methodological design, and implications for educational work. Even though experiments are very common in natural sciences, it has been found that triangulation is often used as a combination of qualitative and quantitative paradigms. The common thread that connects the selected studies in this field is the recognition of importance of inquiry-based learning as a very promising model of active teaching the natural sciences. It could be concluded that such studies require an interdisciplinary approach to the subject of study, both in empirical and theoretical field, providing better understanding of the future research directions of this phenomenon.
Keywords: *inquiry-based learning, innovative approach, methodological design, natural science education, research paradigms*

Introduction

Review of previous ruling attitudes and understandings of students' independent research work in literature have been exhausted by explanations that the abilities for learning and education are based on long-lasting interests and motives, regular habits of intellectual work, and prevailing attitudes. However, the improvement of access to learning also implies the development of more general learning strategies, as well as problem solving and research, with a higher possibility of transfer. This is inquiry-based learning, which represents the promising concept, and encourages students to become mentally active, motivated, cooperative, able to engage in their own research, and progress in the world of constant change. Constructivism, as an optimal theoretical framework for such learning and teaching, is often suggested as an educational paradigm that fully explains and supports the concept of directions of active

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teaching. Constructivist learning is based on student's active participation in problem solving and critical thinking, marked as learning and "construction" of knowledge (Milutinović, 2005, p. 168). The teacher needs to reinvent himself or herself all the time, proposing activities in the classroom which enable students to build and reconstruct their knowledge (Locatelli, 2021).

In recent years, there has been an increased interest in the research approach in natural science education (American Association for the Advancement of Science [AAAS], 1993; Blumenfeld et al., Gagić et al., 2020; 1991; Linn et al., 1994; National Research Council, 1996). Accordingly, inquiry-based learning has been considered the main pedagogical approach through which the quality of teaching should be improved (Akerson & Hanuscin, 2007; Luera & Otto, 2005; Rocard, 2007). This approach involves merging and intertwining the processes of science and teaching (Artigue et al., 2010), where it is not just about motivating students through engaging in practical activities (Finley & Pocovi, 2000; Wheeler, 2000), but the research is seen as an open process in which pupils and students need to engage their personal experience during scientific research in order to better understand the basic aspects of natural sciences (Linn et al., 1996). Inquiry-based learning is a state of mind that directs students to learn "how" and "why", and master research and discovery skills through gaining experience (Alberts, 2000).

General Background

In contemporary methodological approaches, there is an interest in studying inquiry-based learning by examining the possibility of introducing students to research activities (Grandy & Duschl, 2007, according to: Ristić Dedić, 2013) and putting them in the position of conducting "real" research, such as those conducted by scientists (Kuhn, 2005). At the same time, contemporary computer technologies and educational software attract an increasing attention of the educational and scientific community as a result of their potential to support innovative learning models, among which interactive teaching and inquiry-based learning stand out (Odadžić et al., 2017; Pribićević et al. 2019). There is no doubt that there is an increasing number of studies that contribute to the creation of designs for inquiry-based learning based on contemporary educational technology. Thus, for example, a large number of research and development projects currently study the possibilities of using computers and networks to collect, exchange, and analyze scientific data (Blumenfeld et al., 1991; Linn et al., 1996; Welch et al., 1981).

However, despite an extensive support to inquiry-based learning in documents of educational policy, as well as acceptance of the research approach as the most effective in studying natural sciences (on a theoretical level), it is evident that this approach is improperly implemented in pedagogical practice in most countries (Rocard, 2007). The prevailing approach in teaching natural sciences remains too narrow, limited mainly to knowledge transmission and content-based (Osborne & Dillon, 2008; Rocard, 2007). Approaches to knowledge acquisition based on transmission and reproduction are increasingly subject to criticism (Gajić et al., 2021, p.184). The focus is on the active role of students who acquire new knowledge through independent intellectual efforts in the educational process. Mental activation of students, especially in problem-solving and research, contributes to the increased quantity and quality of acquired knowledge, retention, a better understanding of causality, development of critical thinking, student motivation, etc. (Jukić, 2005). Previous relevant research showed that the research approach is more efficient than traditional teaching (Golde & Koeske, 2006; Haury, 1993; McReary et al., 2005; Oliver-Hoyo et al., 2004; Shymansky et al., 1990).

Therefore, considering and analyzing relevant studies in this field seem justified because inquiry-based learning contributes to the adoption of various (research) learning strategies, as well as the expansion of their repertoire. In students it affects more efficient use of different sources of knowledge, management of cognitive processes, and the overall teaching efficiency.

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The research procedures within empirical research applied in the study of inquiry-based learning in education are diverse and complex. Discovering essential characteristics of phenomena and the structure of their relationships often requires the application of qualitative and quantitative paradigms based on ontological, epistemological, and methodological settings. Confrontations of paradigms, the emergence of new ones, attempts of triangulation, are just some of the points that are still being discussed. Thereby, researchers try to test hypotheses with different methodological procedures, examine theoretical assumptions and models for solving relevant research questions, illuminating the scope and limitations of particular methodological paradigms and approaches (Gojkov, 2013). This is understandable because the research of educational phenomena in the school context is extremely complex and dynamic due to the nature of the studied phenomenon, characteristics of the sample, developmental specificities, personality traits of the respondents, and other reasons. Limited methodological possibilities of dealing with complex, hypothetical structures could be an obstacle to a more reliable study of cognitive functioning of personality, as well as to resolving comprehensive and authentic unknowns in researching personality complexes, research learning processes, and skills development in science education.

Therefore, an effort was made to present selected reference research in the field of inquiry- based learning in science education, in order to shed light on different methodological approaches, both for theoretical explanations of selected phenomena, and for understanding of their scope and limitations from a pragmatic point of view in order to improve the practice.

Research Aim

The aim of this research was to consider different methodological approaches from the angle of constructivist, interpretive, and empirical paradigms of inquiry-based learning in science education, in order to systematically describe previous relevant studies of this problem, explain theoretical foundations in science education, and their empirical verification. The research could contribute in two directions: a) clarification of methodological approaches to research inquiry based learning in science education in order to understand their scope and limitations, and provide implications for future research, and b) systematization of research findings crucial for defining key terms of inquiry based learning, identification of optimal teaching (research) strategies in science education, and other issues that are the core of strategic decisions for innovation of the educational process and improvement of the quality of work in school.

Such very important and remarkable studies in the Republic of Serbia are still few in the field of natural sciences. Therefore, the analysis of relevant methodological approaches in studying this phenomenon have been based on foreign research for the most part, and have been presented from three main perspectives (Gajić et al., 2018):

1) Basic theoretical approaches and specific conceptual solutions;

2) Methodological design (research questions / problems, and research methods, techniques and procedures), and

3) Analysis and reinterpretation of the most significant findings.

This approach is expected to enable better understanding of directions of future, interdisciplinary studies of this phenomenon.

Research Tasks

The aim of the research has been implemented through the following research tasks:

1) Analyze basic theoretical settings, approaches, and conceptual solutions in studying inquiry-based learning.

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2) Identify the number of key stages of inquiry-based learning process in the analyzed research.

3) Examine which research issues and problems have been studied in relevant research of inquiry-based learning.

4) Identify the most significant outcomes of inquiry-based learning.

5) Find out what are the most significant challenges that a teacher encounters in inquiry-based learning.

6) Identify which research methods, techniques and procedures have been applied in relevant research of inquiry-based learning.

7) In the light of examination findings (re)interpretate the methodological approaches in the relevant research.

Research Methodology

Research Design

The descriptive method and theoretical analysis, i.e., systematic review of literature, has been applied in the research. Content analysis, in the variant of collecting and analyzing data from textual sources, has been applied to sort/classify source data in the research that relies on qualitative materials, but also on results of empirical studies.

The literature of previous research studies regarding inquiry-based learning have been analyzed qualitatively and reviewed critically. Systematic review of literature focuses on a specific research issue or a problem, representing a very rigorous analysis of the research already conducted and published. A review of existing studies is often more appropriate than conducting a new study (Caulley, 1992). Review of literature represents identification, review, evaluation, and interpretation of available research that answers research questions in a particular field (Kitchenham & Charters, 2007). It is a prescribed methodology that provides a systematic review, transparency, consolidation, and evaluation of studies on a particular topic or issue / problem, with the aim to reduce the bias associated with individual studies (Jesson, et al., 2011). A systematic review is an accepted research methodology that offers researchers answers to a number of questions on the basis of verified results, through a valuable, comprehensive and up-to-date summary of work in a particular field.

Sample

The sample on which the analysis was made consisted of selected texts from printed and digital materials, and available online sources (articles and papers published in scientific journals, books, research studies, reviews, documents).

These sources were accessed by searching for material found in library catalogs or databases or found in browsers such as Google or Google Scholar. Since keywords most succinctly defined a particular selected research problem and were also used to search for resources in electronic databases, in the case of keyword searching in electronic databases, there was obtained a list of sources that contained the keyword set anywhere in their text. The scope of keyword search was in principle very wide, so for the purposes of this research, up to five keywords or phrases were used in order to define the content of the paper. The following were not left out either: synonyms, abbreviations, related terms, spelling in Great Britain and the USA, singular / plural word forms, thesaurus terms (if they were available), etc. Relevant literature was found in different library catalogs, where access to classical and electronic sources of information was allowed: *Web of Science (Wos), Scopus and ProQuest Dissertations & Theses Global*, doctoral dissertations and theses, then the *Social Sciences Citation Index*

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(SSCI), *Scopus, Education Resources Information Center* (ERIC), *Directory of Open Access Journals* (DOAJ) and Elton B Stephens Co. (EBSCO). The criteria for the selection of literature were determined in advance on the basis of which the documents were classified or excluded from the research. When determining the criteria for ensuring the quality of documents, the following was checked: whether the study was a scientific study published in academic journals; whether the study had any limitations or restrictions; whether it came from a reliable source; whether it was positively reviewed and published; what was the attitude of the author, etc. For the ideal selection, there were provided three researchers who reviewed the documents, in order to avoid bias. Unpublished research was eliminated from the further process of analysis. The research articles were downloaded from the journal home page, excluding book reviews, reflections, and editorial comments. The data were cleaned up and relevant information needed for the study, including the methodology, research approach, data collection techniques, and method of data analysis and data analysis software used, was extracted (Ukwoma & Ngulube, 2021). This phase lasted for a period of six months.

Procedures

A systematic review of the literature was focused on a narrowly defined research problem as followed: consideration of different methodological approaches from the angle of constructivist, interpretive and empirical research on inquiry-based learning in science education, in order to systematically describe, evaluate, and verify previous relevant studies related to the issue. It was necessary to realize the following tasks: a) examine basic theoretical approaches and specific conceptual solutions; b) determine methodological design (research problem / problems, and research methods, techniques, and procedures), and c) perform analysis and reinterpretation of the most significant findings. This was secondary research in which the data collected in the primary research were investigated. After selecting the research problem and research tasks, the contents for analysis were selected and classified.

The selected primary research were analyzed through the prism of key research tasks: 1) Analyze the basic theoretical settings, approaches, and conceptual solutions in studying inquiry-based learning; 2) Identify the number of key stages of the inquiry-based learning process in the analyzed research; 3) Examine which research issues and problems were studied in relevant research of inquiry-based learning; 4) Identify the most significant outcomes of inquiry-based learning; 5) Find out what were the most significant challenges encountered by a teacher in inquiry-based learning; 6) Identify which research methods, techniques, and procedures were applied in relevant research of inquiry-based learning; 7) In the light of the examination findings (re)interpretate the methodological approaches in relevant research.

The systematic review consisted of precisely defined steps with the aim to ensure research rigor. First, the appropriate research problem and tasks were formulated. Second, the search terms and selected databases were defined. Third, inclusion and exclusion criteria were used, which were guidelines for the further literature search. Fourth, the scientific quality of the obtained publications was evaluated by using predefined quality criteria. Only studies that met the quality requirements were included in this review. Finally, data that answered the research tasks were extracted (Jukić-Matić & Bognar, 2019).

Data Analysis

The references were transferred to the Excel table and supplemented with data necessary for the analysis. The data were arranged in a way that each document represented one row, whereby the columns represented the criteria on the basis of which the documents were included in the research. They were structured in such a way as to show:

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1. Bibliographic data on the material (the author, year of publication, issue or research, title of the document, type of material);

2. Geographical review according to the origin of the documents (the continent, country, city, certain geographical area);

3. Research design;

4 Evaluation details on individual studies (how they were used, whether some were more important than others, whether they were control experiments or observational studies, etc.);

4. The applied methods were presented (types, reliability, qualitative or quantitative approach, experiments, etc.);

5. Subject of research;

6. Variables in research;

7. Applied research techniques and instruments (survey, interview, meta-analysis, systematic observation, etc.);

7. Results (studies or discussions, statistically significant / insignificant, positive / negative, declining / increasing, etc.).

Research Results

Basic Theoretical Settings, Approaches and Conceptual Solutions in Studying Inquiry-based Learning

Active and inquiry-based learning is not a new idea. It was advocated by many scholars, educators, psychologists, philosophers, centuries ago. During the development of psychological, didactic, and methodological thought, the scholars recognized the need for student´s thinking. Thus, an independent work and research in teaching was recognized, although this was not always present in pedagogical practice. In their studies of inquiry-based learning, most researchers started from the theoretical assumptions of J. John Dewey, who played a very notable role in the reform of education in the first half of the 20th century. Dewey believed that, instead of emphasizing memorizing facts, science education should enable students to think and act scientifically (Dewey, 1997; National Research Council, 2000). In addition to Dewey's theoretical assumptions, Jean Piaget and other prominent representatives of the Geneva School of Psychology also offered theoretical basis for establishing inquiry-based learning. According to the theory of development of logical structures, the Swiss psychologist understood learning as a process in which students discovered independently through the research, thus acquiring new knowledge (Piaget, 1988). The third theoretical basis of inquiry-based learning was based on the ideas of Lev Semyonovich Vygotsky, who tried to resolve and correctly set the relationship between learning and development. Vygotsky's theory of the "zone of future development" implied maximum students’ activity, since students' mental and emotional development could only be achieved on personal efforts (Vygotsky, 1983). In addition to the theoretical basis, some educational theorists and practitioners were also inspired by the work of Jerome Bruner. They accepted research-based methods as the optimal way to learn the scientific content, but also to develop the ability for the research work (Bruner, 1960).

These echoes were also reflected in reviews of research published over the past decades. The early research syntheses of Bittinger (Bittinger, 1968, according to: Panjwani, 2015) and Hermann (Hermann, 1969, according to: Panjwani, 2015) found that research-based learning was more efficient than traditional lecture-based learning patterns. In addition, Hermann (Hermann, 1969, according to: Panjwani, 2015) found some indicators that the effectiveness of inquiry-based learning depended on the guidelines that pupils and students had received during the research process in teaching. Despite significant variations in the amount and type of teacher´s instructions delivered during learning activity, some research results, as well as comparative analysis, showed that the teacher´s advice, as well as clear and precise guidance during work, was extremely important (Panjwani, 2015). Thirty years later, De Jong and Van Joolingen (1998) studied the literature on inquiry-based learning established on simulation. After analyzing the typical problems faced by pupils and students in different phases of the research cycle, the authors synthesized the empirical research, comparing the efficiency of simulations with and without additional instructions, namely guidance. It was found that simulations, accompanied by guidance, i.e., "instructional measures", led to better learning outcomes than simulations without such guidance. Three measures were proven to be particularly effective: enabling students to access relevant information during the research process, preparing tasks for structuring the research process, and gradually limiting the complexity of research process as the model progressed (De Jong et al., 2013).

Based on the results obtained by researchers in this field, representatives of the constructivist learning environment (CLE - Constructivist Learning Environment) highlighted the following as elements of inquiry-based learning and constructivist teaching (Jonassen 1994; according to: Bošnjak, 2009): activism, constructiveness, cooperation, communication, reflexivity, contextuality, and complexity and purposefulness. According to Brooks and Brooks (1999, p. 18-24), and in the light of advanced didactic strategies, the "constructivist classroom" differed from the traditional classroom in guided teaching activity, i.e., guided discovery.

At the end of the 20th century, within the framework of the Biological Sciences Curriculum Study (BSCS), a model called BSCS 5E instructional model was developed (Bybee et al., 2006). The 5E teaching model was based on the elements of cognitive learning theory and cognitive psychology, emphasizing the following phases of learning activity: *engage*, *explore*, *explain*, *elaborate*, and *evaluate*. When applying this teaching model, students were able to redefine, reorganize, elaborate, and change their knowledge and original conceptions through interaction with contents, in cooperation with peers, through self-reflection (Bybee, 1997). Many studies (Duran & Duran, 2004; Ergin et al., 2008; Kilavuz, 2005; Sen & Oskay, 2017; Yadigaroglu & Demircioglu, 2012) confirmed the importance of applying constructivist elements in teaching, which primarily led to better educational achievement, increased understanding of the content, as well as the ability to relate teaching materials to real-life situations. As the repertoire of students' knowledge and skills changed through research activities, it was common to refer to these processes as the processes of inquiry or inductive learning. *Inquiry-based learning (Am.E.)* or *enquiry-based learning (Br.E.)*, *inquiry learning,* or *inquiry-guided learning* was a constructivist teaching strategy adopted in the 1970s (Spronken-Smith & Walker, 2010).

Key Stages of the Learning Process in the Analyzed Research

Inquiry-based learning was represented in a variety of (natural) disciplines, including physics (Fencl & Scheel, 2005; Heflich et al., 2001; McDermott, 1995; Thacker et al., 1994), chemistry (Hrin et al., 2014; Jalil, 2006; Lewis & Lewis, 2005; Oliver-Hoyo et al., 2004; Oliver-Hoyo & Allen, 2005) and biology (Londraville et al., 2002). Likewise, many researchers sought to answer the question of how student could think and act as scientists. Hogan and Fisherkeller (Hogan & Fisherkeller, 2000, according to: Chowdhury, 2016) proposed four phases of the learning process to be included in teaching activities: 1) setting the hypothesis, 2) designing the experiment, 3) interpreting results, and 4) communicating and discussing the results. Some authors suggested different levels, i.e., ways of inquiry-based learning, depending on the level of support provided: a) structured inquiry, b) guided research, and c) open inquiry (Colburn, 2006; Spronken-Smith & Walker, 2010). In their scientific works, the authors also differed in terms of listing different stages of inquiry-based learning and teaching: 1) examination, 2) collection, 3) assumption, 4) implementation, execution, 5) summary, result and 6) communication, presentation (Liewellyn, 2014).

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It is evident that the number of stages, phases, or components differs in the analyzed research. Table 1 shows the stages and key components of inquiry-based learning identified by researchers in their studies.

Table 1
Components of Inquiry-based Learning (Chowdhury, 2016)

Researchers/references	Number of components	Names of components
Pedaste et al. (2015)	Five executed stages	Orienting, conceptualizing, researching, concluding, discussing
Callison & Baker (2014)	Five basic elements	Examining, researching, assimilating, concluding, reflecting
Li et. al., (2010)	Five key steps	Examining, researching, creating, discussing, reflecting
Marshall & Horton (2011)	Four common components	Participating, researching, explaining, expanding
Luera et al. (2003)	Five key components	Inclusion, researching, explaining, expanding, assessing
Liewellyn (2014)	Six basic stages	Examining, collecting, assuming, implementing, summing, presenting
Hogan & Fisherkeller, 2000, according to Chowdhury (2016)	Four key phases	Assuming, researching, interpreting, discussing

It could be noticed that the number of phases in the conducted research ranged from four to six, but most often it was five. The names of individual stages (components) also differed, more terminologically than essentially.

Research Issues and Problems Studied in Analyzed Research

Based on the analysis of aims and tasks of previous relevant research, a wide range of different research issues and problems could be encountered: a) researching the effects of this teaching method in relation to traditional learning and teaching patterns, b) researching students' competencies for inquiry work, c) determining factors that contribute to successful implementation of inquiry-based learning in biology teaching, d) examining possibilities provided by curricula for the implementation of research in teaching procedure, e) examining teachers' opinions and attitudes towards inquiry-based learning, etc. Key research questions and problems are shown in Table 2.

Table 2
Key Issues and Problems in Relevant Research studies

Researchers/references	Research questions
Rissing & Cogan (2009); Thijs & Van Den Akker (2009); Zerafa & Gatt (2014);	What are possibilities offered by the curricula of natural sciences for inquiry-based learning?
Baldwin, et al. (1999).	What student´s competences are being developed? Are there differences between biology students and other students in terms of understanding science?
Bošnjak et al. (2016); Drakulić (2007); Gormaly et **al**. (2009); Lott (1983); Schneider (2002); Shymansky (1990); Von Secker (2002); Weinstein (1982);	What are the outcomes of learning compared to the traditional concept? How to increase student´s achievement and motivation in the field of natural sciences by applying inquiry-based learning?
Ministry of Education, Employment and the Family (2011);	What are the possibilities of monitoring and evaluating the effects of inquiry-based learning?
Gatt et al. (2014); Gormaly et. al. (2009); Harlen (2012); Johnston et al. (2012); Mullis et al. (2012); OECD (2013); Osborne & Dillon (2008); Rorty (1998); Tytler (2007); Zerafa & Gatt (2014);	Does the introduction of inquiry-based learning depend on the students' age, i.e., can elementary school pupils do the research during their education?
Anderson (2002); Heppner et al. (2006); Moss (1997); Panjwani (2015); Sundberg (1992); Sundberg & Moncada (1994); Van Den Akker (2003, 2010); Yerrick (2000); Zerafa & Gatt (2014); Zohar & Aharon-Kravetsky (2005);	What are the challenges encountered by the teacher in inquiry-based learning?
Basaga et al. (1994); Berg et al. (2003); Hall & McCurdy (1990); Luckie et al. (2004); Saavala (2008); Sundberg & Moncada (1994); Tytler (2007);	Does inquiry-based learning develop competences for research work in students?
Carolan et al. (2014); D'Angelo et al. (2014); Lazorden & Harmisen (2016);	What are the effects of different types of guidance in the inquiry-based learning in terms of students' educational achievements, learning outcomes, and learning satisfaction?
Buckner & Kim (2014); Odadžić et al. (2017); Pribićević et al. (2019);	Is it possible to implement modern educational technologies in interactive and inquiry-based learning, and what are the effects?

Based on the presented results, it could be concluded that the possibilities offered by the science curricula for inquiry-based learning were still insufficiently studied in the literature. Some basic tendencies indicated that the existing curricula were not flexible enough, failing to support optimal research in teaching (Rissing & Cogan, 2009; Thijs & Van Den Akker, 2009; Zerafa & Gatt, 2014). The key requirement was that (despite the insufficient flexibility of the curriculum) it was necessary for the teacher to set aside enough time to engage students in a dialogue with the material world, so that they could observe, examine, predict, discuss, and reflect the data and evidence in a logical way (Alberts, 2000; Artigue et al. 2010; Crawford, 2009; National Research Council, 1996; Wheeler, 2000). In the classroom, every student should be provided with individualized access to the content, as well as the opportunity to develop, articulate, and refine their own ideas (Harlen & Allende, 2009). Through the research process, students developed cognitive skills, such as problem-solving skills, data assessment and interpretation skills, as well as research skills (Hanauer et al., 2009).

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The Most Significant Outcomes of Inquiry-based Learning in Analyzed Research

When it comes to *learning outcomes through inquiry-based learning*, numerous empirical studies (Baldwin et al., 1999; Lott, 1983; Schneider et al., 2002; Shymansky, 1990; Von Secker, 2002; Weinstein, 1982) have shown that students' mental activation and independent work in the learning process, especially inquiry-based learning, contributes to the increased quantity of knowledge, sustainability of acquired knowledge, higher applicability and transfer of acquired knowledge, better understanding of causality (cause and effect), higher capacity for independent work, research and learning, development of the critical thinking, development of creative thinking and sharing, flexibility and fluency of thinking, development of the research spirit, student´s motivation, persistence in the search for rational solutions, state of relaxation and satisfaction due to the successful solutions of the problem, goal orientation (problem solving), desire to cooperate with others, etc.

In terms of examining the *differences that exist between biology students and other students when it comes to understanding science,* it has been found that biology students show higher level of confidence in explaining biological ideas, writing and criticism towards laboratory reports, by using scientific approaches to problem solving, including analytical skills for performing experiments and a general confidence for the course success (Baldwin et al., 1999). Based on comparative analysis, some researchers have noted that teaching biology based on the concept of inquiry-based learning encourages a "research style" of behavior, both in students and teachers. The study has also found that teachers could encourage students to research even in the traditional system of teaching.

Most studies on the effectiveness of inquiry-based learning have examined possibilities of *developing students' competence for the research work* (Saavala, 2008; Tytler, 2007). Measuring the students' achievement in acquiring knowledge and conceptual understanding, the studies showed significantly better achievement in students who adopted teaching contents in this way (Basaga et al., 1994; Hall & McCurdy, 1990; Luckie et al., 2004; Sundberg & Moncada, 1994). However, other researchers found that there were no statistically significant differences in achievements among students who did their research in laboratory (Jackman et al., 1987; Pavelich & Abraham, 1979), i.e., they found that students showed more pronounced ability to reflect and describe concepts, but they found no differences in general knowledge or understanding (Berg et al., 2003).

Comparing the effects of inquiry-based learning with the traditional concept of teaching there was an indication that learning outcomes were better with an appropriate teacher support (instruction in the role of guided research) (Lazonder & Harmsen, 2016). Based on students' assessments of the teachers' role in the research process made according to their own epistemological beliefs, as well as based on specific questions about the students' experience in laboratory, the authors concluded that student´s attitude towards science changed significantly, and student´s autonomy was more pronounced (Bošnjak et al., 2016; Drakulić, 2007; Gormaly et al., 2009; Lott, 1983; Schneider et al., 2002; Shymansky, 1990; Weinstein, 1982).

Researchers were especially interested in whether the introduction of inquiry-based learning in education depended on the age of students, i.e., whether primary school pupils could research during the learning process. The studies showed that primary school pupils were ready for the research work, highly motivated for practical work in the classroom, intellectually curious and active, and that they especially liked asking questions (Gatt et al., 2014; Harlen, 2012; Rorty, 1998; Johnston et al., 2012; Mullis et al., 2012; OECD, 2013; Osborne & Dillon, 2008; Tytler, 2007; Zerafa & Gatt, 2014). It was also found that students with better school achievement and those who had more developed cognitive abilities were also better in accepting inquiry-based learning (Gormaly et al., 2009).

Most Significant Challenges Encountered by a Teacher in Inquiry-based Learning

What particularly captured the researchers' attention was the question of *what challenges does teacher face* in the inquiry-based learning and learning process? Research results showed that teachers faced numerous challenges, the most significant of which was the lack of time for research, need to develop and strengthen teacher competencies in this field, as well as readiness for the additional efforts required by this approach (Anderson, 2002; Akker, 2003, 2010; Heppner et al., 2006; Moss, 1997; Panjwani, 2015; Sundberg & Moncada, 1994; Van Den Sundberg, 1992; Zerafa & Gatt, 2014; Zohar & Aharon-Kravetsky, 2005; Yerrick, 2000). Teachers especially emphasized a need to be introduced to didactic and methodological requirements which should be taken into account when applying inquiry-based learning. They also emphasized the fact that preparation and organization of such classes was a very demanding and complex job (Golubović-Ilić, 2013).

As the role of teachers in inquiry-based learning is extremely important, researchers in their studies have tried to answer the question of what is the optimum level of guidance / directions in teaching? Key approaches to guidance in inquiry-based learning, as identified by different researchers, are shown here (Chowdhury, 2016). Teachers should provide different levels of guidance: structured, guided, and open research (Banchi & Bell, 2008); Teachers must provide more than one instruction in order to develop critical thinking to optimize learning outcomes (Ku et al., 2014); Teachers need to learn how to ask their students essential questions in order to encourage them to critical thinking and innovation (Wilhelm, 2014); Students participating in the research should be able to independently discover the answers through their own active engagement and gaining new experiences (Ireland et al., 2012); Although related to difficulties, modern technologies need to be incorporated into the process of optimizing inquiry based learning (Buckner & Kim, 2014); Students are much better influenced by teachers who often ask questions than by teachers who mainly teach (transfer knowledge) (Marriott, 2014); Student research should be conducted before receiving explanations by the teacher (Marshall & Horton, 2011). Two important aspects of promotion of the inquiry-based learning are the following: asking essential questions and fostering focused discussion (Brown, 2012); Open research question templates encourage students to actively participate in the research (Hermann & Miranda, 2010).

Researchers sought to determine effects of different types of guidance in inquiry-based learning and have found that guided research has a number of advantages over the open, unguided research (Carolan et al., 2014; D'Angelo et al., 2014; Lazorden & Harmisen, 2016). Students who have some kind of guidance are more capable to solve tasks, more successful in gathering actual information and achieving better results on tests after the research work. The instructions are equally useful for students of different ages, enabling more efficient inclusion in research and learning, which is a special incentive for gifted students (Gajić et al., 2021).

However, results of relevant research in education of natural sciences indicate that inquiry-based learning is insufficiently applied. Poor equipment of educational institutions, organizational problems, teachers´ insufficiently developed competencies for inquiry-based learning (Anderson, 2002), and teachers´ insufficient willingness to include modern educational technology in the teaching process despite the scientific proof that they enable teachers quickly and easily rearrange and innovate teaching materials in the electronic form, are the most often cited obstacles for its wider implementation (Ally et al., 2014). Furthermore, insufficient application of inquiry-based approach in educational process can be related to pupils´ and students´ insufficient scientific knowledge about the nature and development of scientific thinking and inquiry-based learning, and thus, to insufficient use of existing scientific knowledge, which is essential for creation of high-quality teaching practice.

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Research Methods, Techniques, and Procedures Applied in Analyzed Research of Inquiry-based Learning

When it comes to research methods, techniques, and procedures, researchers apply a number of techniques and procedures that contribute to more comprehensive research and understanding of the selected problem. Most commonly used methods, techniques, and procedures are presented in Table 3.

Table 3
Most Often Used Research Methods, Techniques, and Procedures in Analyzed Research

Researchers/references	Research methods, techniques, and procedures
Bošnjak (2015); Bošnjak et al. (2016);	Descriptive, causal, and comparative method
Schauble et al. (1995); Bošnjak (2015) Bošnjak et al. (2016); Drakulić (2007);	Experiment with parallel groups Factor rotation experiment Ex post-facto experiment
Zerafa & Gatt (2014);	Multiple case studies Interpretative case studies
Zerafa and Gatt (2014); Linn et al. (1998); Wallace et al. (1998); Thijs & Van Den Akker (2009).	Method of (theoretical) analysis of documentation: (expert reviews, teachers' diaries: - reflective practitioners, photos, documents, observation protocols, websites, forums, blogs, etc.)
Lott (1983); Schneider et al. (2002); Shymansky (1990); Von Secker (2002); Weinstein (1982); Lazorden & Harmisen (2016);	Meta analysis
Zerafa & Gatt (2014); Panjwani (2015);	Interviews Structured Non-structured
Gormaly et. al. (2009);	Discussion in focus groups
Norris et al. (2003); Wheeler-Toppen et al. (2005); Bošnjak (2015); Bošnjak et al. (2016); Drakulić (2007);	Testing
Baldwin et al. (1999); Bošnjak et al. (2016); Drakulić (2007);	Surveying, scaling

It has been found that triangulation is commonly used as a combination of qualitative and quantitative paradigms (Gormaly et al., 2009), but that the qualitative research is common as well (Lazonder & Harmsen, 2016; Zerafa & Gatt, 2014). However, quantitative research still prevails (Baldwin et al., 1999; Norris, et al., 2003; Wheeler-Toppen et al., 2005).

In the field of natural sciences, methodological research design very often includes controlled experimentation (Schauble et al., 1995), modeling (Jackson et al., 1996; Penner et al., 1997; Resnick, 1994; Wilensky & Resnick, 1999), synthesis of primary sources (Linn et al., 1998; Wallace et al., 1998), and quantitative data research (Hancock et al., 1992; Tabak et al., 1996). Namely, the nature of the studied phenomenon should be taken into account, since the complexity of the structure of relations and interdependence in the educational process is such that the notion of condition should be introduced instead of one-way and unambiguous notion of cause. Different personality traits of pupils, students, and teachers further complicate the research, including conative, affective, motivational and other dimensions, in addition to cognitive dimensions, which are difficult to control and measure precisely. The presence of positivist and interpretive epistemology is also reflected in the research approaches such as survey and case study that have been used (Ukwoma & Ngulube, 2021). It is evident that experimental research is often combined and supplemented with other methods and research procedures, i.e., surveys, interviews, case studies, focus group discussions, etc.

Discussion

The analysis of relevant previous research has shown that in their research studies, a number of authors have confirmed the importance of the application of constructivist elements in teaching, i.e., inquiry-based learning. Elements of constructivist theory in teaching natural sciences have been highlighted, and an instructive model of learning has been developed based on elements of cognitive theory of learning and cognitive psychology (Bybee et al., 2006).

A review of previous relevant research indicates that different methodological approaches and procedures have been applied, as well as that they contain a wide range of different research issues and problems. The most significant systematized research results obtained by the authors in this field could be grouped as follows:

- Numerous researchers have suggested *different levels of inquiry-based learning*, i.e., *levels of support* provided in their studies. There are obvious differences in relation to the number of stages (from four to six), as well as the names of the components of research learning. However, these differences are more terminological than essential.

- Possibilities provided by teaching *curricula*, especially biology, are still insufficiently researched in the literature regarding the research approach in teaching. Some basic tendencies indicate that existing curricula are not flexible enough, and do not support optimal research in teaching (Rissing & Cogan, 2009; Thijs & Van Den Akker, 2009; Zerafa & Gatt, 2014). These results correspond to findings of other researchers who have indicated that teachers' concerns about curricula insufficiently support specificities, aims, outcomes, as well as different phases and components of inquiry-based learning (Natural Curiosity, 2011).

- When it comes to *learning outcomes* through the research approach, a number of empirical studies (Baldwin et al., 1999; Lott, 1983; Schneider et al., 2002; Shymansky, 1990; Von Secker, 2002; Weinstein, 1982), have shown that mental activation of students and independent work in the teaching process, especially research education, contributes to: increased quality of knowledge, greater transfer of acquired knowledge, as well as the development of competencies for the student research work.

- The key concept of the research approach in teaching is instruction, i.e., different types of *guidance by teachers*. It is important to point out that the guided research has a number of advantages compared to open, non-guided research (Carolan et al., 2014; D´Angelo et al., 2014; Lazorden & Harmisen, 2016).

- In terms of *monitoring and evaluating the effects of inquiry-based learning*, research checklists filled by the students during classes, portfolio, work reports, self-evaluation of student´s achievement, etc. proved to be optimal (Ministry of Education, Employment, and the Family, 2011; Sawada et al., 2002).

- When it comes to the issue what *challenges a teacher faces in the research teaching process*, the results of the analysis have shown that there are numerous challenges. The most significant are lack of time for the research, a need to develop and strengthen teacher competencies in this field, as well as their digital competencies for the application of modern educational technology (Anderson, 2002; Heppner et al., 2006; Moss, 1997; Panjwani, 2015; Sudberg, 1992; Sundberg et al., 1992; Van Den Akker, 2003, 2010; Zerafa & Gatt, 2014; Zohar & Aharon-Kravetsky, 2005; Yerrick, 2000).

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- A significant requirement of modern teaching is the *application of modern teaching aids and tools*, and above all, information and communication technology (ICT) in the teaching process.

Although positive effects of inquiry-based learning in science education have been confirmed, the realized studies indicate that this is insufficiently applied, and the reasons for that may be different. Poor equipment of educational institutions, organizational problems, insufficiently developed teacher competencies for inquiry-based learning, as well as the dominant traditional culture of teaching natural sciences in educational institutions, are most frequently cited as obstacles to wider implementation (Anderson, 2002).

Results of the previous research point to the conclusion that the range of applied methods, techniques, and procedures is very wide indeed. Triangulation has been found to be commonly used as a combination of qualitative and quantitative paradigms (Gormaly et al., 2009). Although experimenting is very common in natural sciences, the holistic approach and comprehensive analysis of effects through quantitative and qualitative approach are increasingly advocated under the influence of pedagogical-psychological and other scientific disciplines. Such research often requires an interdisciplinary approach, both in the field of empirical and theoretical research of the subject. This is completely understandable as some aspects of the problem could be equally subject to research within several scientific disciplines. No doubt that the research methodology is an important aspect of the research procedure in the problem solving and discovery of new knowledge, although the methodology to adopt in the study depends on the nature of the problem (Ukwoma & Ngulube, 2021).

What connects the selected studies in this field is the recognition of importance of inquiry-based learning of natural sciences as a very promising model of active learning and teaching (Koksal & Berberoglu, 2014), which is based on students' mental activation, research questions, critical thinking, and problem solving, that result in the high-quality knowledge and stronger students' competencies for independent research in teaching.

Conclusions and Implications

The comparison of the analyzed research is quite complex due to the fact that every study differs in the methodological approach, type of research, scope, degree of definition of research tasks, as well as in the applied instruments.

The analyzed papers are presented from the perspective of: 1) basic theoretical assumptions and characteristic conceptual solutions, 2) reviews, analysis and evaluations of methods and techniques used in research, and 3) analysis and reinterpretation of the most significant findings. Based on the analysis, it has been concluded that the analyzed research studies are very diverse and heterogeneous, and that they differ from one another both in terms of theoretical starting points, conceptual definitions and solutions, methodological design, and theoretical practical implications.

Considerations of relevant research point to the general conclusion that the adoption of different (research) learning strategies, as well as the expansion of their repertoire, increases the efficacy of using different sources of knowledge, management of cognitive processes, as well as efficacy of overall teaching.

Based on the review of relevant studies on inquiry-based learning in teaching natural sciences, it could be concluded that they have been primarily aimed at the scientific verification of new knowledge, procedures, methods of work, etc. The conducted research has shown that it is methodologically possible to introduce certain methodological and other innovations in the regular course of teaching work in order to determine their efficiency in comparison to some other educational procedures. In addition, students' specific creative and critical solutions and their ability to master certain techniques of work, as relatively exact quantities that can be measured by appropriate tests and scales, provide a wide opportunity for the application of pedagogical experiments. However, exactness of the experiment is influenced by a number of factors and should be understood as relatively reliable and efficient method with all its advantages and limitations. There is no doubt that in this field there is still a search for ways, specific methods, and instruments by which more precise research could be carried out.

Combining various methodological approaches seems to be very effective, so we agree with the standpoint of those scholars who believe that different research strategies and approaches should be used in studying this field. In addition to quantitative approach and experimental research design, it is necessary to use theoretical analysis, interviews, discussion in focus groups, etc. for more accurate and qualitative assessment of the effects of research work in education of natural sciences. Qualitative results from interviews, for example, can provide an insight into the segments of the studied problem that elude statistical analysis. In addition, these results may also be used for directing the focus of future studies on the potential variables that should be taken into account.

The impression is that observation is neglected in the analyzed research (with the application of observation protocols) which, in some cases, might be a better choice than surveying, scaling or testing, because it enables access to a larger amount of information, while reducing the possibility of giving socially desirable answers and deeper understanding of the issue. It also enables the researcher to observe verbal and nonverbal reactions of students and teachers, teachers' activities, realization of teaching activities, procedure of systematization of students' knowledge, forms of student motivation, as well as conditions for their work, in order to collect relevant data necessary for the research.

When it comes to practical implications of this research, it could be stated that it provides not only a concise and synthesized overview of the study of literature in this field, but it also offers quality assessment of the existing research and indicates the need for new studies. In this way, it provides important information, not only for practice, but also for future research endeavors. The study of the phenomenon of inquiry-based learning has gone through different concepts over time: from normative, through empirical and hermeneutic concepts, to the theory of systems. New methodological concepts are also hinted at, which promise new possibilities in terms of a stronger prediction of manifestation and encouragement of the complex phenomenon of research learning in the education of natural sciences. It is especially important to create conditions for methodological flexibility in this field because different ways of research enable the choice between nomothetic and idiographic approach, as well as their complementarity, enabling researchers to choose how to approach the research, depending on the studied problem.

The new research paradigm offers a different approach and alternative procedures that greatly contribute to a more comprehensive and in-depth study and clarification of this issue. The assumption of obtaining as complete and objective data as possible in this field is conditioned by the application of different research procedures and strategies within both paradigms, quantitative and qualitative. Also, there is an agreement with the advocates of epistemological holism *that a coherent approach* is required when examining this issue. Only the application of several different epistemological approaches and methodological concepts stimulates the dynamics of the research process, contributes to obtaining more valid data and drawing more reliable conclusions on the issue of inquiry-based learning in science education.

Nevertheless, many questions remain open and debatable for methodologists. For example, how to decide which indicators in the research practice should be given more importance: empirical reality, numerical data obtained by statisticians, or interpretations derived from qualitative approaches? Certainly, specific difficulties arise from the fact that the application of several different techniques, methods and instruments requires from them to be harmonized according to certain criteria. Also, we should not overlook the fact that triangulation does not guarantee validity and objectivity in the interpretation of data. In any case, it is necessary to meaningfully combine quantitative and qualitative research strategies, techniques and procedures in studying such complex and dynamic phenomena. This would result in significant implications in terms of improving quality in inquiry-based learning, which would also create conditions for achieving modernization and optimization of science education as one of the socially desirable aims.

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Declaration of Interest

Authors declare no competing interest.

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