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Exploring Biological Literacy: A Systematic Literature Review of Biological Literacy

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Abstract: A large number of articles in the field of science education reflect on scientific literacy as the main goal of science education (SE), although often with varying viewpoints. Nevertheless, researchers have begun to highlight subject-specific teaching practices that are expected to specifically enhance science subject teaching, including biology. The main aim of this theoretical article is to come on consensus and to conceptualise the term biological literacy (BL) more clearly and to present a theoretical concept of BL, composed on the basis of systematically analysed articles. This theoretical concept includes two dimensions of BL: (1) cognitive (cognitive skills, conceptual understanding, biological inquiry) and (2) affective dimension, based on systematic literature review (SLR). This theoretical concept also includes in addition four dimensions of BL: (3) sustainability; (4) interdisciplinarity, (5) career awareness and (6) nature of biology (NOB), based on literature review (LR) of recent decades, that was conducted to write theoretical overview of this research.

Keywords: *Biology education, biological literacy, theoretical concept, systematic literature review.*

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Introduction

Biology is a fundamental and applied science discipline, which is expanding at a very high rate and plays an important role in our understanding of life at every level – from the molecular biology level to interactions on the global scale (Duncan & Boerwinkel, 2018; Reiss & Kampourakis, 2018). In this respect, it is not surprising that 21st century biology education (BE) encompasses extensive new concepts and methods when compared with the previous century, e.g. genetic engineering methods. In forward-looking BE, it is important to include these advances in general school primary and secondary BE.

Nowadays, biological knowledge is seen as crucial for students as future citizens in making biologically reasoned decisions in their everyday life – e.g. decisions re-vaccination; becoming a gene donor; selecting suitable medical treatment; determination of healthy diet; and selecting the best medically approved hygiene etc.

Many articles have been published about determining and putting forward the need to develop scientific literacy (SL) (Eijck & Roth, 2010; Garthwaite et al., 2014; Holbrook & Rannikmäe, 2009; Klucevsek, 2017; Lederman et al., 2013; Roberts & Bybee, 2014; Roberts & Gott, 2010; Smith et al., 2012). SL is an extremely broad term and encompasses literacies within the different natural sciences sub-components, such as geography/earth science, biology/life science, physics and chemistry (Bybee, 2009; Demir, 2016; Fives et al., 2014).

Biological literacy (BL), as a subset of SL, has been conceptualised by Uno and Bybee (1994), who have argued that biological literacy was not a single endpoint that can be attained within one biology course, but is a continuum the acquisition of which develops throughout life.

After the before mentioned comprehensive article, BL has got less attention in educational literature than SL – during the period 1954–2020 according to EBSCOhost databases only 584 academic articles included the term “biological literacy” and 11629 academic articles were written about scientific literacy. Comparatively small number of articles have specifically mentioned BL in the 20th century (Mertens & Hendrix, 1982; Riddle, 1954; Uno & Bybee, 1994) and in

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the recent last decades the term of BL has been occurred again in the academic literature (Narguizian, 2019; Weber, 2017; Wright, 2005).

Even in this case of few educators and scientists do not use and understand the term "biological literacy" in the same way and so far, there has been little agreement about the definition of BL. In the context of this study, BL is recognised as a subset of scientific literacy, focusing mainly on the biological context and wishing to widen the horizons of biology education (BE). Hence, we hope this study will help to bridge the gap between different conceptualisations of BL and create a theoretical generalizing concept of BL.

Since the publication of the comprehensive BL article (Uno & Bybee, 1994) BL has received much less attention in educational literature than SL. In fact during the period 1954 – 2020, according to EBSCOhost databases, only 584 academic articles include the term 'biological literacy', while 11629 academic articles were written related to 'scientific literacy'. Comparatively small number of articles have specifically mentioned BL in the 20th century (Mertens & Hendrix, 1982; Riddle, 1954; Uno & Bybee, 1994). However, in the last decade, the term BL has again become an area of interest in the academic literature (Narguizian, 2019; Weber, 2017; Wright, 2005). Nevertheless, educators and scientists do not seem to conceptualise the term "biological literacy" in the same way. And, so far, there seems to be little agreement about the manner in which BL is defined.

In the context of this study, it is important that BL is recognised as a subset of scientific literacy, focusing mainly on biological context and striving to widen the horizons of biology education (BE). The aim of this study is to seek to bridge the gap between the different conceptualisations of BL and create a unified, theoretical concept of BL. A major intention of highlighting BL is the need for society to cope with a rapidly changing and complicated biology-related world and to play a role in making justified decisions where biological aspects are seen as major components. While many people express beliefs about scientific processes, they don't necessarily appreciate the science and hence are prone to making non-scientific judgements – e.g. rejection of vaccinations and refuse of wearing the masks in pandemic situation of coronavirus disease (COVID-19).

This study addresses the degree of literature consensus related to the meaning of BL within BE. As there has not been a systematic literature review (SLR) related to the definition of BL, the goal of this study is to create a theoretically justified concept for BL. To achieve this goal, a systematic analysis is undertaken to conceptualise BL and to create a theoretical model.

Theoretical Background

Discipline-based education research (DBER) is an emerging, interdisciplinary field of scholarship geared toward understanding and raising discipline-specific teaching and learning DBER is a rising, interdisciplinary field, that is aimed at understanding and improving discipline-specific teaching and learning (Dolan et al., 2018). The number faculty members in the science, technology, engineering, and mathematics (STEM) field involved in DBER has grown rapidly in recent years (ibid). Biology education researchers form a part of this enlarging field (Singer et al., 2013). And the major problem identified is the necessity to undertake research in-depth within each science discipline separately. That leads to a need to conceptualise biological literacy as a key focus within scientific literacy.

The use of term of biological literacy (BL) in different studies has been increased in the last decades and a considerable number of these refer to the study of Uno and Bybee (1994), outlined, in their BL model, four levels applicable for high school and college teaching and assessment, namely: nominal, functional, structural, and multidimensional, These characteristics as still in use for amplifying scientific literacy (SL) levels and hence. describe the dimensions of biological literacy which are seen as in common with SL (i.e. knowing and understanding the characteristics of scientific (biological) knowledge, the values of science (biology), and the methods and processes of scientific (biological) inquiry, the nature of science(biology), But within this it is important to clearly recognize the more specific aspects associated with identifying a biologically literate person: understanding biological principles and major concepts of biology, the impact of humans on the biosphere, the historical development of biological concepts, personal values regarding biological investigations, bio- and cultural-diversity, the impact of biology and biotechnology on society, and the importance of biology for the individual; And in common with scientific literacy the importance of thinking creatively, formulating questions about nature, reasoning logically and critically, evaluating information, using technologies for biological applications appropriately, making personal and ethical decisions related to biologically-related issues, and applying biological knowledge to solve problems (Uno & Bybee, 1994).

There is a concern that within science education (SE) the concept of BL could be raised, without the term being clearly clarified (Dorfner et al., 2018). Also, the literature notes that there are many sub-literacies or facets of BL which can be included into BL, e.g. botanical literacy (Uno, 2009); genetic literacy (Cebesoy & Tekkaya, 2012; Stern & Kampourakis, 2017); ecological literacy (Cheruvelil & Ye, 2012; Ertekin & Yüksel, 2014), biochemical literacy (Evans et al., 2020), biotechnology literacy (Firat & Köksal, 2019), etc.

Literacy is a social construct that has different meaning to different cultural groups. Also, its meaning changes over time. While the term "literacy" specifically refers to a person's ability to read and understand knowledge in the field of study (Cope & Kalantzis, 2000), its meaning has bene widened to relate to conceptualisations appropriate for any identified field of study. Ward (2011) in putting forward that BL is a subset of SL recognised it mostly had the same characteristics, but is strictly referring to biological knowledge. However, defining the boundaries of biological knowledge is seen as problematic and hence there is a problem of unambiguity of the concept of BL (Dorfner et al., 2018).

Methodology

The systematic literature review is intended to provide an overview of the definitions and dimensions of biological literacy, based on relevant literature. Based on this aim, three research questions were posed in the study:

1. How is 'biological literacy' or 'biology literacy' defined in the academic literature?

2. What dimensions of biological literacy have been put forward and discussed in the academic literature?

3. What other dimensions need to be added to the conception of biological literacy in addition to systematic literacy review based on the recent academic literature about biology education?

Undertaking a Systematic Literature Search

A systematic literature search of academic articles was undertaken to gain an overview of the conception of biological literacy and related dimensions. While there are numerous studies on ways of conducting a literature review (Fisch & Block, 2018; Rowley & Slack, 2004). For this study the systematic literature review's guide by Aguinis et al., (2018) was used. The six steps, described by Aguinis et al., used to identify journals, articles and make recommendations were identified as: (1) determination of goal and scope of review; (2) determination of procedure to select journals; (3) calibration of the source selection process; (4) selection of sources; (5) calibration of the content extraction process; (6) extraction of relevant content.

The search of research articles was conducted, as shown in Figure 1, in April 2020 and updated for more recent articles in December 2020, using an electronic EBSCOhost database to select relevant articles. This database was chosen as it included information from many relevant databases (e.g., ERIC, Science Direct, Academic Search Complete) and, therefore, gave a very broad overview of existing literature within different fields of studies. The keywords used for the search were the following: *'biological literacy', OR 'biology literacy'.* The full texts were searched, allowing EBSCOhost service to search for related words. After meeting the inclusion and exclusion criteria, 38 articles were used in this systematic literature review.

Inclusion and Exclusion Criteria

A manual search process was used to identify articles which addressed biological literacy (BL) in the title. Three independent coders read through the abstract, or if needed, the full text to classify each article. This helped to calibrate the source selection process and to see if the chosen articles were indeed about BL. The inclusion criteria were the following (1) focusing on defining BL and its aspects; (2) published in English language; (3) published in a peer-reviewed academic journal.

Articles not directly relevant to the field of study, were excluded from the review.

The search was limited to articles from academic journals. This resulted in the identification of 505 articles. Two additional articles, identified from the references cited in the searched articles were added. After removing duplication of articles and articles published in a foreign language, the number of articles used in this study was reduced to 74. Based on additional duplication checks. An additional 12 articles were excluded. When the abstracts of the 62 article were checked for eligibility, 12 further articles not focusing on the meaning of BL were excluded. The full texts for the remaining 50-articles full were analysed, based on whether the concept of BL was defined and a further 12 articles, were excluded as they did not meet the criteria of defining BL. The articles finally included in the systematic review protocol are illustrated in Appendix 1, seen as preferred reporting items for systematic literature review (Moher et al., 2015).

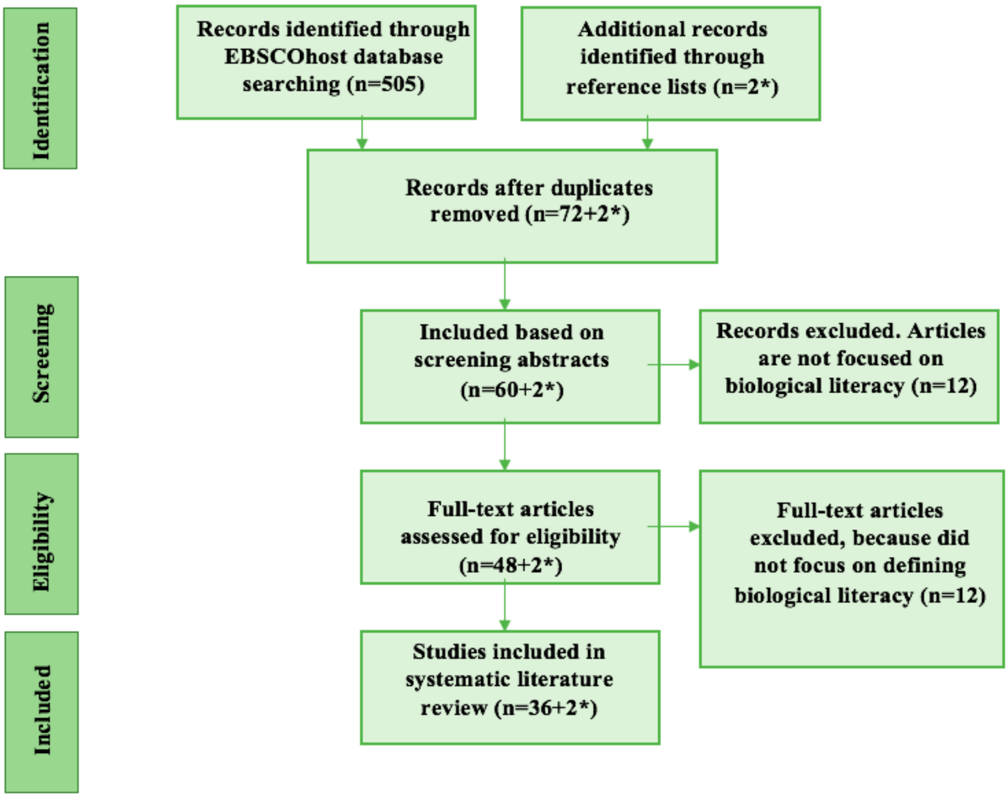

Figure 1. Flowchart of the search and screening process

**Two articles were identified from the reference lists of the initially found articles and then these articles were treated as the articles found in EBSCOhost database search.*

Note. Flow of information through the different phases of a systematic review by Moher *et al.*, (2009) was used.

Data analysis

The screening of titles and abstracts was undertaken by two biology education researchers. They separately assessed every inclusion and exclusion criterion on a scale 0 – 2, where 0 –not enough evidence to decide; 1 – the criteria are not met, as it includes an exclusion criterion, and 2 – all 3 inclusion criteria are met. The differences in decisions made were discussed until a consensus agreement was reached.

In the case of awarding the scale of 0, the article was further assessed, based on the full text to allow a final decision about inclusion. Weighted kappa for inter-rater agreement of the final decisions on the inclusion of the articles was substantial (k= .73), p < .0001) (Landis & Koch, 1977) indicating there was a statistically significant agreement between the researchers.

Findings

The findings indicated an increased use of the term BL in academic articles, although there was not a modern widely accepted definition of BL. This is despite the fact that 7 articles on biological literacy (BL), included into the systematic literature review (SLR), were published in last century and 31 in the 21st century, indicated that the concept of BL, defined in 1994 by Uno and Bybee, needed to be updated,

According to the findings of systematic literature review, 7 different components of BL were outlined and validated by the expert group of three biology teachers and three BE researchers.

The identified 7 components of biological literacy

1. Knowledge

Biological knowledge (Köksal & Köksal, 2012; May et al., 2013; Mertens & Hendrix, 1982; Post et al., 2017; Uno, 2009) or content knowledge (Kampa & Köller, 2016) is one the most important components of biological literacy (BL). Demastes and Wandersee (1992) suggested that essence of BL is to understand biological principles: information, energy flow, organisms and evolution. Same aspects were emphasised by Uno and Bybee in 1994. Later named as core concepts of BL (Begley, 2012; Brigati et al., 2020; Fiedler et al., 2019; Illingworth *et al*., 2012; Weber, 2014, 2017; Wright et al., 2020) e.g. evolution (Pope et al., 2017); structure & function; information flow (Venkakesh & Makky), exchange & storage; pathways & transformations of energy & matter; systems outlined by Weber 2017. Some authors have used term of key concepts of BL in the meaning of core concepts (Narguizian, 2019; Suwono et al., 2017). McInerney (1996) emphasised that biological concepts are not only important for biology education. Klymkowsky (2010) indicated that conceptual understanding is crucial for BL and later Klymkowsky (2010) introduced in his essay three pillars (evolutionary thinking, molecular foundations, and network behaviour) of biology and addressed the need of contextualisation.

Hartley et al. (2012) investigated more in depth energy and matter as one of the core concepts of BL. Structure and function was described by Halmo et al., 2018. Evolution is more investigated by Brigati et al. (2020); Hoagstrom et al. (2019) as evolution is often misunderstood by students (Sbeglia & Nehm, 2019). Biology as a discipline has some concepts that are unique to this branch of science, e.g. students' understanding of cladograms (Davenport et al., 2015).

2. Abilities

From the early articles, the problem solving has been an important component of BL (Lemons, 1994; Mertens & Hendrix, 1982; Post et al., 2017; Roberts, 2001; Suwono et al., 2017; Uno & Bybee, 1994; Wright, 2005). Many authors considered the decision-making skill (e.g. personal and ethical) as an essential component of BL (Köksal & Köksal, 2012; Mertens & Hendrix, 1982; Suwono et al., 2017; Uno & Bybee, 1994) and Roberts (2001) emphasised its integral role in biological issues. Responsible environmental decision-making is indicated by Zangori and Koontz (2017). Lemons (1994) put forward that critical thinking skills are part of BL and creative thinking skills were added by Uno and Bybee (1994). Hoots (1999) pointed out that scientific thinking was needed for BL. Post et al. (2017) investigated students' decision making and reasoning skills as the components of BL as well as scientific creativity.

All above mentioned skills could be categorised as core competences of BL that are outlined by Begley in 2012 (incl. core competencies described by Brigati et al., 2020) or as cognitive abilities indicated by Kampa and Köller in 2016.

Some skills are unique to BL e.g. tree-thinking (Baum & Offner, 2008; Davenport et al., 2015) that is ability to conceptualise evolution in terms of phylogenetic trees.

Already in 1982 Mertens and Hendrix described scientific methods as a component of biological literacy and Uno and Bybee (1994) described this as methods and process referred by Köksal and Köksal (2012). Uno and Bybee (1994) have addressed using biotechnology as important skills for biologically literate students. In 2009 Uno introduced inquiry skills, that were emphasised later by many authors (Kampa & Köller, 2016) as a component of BL.

3. Affective dimension

Values have been indicated as part of biological literacy since beginning (Mertens & Hendrix, 1982; Uno & Bybee, 1994) and Gardner et al. (2016) specified affective dimensions (attitudes, interests, perceptions beliefs). Onel and Firat Durdukoca (2019) identified attitudes toward biology on high school students.

4. Environmental competencies

Environmental competencies were put forward in the articles by Lemons (1994), while Uno and Bybee (1994) indicated the importance of the impact of humans on the biosphere.

5. Integration

In the first reviewed article Oscar Riddle (1954) indicated that biology should be connected to society and Uno and Bybee (1994) emphasized the need for integration in biology. Lemons (1994) suggested that BL should have interdisciplinary content. Baumgartner et al. (2015) emphasised that quantitative literacy is essential to BL requiring the students to apply their mathematical skills to biological problem solving.

6. Nature of science (NOS)

Roberts (2001) put forward the need of understanding nature of science in the context of biology education and the same was stated by Köksal & Köksal (2012) and Narguizian (2019).

The identified 7 components of biological literacy are shown in figure 2.

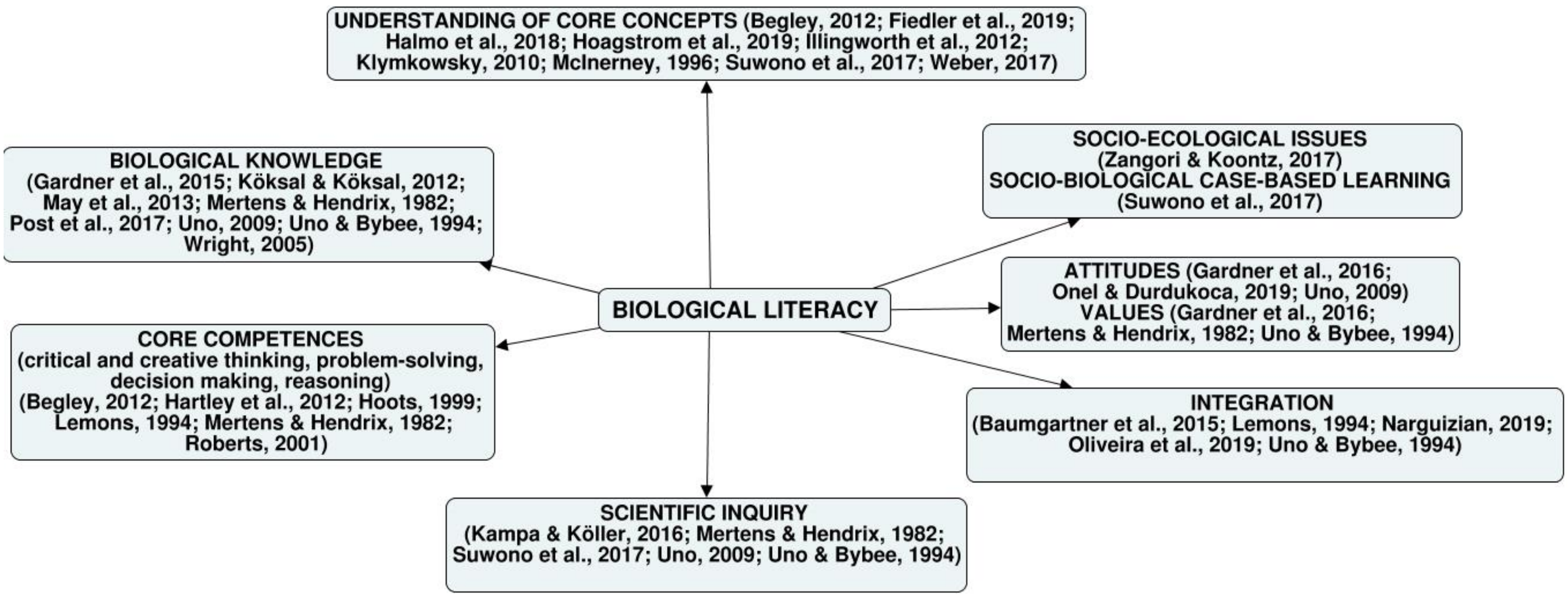

Figure 2. Biological literacy according to the content analysis of the systematic literature review

Discussion

Phrase *Scientific Literacy (SL)* is used to express the major goal of contemporary Science Education (SE) (Uno & Bybee, 1994). The authors draw attention that as similarly the main goal of the 21st century Biology Education (BE) should be the development of biological literacy (BL).

Analysing the findings of systematic literature review and the other sources of literature, the authors of this study identified six dimensions of BL in up-to-date terms.

1. Cognitive dimension (biological knowledge, conceptual understanding, cognitive skills and biological inquiry).

Mertens and Hendrix (1982) and Uno and Bybee (1994) have defined BL through biological knowledge. Also, biologically literate people should know and should use biological language. Biological knowledge is an important aspect of BL as well as core concepts (Mertens & Hendrix, 1982; Post et al., 2017; Uno, 2009).

Conceptual understanding of scientific knowledge is one important part of SL (Klymkowsky, 2005) and this can be applied also to BL (Uno & Bybee, 1994). Rita Hoots (1999) outlined that students should understand nature and biological knowledge. The same aspects were addressed a decade before by Jones (1989), who put more emphasis on the perspective about science.

Biologically literate people should understand the core concepts of biology (Begley, 2012; Demastes & Wandersee, 1992; Illingworth *et al*., 2012; Uno & Bybee, 1994). Biological literate students should recognize the diversity of organisms and the classification of organisms (Oliveira et al., 2019). McInerney (1996) pointed out that biological concepts are not only important for BE. All citizens should to know the main concepts of biology. Cognitive skills refer to the use of mental activities e.g. remembering, analysing, understanding, learning, and reasoning. Uno and Bybee (1994) referred to these as scientific abilities and later Kampa and Köller (2016) named them cognitive abilities. In the following paragraph the components of cognitive skills as part of the BL are elucidated.

Mertens and Hendrix (1982) identified that problem solving and responsible decision making are parts of BL. Students should be equipped with practical problem- solving, which means that they should solve problems that are usually complex problems in real life situations e.g. problems which relate to their health. Vickers et al. (2003) considered the ability to solve problems as a core cognitive component of BL. The other authors also draw attention that personal decision making as the process that itself depends on personal values and other characteristics (Green, 1997; Trevino, 1986).

Critical thinking and scientific thinking skills are included into BL from the initial concept of BL (Hoots, 1999; Uno & Bybee, 1994). Afterwards Post et al. (2017) added the problem solving, decision making and also the scientific creativity as important components of BL. Enhancing students' scientific creativity is critical for every aspect of thinking and learning (Hu et al., 2013). There is found a relationship between general cognitive abilities and academic achievement (Kampa & Köller, 2016).

According to AAAS (2011), BL has its own core concepts (e.g. evolution; structure and function; information flow, exchange, and storage; pathways and transformations of energy and matter; and systems). Before mentioned report (AAAS, 2011) puts more focus on core competences and disciplinary practices (process of science; quantitative reasoning; modelling/simulation; interdisciplinary principles; collaboration and communication; science and society).

It has been concluded that providing students with core concepts in biology can help them to process new information and core competences can show how practicing biologist study biology in the real world. Understanding and learning about biological concepts is important, but students need to learn how to use these concepts in different situations as well. Biological knowledge is needed to comprehend the core concepts of biology and to understand and apply these concepts in socio-scientific or socio-ecological issues Begley (2012).

Mertens and Hendrix (1982) have defined BL through scientific methods. For Lederman (2018) scientific inquiry is broader than science method and extends beyond process skills (observing, inferring, classifying, predicting, measuring, questioning, interpreting, analysing data). Comparing biology with other science disciplines it uses more observation rather than experimenting as a scientific method. Biologically literate people could design and carry out with an investigation in biology. This includes that they can use specific biological inquiry skills.

The authors of this study want to outline some aspects that were not indicated in the articles of the systematic literature review.

The authors draw attention to the importance of psychomotor skills. Psychomotor skills are needed in biology learning (Yip, 2000) and these should be developed through practical and laboratory work e.g. microscoping and dissection skills and other practical laboratory skills (Gould et al., 2019; Holstermann et al., 2009; Hunt et al., 2012). According to educational psychologist Bloom et al. (1956) psychomotor skills lead to higher forms of thinking that has not been mentioned in the articles about BL. The authors draw attention to other important components of inquiry skills e.g. safety, collaboration and communication (Ellis & Riches, 1978; Scott-Phillips, 2008; Vermeulen et al., 2013).

2. Affective dimension

Uno and Bybee (1994) included that biologically literate students should value biology. Biologically literate people should have positive attitude towards biology. The affective dimension as an important part of biological literacy (BL) is added to the model of BL. The affect refers to one's attachment to object or ideas – it can be negative or positive. We argue that students should own positive values towards biology to make bioethical choices. Bioethical choices regard to biological and medical progress. Bioethics has addressed many debates over the boundaries of life e.g. abortion, vaccination, organ donation or human experimentation etc. (Bryant & Velle, 2018).

3. Sustainability dimension

Authors of this study argue that one dimension of biological literacy should be sustainability which consists of responsible decision-making and responsible behaviour towards environment. Uno and Bybee (1994) indicated the impact of people on biosphere, but sustainability is wider. To enhance a sustainability worldview, students should have the ability to act that has meaningful impact (Nolet, 2017). The dimension of sustainability involves global competences. Global competence is defined as multidimensional capacity, when people can examine local, global and intercultural issues, understand and appreciate different perspectives and world views, interact successfully and respectfully with others, and take responsible action toward sustainability and well-being (Organisation for Economic Co-operation and Development (OECD), 2018). Global competences can promote people knowledge and skills towards sustainability. BL should develop students' critical awareness of human relationships with nature (Oliveira et al., 2019). Narguizian (2019) address that all educators should help students to understand of Human-Earth relationship.

4. Interdisciplinarity dimension

Biology is a very complex discipline in terms of research methodology. Its diversity is reflected in its many different sub-fields which have developed into separate biological sciences and their goal is developing the field-based literacies e.g. environmental, ecological, health, genetic and literacies (Jacque et al., 2016; Kaye & Korf, 2013; Krakow et al., 2017; Voithofer, 2012) that all are related to BL. Biotechnology is an innovative field that is growing in popularity (Lazaros & Embree, 2016).

Biology is also an interdisciplinary science across fields, being interrelated with different disciplines, such as computer or digital science, info technology, etc. That's why BE and BL are related to many other literacies that supplies the biologically literate person with extra competences, e.g. quantitative literacy, digital literacy and information literacy (Baumgartner et al., 2015; Porter, 2005).

Nagle (2013) discussed in her study about the nature of modern biology. She brought out that educators must provide students with opportunities to engage in studying interdisciplinary scientific questions or problems, e.g. to use overarching themes, problems or socio-scientific issues. BL is needed because biologically literate people can make decisions about the socio-scientific issues. Socio-scientific issues, health-related issues, and bioethical issues should be used in biology lessons to promote BL.

5. Dimension of Nature of biology (NOB)

Kloser (2012) argued that biology has many unique methods and he stated that biology is a leading science of the 21st century as new discoveries and new frontiers in biology will raise new ethical questions and cause new public debates. He said that nature of biology (NOB) is a key biological concept. Authors of this study argue that within biology education the term NOB could be used instead of nature of science because of the specific features of life sciences and it has been seen as a subset of nature of science. NOB has been investigated by many studies (Adegboye et al., 2017; Kloser, 2012).

6. Dimension of biology-related career awareness

The 21st century biology education should consider with biology-related careers. Students should be aware of careers that are related to biology and are introduced to them at biology lessons. Therefore, the teachers themselves should be familiar with the new biology-based career choices and the competences are needed for them (Šorgo & Špernjak, 2020). The aim of Finnish study (Uitto, 2014) was to explain upper-secondary school students' orientation towards biology-related careers. The results of this study showed that girls' self-efficacy beliefs influenced their biology-related career expectations, while boys were mostly directed by their interest in and positive attitudes towards biology.

The goal of this study was to get an overview of the aspects and dimensions of BL mentioned in literature and update the concept of biological literacy. Biological literacy can be defined as an interdisciplinary competence, including biological knowledge and conceptual understanding of biological core concepts; cognitive skills, enabling the citizenship to cope scientifically creatively in their future lives, solving problems, making socio-scientifically reasoned decisions; acknowledging the changeable nature of biology; being guided by positive values and attitudes towards biology, making theoretically justified bioethical choices and being aware of biology-related careers to that all together enhances students' ability to of cope with their future life and contribute to society.

Summarising the literature review the following updated model of biological literacy was constructed (Figure 3).

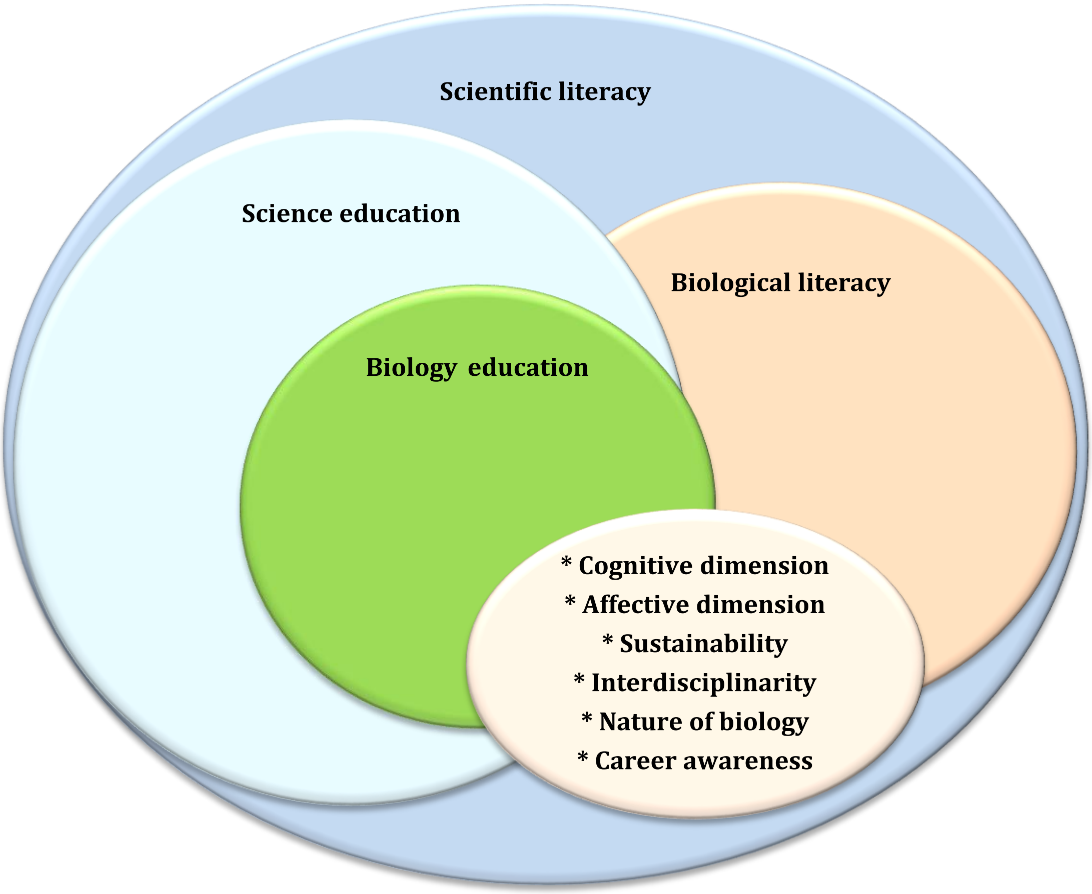

Figure 3: The updated literature-based model of biological literacy

Conclusions

Systematic review of articles dealing with biological literacy revealed that although the term "biological literacy" was introduced already in 1954 by Riddle but the comprehensive concept of BL was created by Uno and Bybee (1994). During the next decades there was made a very few attempts to define the BL as most of the authors and administrative documents referred to the concept of Uno and Bybee or described different aspects of BL. By the time being the biological situations and hence the BL have been changed drastically and the concept of BL should embrace more than biological knowledge and core concepts, e.g. biological scientific language and terms, specific biological investigating methods, the NOB, awareness of biology-related careers and biological values and thus BL is largely a distinguishing term compared to SL. BL was conceptualised many decades ago and different authors have given additional aspects into the concepts. As biological education is interdisciplinary and hence understanding the essence of biological essence needs more than biological knowledge and biological skills, these biological situations involve wider aspects such as biotechnological, bioethical, bioinformatical etc. ideas that should be added to the concept of BL that is largely a useful term when the biological aspects refer to the nature of the context driving the learning.

The goal of this study was to get an overview of the aspects and dimensions, mentioned in literature and update the meaning of BL as an interdisciplinary concept, including biological knowledge and core concepts, includes socio-scientific issues focused on biological issues, positive values and attitudes towards biology, biology-related career awareness that all together enhances students' cognitive skills, e.g. problem solving, decision making, socio-scientific reasoning and argumentation skills, etc., enabling the citizenship to cope creatively in their future lives. Authors of this study have included new aspects in the model – biologically literate students should make theoretically justified bioethical choices, they should make theoretically justified choices about their health and environment.

Authors of this study admit that the theoretically created concept of BL is constantly changing as biology as scientific discipline evolves rapidly in time and so does the biology education and according to this biological literacy. We suggest to consider implementing the updated model of BL into curriculum development.

Overall, biology at school should enhance students' BL so that they can become informed participants in the biology-related debates and issues that take place in society.

As a result of the current research, the concept of BL includes the following dimensions including a variety of aspects, elucidated in this study: (1) cognitive dimension of BL: biological knowledge, conceptual understanding of core concepts of biology; cognitive skills; problem solving; decision making, reasoning, argumentation and scientific creativity; biological inquiry skills; (2) affective dimension of BL: values; attitudes; bioethics; (3) biology-related career awareness (4) sustainability; (5) interdisciplinarity of biology; and (6) nature of biology (NOB).

The created theoretical concept of BL can also contribute to construction of assessment instruments suitable for measuring the level of gymnasium students' BL.

Recommendations

An overall suggestion for future research is to use the developed model of biological literacy to measure different dimensions of it. To get a better sense of the practical use of the dimensions of biological literacy to teaching, the nature of biological literacy might need more investigation. Our review revealed that most of the empirical studies measuring biological literacy didn't clarify the meaning of the concept. Therefore, we suggest that further studies should focus on developed model and apply it in developing process of different assessment instruments. In our study we indicated 6 dimensions of biological literacy, that should be implemented in curriculum development.

Limitations

The study also had some limitations that should be taken into account in applying the findings. It is necessary to be aware of the data collection, the result of which was a rather modest including 38 articles. The articles reviewed had sometimes limitations in presenting evidence of the quality of instruments used for assessing the biological literacy.

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Authorship Contribution Statement

Semilarski: Conceptualization, design, analysis, writing. Laius: Editing/reviewing, supervision.

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Appendix

Table A1. The overview of research articles included in systematic literature review

No	Year	Journal	Authors	Aspects of biological literacy (BL)	Research type
1.	1954	The American Biology Teacher	Riddle	Connection between biology and society.	LR
2.	1982	The American Biology Teacher	Mertens, & Hendrix	Biological knowledge; scientific methods; personal and societal problem solving; bioethical decision-making; values.	LR
3.	1992	BioScience	Demastes & Wandersee,	Core principles of biology: information, energy flow, organisms and evolution.	LR SR of major metropolitan daily newspaper
4.	1994	BioScience	Uno & Bybee	Knowledge and understating; major concepts of biology; formulating questions, reasoning logically and critically; creative thinking; making personal and ethical decisions; methods and processes of inquiry; integration; values; using biotechnologies appropriately.	LR
5.	1994	BioScience	Lemons	Environmental competencies, interdisciplinary content, critical thinking, problem-solving skills.	LR
6.	1996	The Quarterly Review of Biology	McInerney	Biological concepts are not only important for BE.	LR
7.	1999	The American Teacher	Hoots	Scientific thinking; understanding nature.	ER
8.	2001	Journal of Biological Education	Roberts	Understanding of NOS; development of higher-level thinking skills e.g. problem solving; decision-making in biological issues; procedural ideas; students' perceptions of biology in the curriculum.	LR
9.	2005	American Society for Cell Biology	Wright	Learning how to use scientific knowledge to solve relevant problems.	LR
10.	2005	Cell Biology Education	Klymkows-ky	Conceptual understanding; reading level.	LR
11.	2008	The American Teacher	Baum & Offner	Tree-thinking ability to conceptualise evolution in terms of phylogenetic trees	LR
12.	2009	American Journal of Botany	Uno	Botanical literacy is a subset of BL. interest basic knowledge and inquiry skills.	LR
13.	2010	CBE – Life Sciences Education	Klymkow-sky	3 pillars – evolutionary thinking, molecular foundations, network behaviour.	LR
14.	2011	The American Teacher	Ward	BL is a subset of scientific literacy.	LR
15.	2012	BioScience	Hartley et al.	Energy and matter as one of the core concepts of BL.	LR
16.	2012	Journal of Microbiology & Biology Education	Begley	Core concepts and core competences.	ER
17.	2012	International Journal of Innovation of Science and Mathematics Education	Illingworth et al.	The major concepts within the field of biology, the impacts of biological advances on society.	ER
18.	2012	Education in Medicine Journal	Köksal & Köksal	BL abilities: knowledge, applying knowledge, nature of science, methods and processes, decision making.	ER

Table A1. Continued

No	Year	Journal	Authors	Aspects of biological literacy (BL)	Research type
19.	2013	The American Biology Teacher	May et al.	Biological knowledge combined with contextual meaning.	LR
20.	2014	Journal of Microbiology & Biology Education	Weber, 2014	Measuring the increase of BL of students by their ability to connect five core concepts of BL described by AAAS 2011.	ER
21.	2015	The American Biology Teacher	Davenport et al.,	Students' understanding of cladograms and tree thinking is required for BL.	LR
22.	2015	The American Biology Teacher	Baumgartner et al.	Quantitative literacy is essential to BL.	ER
23.	2016	The American Biology Teacher	Gardner et al.	Matrix of knowledge about the physical universe; affective dimensions (attitudes, interests, perceptions beliefs).	ER
24.	2016	Science Education	Kampa & Köller	Content knowledge, scientific inquiry, cognitive abilities, verbal skills.	ER
25.	2017	The American Biology Teacher	Weber, C.F.	Core concepts of BL: evolution; structure & function; information flow, exchange & storage; pathways & transformations of energy & matter; systems.	ER
26.	2017	Estonian Journal of Education	Post et al.,	Biological knowledge; problem solving; decision making and reasoning, and the fluency aspect of the scientific creativity.	ER
27.	2017	Evolution: Education and Outreach	Pope et al.	Evolution by natural selection are fundamental to biological literacy, misconceptions.	ER
28.	2017	Journal Pendidikan IPA Indonesia	Suwono et al.	Key concepts to make decisions in solving problems through scientific inquiry. Socio-biological case-based learning could enhance the BL and critical thinking skills.	ER
29.	2017	Journal of Biological Education	Zangori & Koontz	Understanding of socio-ecological issues and connection between the processes and systems that leads to responsible environmental decision-making.	LR
30.	2018	Biochemistry and molecular biology education	Halmo et al.	Structure and function is one of the five core concepts of BL.	ER
31.	2019	Journal of Ethnobiology and Ethnomedicine	Oliveira et al.	Recognition of the diversity of organisms, including the classification; developing critical awareness of human relationships with nature	ER
32.	2019	The American Biology Teacher	Narguizian	The living systems are interconnected; Earth processes and human activity are mutually intertwined; knowledge of evolutionary matters; flow of energy; humanity is linked to all living things; NOS.	LR
33.	2019	Journal of Research in Science Education	Fiedler et al	Core concepts of biological literacy.	ER
34.	2019	Science Education	Sbeglia & Ross	Evolution is a disciplinary central concept to BL, being misunderstood by students.	ER

Table A1. Continued

No	Year	Journal	Authors	Aspects of biological literacy (BL)	Research type
35.	2019	The American Teacher	Hoagstrom et al.	Evolution is one of five core concepts for BL presents a teaching challenge because it requires conceptual understanding of a long-term processes.	ER
36.	2020	PLoS ONE	Brigati et al.	Core concepts for BL and the core competencies and disciplinary practices.	ER
37.	2020	The American Biology Teacher	Venkatesh & Makky	Information flow, epigenetics, regulation of gene expression.	LR
38.	2020	The American Biology Teacher	Wright et al.	Five core concepts for BL.	LR

*BL – Biological literacy; Type of study: *ER – Empirical research *LR – Literature Review