MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2024, 20(2), em2399
ISSN:1305-8223 (online)
OPEN ACCESS Review Article https://doi.org/10.29333/ejmste/14157

Protist literacy: A novel concept of protist learning in higher education

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Received 06 September 2023 ▪ Accepted 05 January 2024

Abstract

Protist education in universities primarily focuses on acquiring knowledge about species classification within the protist. Protist literacy emerged as a theoretical framework exploring the interplay between humans and protists within daily existence. This systematic literature review (SLR) provides a comprehensive understanding of protist literacy and identifies several dimensions. This SLR utilized PRISMA diagram to execute the inclusion and exclusion methods. According to SLR results, the concept of protist literacy refers to the ability of university students to analyze, comprehend, and implement the knowledge of protists to solve everyday problems. Protist literacy consists of seven dimensions: conceptual knowledge, relation information, fact evaluation, real solution, argument identification, self-confidence, and scientific value. The results of the current study imply that protist literacy is a potential variable to be further explored in protist learning.

Keywords: scientific literacy, protist literacy, protist learning

INTRODUCTION

Acquiring scientific literacy enhances college students' aptitude to interpret data presented in diverse formats, apply scientific reasoning, and identify connections between science, technology, society, and the environment (Xuan et al., 2019). University students who possess sufficient scientific literacy skills can generate research inquiries of superior quality, construct scientifically testable hypotheses, and devise experiments (Virtič, 2022). The advancement of science and technology is significantly impacted by students' scientific literacy, which serves as a foundational element in the growth of a scientific community (Čipková et al., 2018). The development of scientific literacy can be enhanced through the study of protists (Mahanal et al., 2020).

Protists represent the predominant portion of the eukaryotic variety and significantly influence ecological phenomena on our planet. However, the public frequently overlooks them (Etten et al., 2022). It is crucial to provide education on Protista to both college students and the community. Disseminating knowledge about Protista can be achieved through exhibitions, workshops, or social media platforms, ensuring that both university students and the public are aware of the significant role that Protista play in human existence (Buonanno et al., 2020). Protists in science education, particularly higher education, require specific focus and consideration. Using protists as model organisms in class is highly beneficial for explaining fundamental concepts in biological science, including physiology, ecology, systematics, and evolution (Berney et al., 2017).

The study of protists in college includes plant-like protists, animal-like protists and fungus-like protists. Protist organisms are all eukaryotic organisms other than animals, plants, and fungi (Archibald et al., 2017). Protist organisms are studied much less frequently than other eukaryotic organisms such as animals, fungi, and plants. In general, protists are microscopic. Protists can lead solitary existence, feed on eukaryotes or other small prokaryotes, and form colonies (Burki et al., 2021). Protists dominate various living organisms and perform a crucial role in all ecosystems (Adl et al., 2012, 2019). Protists are the most diverse eukaryotes and play a significant function in the food chain (Geisen et al., 2018, 2021). Protists comprise most of the eukaryotic phylogenetic diversity. Protists are an extremely diverse group of paraphyletic unicellular eukaryotes (Adl et al., 2012). Metagenetic studies utilizing environmental

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Contribution to the literature

- This paper examines and analyzes scholarly literature about the concept of scientific literacy. The foundation for the development of Protist literacy was established by examining multiple publications discussing scientific literacy. Other academics have never studied protist literacy.
- This systematic literature review (SLR) is constrained to original papers, restricting the research scope to the specific research subject or theme.
- The formulation of the concept and dimensions of protist literacy is a scholarly endeavor aimed at understanding and promoting the development of literacy skills within the protist learning environment at the tertiary level.

deoxyribonucleic acid demonstrate the vast diversity of protist lineages (Pawlowski, 2014).

Students in higher education find it difficult to comprehend protists (Etten et al., 2022) because protist organisms are extremely microscopic and challenging to observe (Kirmizigul & Kizilay, 2020). University students can only view images lecturers present and study extremely extensive protists-related content (Yunanda et al., 2019). Sihombing and Pranoto (2021) assert that learning about protists necessitates a knowledge of Latin, whereas the objects examined in the course cannot be observed without a microscope. Students at the university are required to memorize more information than they see explicitly. The issue lies in the fact that protist education mostly centers around the taxonomic classification of protist organisms (Kirmizigul & Kizilay, 2020). Thus, to ensure that protist instruction does not solely focus on the systematics of protists, promoting protist literacy in the classroom is imperative.

Emphasizing the importance and potential of protist knowledge, the concept of protist literacy is introduced. Protist literacy is a prerequisite for comprehension of organismal issues in daily life. Protist literacy is crucial as it enables college students to comprehend protists and effectively utilize protist-related concepts to address everyday situations with protists (Mahanal et al., 2020). Understanding protist organisms is crucial for human survival in the future (Merlo et al., 2021). Several protist-related investigations support the sustainable development goals (SDGs). Guler et al. (2022) discovered that astaxanthin extracted from the algal species *Haematococcus pluvialis* inhibited the growth of lung cancer cells. These findings support the third SDG, i.e., excellent health and well-being. Algae-based wastewater remediation research was initiated to support the sixth SDG, i.e., clean water and sanitation (Delanka-Pedige et al., 2020).

Protist researchers and learning specialists must work to establish the notion of protist literacy so that university students can learn more about protist organisms. University students must study protist organisms to meet the demands of the 21st century (Loy et al., 2021; Putri et al., 2021). University students should also comprehend the issues between protist organisms and humans to devise appropriate solutions (Fu et al., 2021; Kathiraven et al., 2015; Mahanal et al., 2022; Vanier et al., 2018).

The formulation of protist literacy is grounded in the scientific literacy framework. Protist literacy has yet to be included in science education, but the concept of scientific literacy has been integrated into science education (Alneyadi, 2019; Gu et al., 2019; Husamah et al., 2022; Sharon & Baram-Tsabari, 2020). In addition to scientific literacy, there are other literacies associated with the study of protists, namely biological literacy (Semilarski & Laius, 2021; Semilarski et al., 2019), environmental literacy (Liang et al., 2018; Nurwidodo et al., 2020), ecological literacy (Hammarsten et al., 2019; Pitman et al., 2018), and species literacy (Hooykaas et al., 2019). Hence, a comprehensive examination of the existing literature about protist literacy has yet to be conducted in the form of an SLR.

This SLR provides a comprehensive definition and elucidation of protist literacy, a notion rooted in the broader framework of scientific literacy. This paper also explains the various dimensions of protist literacy. This SLR is anticipated to advance biology education research, particularly in the domain of protists inside tertiary educational settings. This paper focused on examining original articles that pertained to the topic of scientific literacy.

METHODS

Research Framework

The present investigation constitutes an SLR, a rigorous and methodical approach to finding, selecting, and evaluating relevant research by the specified inquiries (Purssell & McCrae, 2020). SLR can potentially enhance the quality, reliability, and validity of the material acquired for addressing research questions (Xiao & Watson, 2019). We employed SLR technique, utilizing a qualitative synthesis approach, to methodically explore a range of works about a specific subject and gather the data from these studies (Seers, 2012).

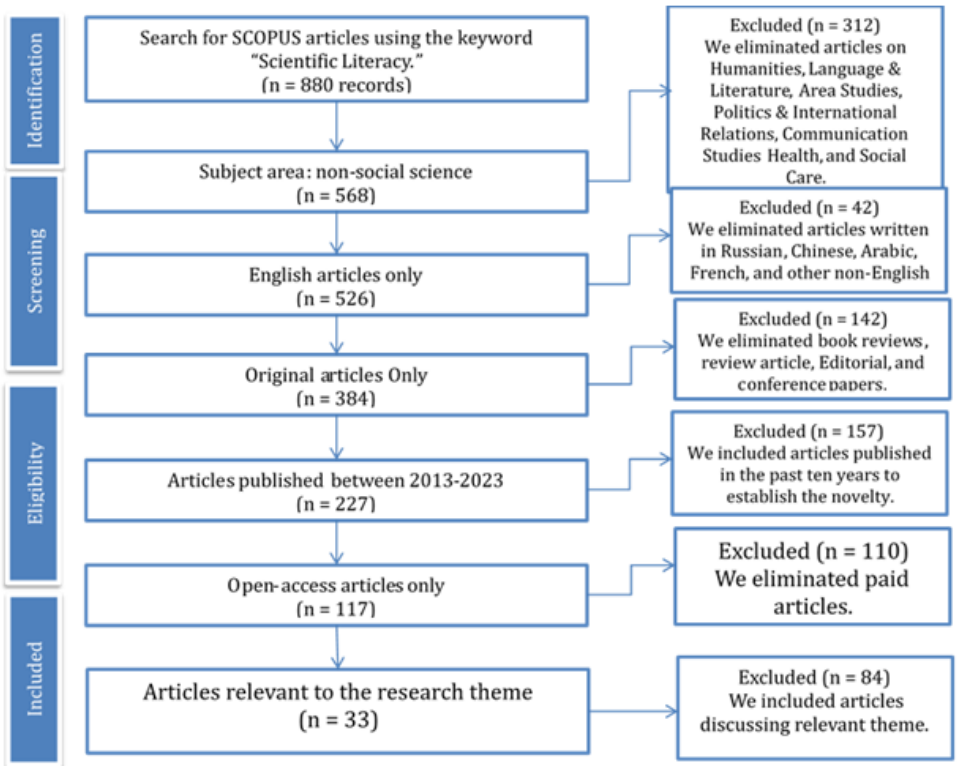

Figure 1. PRISMA diagram (Source: Authors' own elaboration)

Research Questions

Research questions play a crucial role in delineating extent and concentration of a research endeavor. The research questions are formulated, as follows.

RQ1. What is protist literacy based on various concepts of scientific literacy?

RQ2. What are the dimensions of protist literacy as suggested by various concepts of scientific literacy?

Search Article & Inclusion Criteria

We utilized the keyword "scientific literacy" to search the articles on the Scopus database. The search history on the Scopus database includes TITLE ("Scientific literacy") AND (LIMIT-TO (SUBJAREA, "SOCI")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013)) AND (LIMIT-TO (OA, "all")). We found 880 articles that contain the keyword "scientific literacy" using the search criteria. Utilizing PRISMA model, article inclusion and exclusion decisions were made. PRISMA model employed refers to research (Gallagher et al., 2016), using PRISMA model in its SLR. The following points constitute the basis for article inclusion in this SLR.

1. The article has a subject area of non-social science.
2. The article is written in English.
3. The article belongs to the original article.
4. The article was published in the last ten years, from 2013 to 2023.
5. The article is open access.
6. The article contains research on scientific literacy.

Figure 1 illustrates the methodology employed in this study for the inclusion and exclusion of articles. Out of the initial pool of 880 Scopus articles identified, a total of 312 articles were excluded due to their relevance to social sciences. Hence, the corpus encompassed 568 articles, as this research specifically concentrated on social science within education. We eliminated 42 articles composed in languages other than English and thus obtained 526 articles that were written in English. We excluded the articles due to our limited comprehension of non-English articles. Then, we found 384 original articles and excluded 142 book reviews, review articles, editorials, or conference papers. Our selection criteria prioritized original publications to emphasize exclusively the outcomes of completed research.

The articles discussed in this study were published in the Scopus database between 2013 and 2023. We included articles from the last 10 years to obtain the most recent data. Based on this criterion, 157 articles were eliminated because they were not published between 2013 and 2023. Therefore, 227 articles published between 2013 and 2023 were obtained for the further screening. After that, 110 paid articles were eliminated, and 117 open-access articles were retained.

Table 1. Information on scientific literacy definition from articles analyzed in this study

No	Information	References
1	Scientific literacy is an individual's ability to engage in scientific activities like describing scientific phenomena, analyzing & planning scientific investigations, & processing data & evidence.	Dewi et al. (2021) & Xie et al. (2023)
2	Scientific literacy refers to an individual's capacity to understand, convey, & use scientific knowledge to solve problems involving natural phenomena or real-world situations.	Angraini et al. (2023), Dopico et al. (2021), O'toole et al. (2020), Queiruga-Dios et al. (2020), Stylos et al. (2023), Tasquier et al. (2022), Valladares (2021), Vogelzang et al. (2020), Winarni and Purwandari (2019), Yang et al. (2021), & Zainuri et al. (2022)
3	Scientific literacy is an understanding/knowledge of scientific concepts & processes that individuals need, especially when making decisions, contributing to solving everyday life problems.	Cartwright et al. (2020), Heliawati et al. (2022), Ke et al. (2021), Motoki et al. (2021), Palines and Cruz (2021), Sengul (2019), Suwono et al. (2022), & Vieira and Tenreiro-Vieira (2016)
4	Scientific literacy is characterized as capacity to apply scientific knowledge to identify questions, make evidence-based conclusions, explain & anticipate events, & solve natural problems.	Chen and Liu (2018), Jufrida et al. (2019), Saija et al. (2022), & Shaffer et al. (2019)
5	Scientific literacy is ability to read, write, & communicate scientific topics & socio-scientific issues related to culture & individual student's understanding in ordinary life, as well as to comprehend procedures involved in developing new scientific knowledge & technology.	Al-Rsa'i (2013) & Wahyu et al. (2020)
6	Scientific literacy is ability to engage in issues related to science & scientific ideas as a reflective society.	Ekantini and Wilujeng (2018), Paristiowati et al. (2019), & Wang et al. (2019)
7	Scientific literacy refers to an understanding of science that enables one to participate in socio-scientific topics & make informed decisions about these issues, as well as an appreciation of processes, values, & ethics related to science.	Al Sultan et al. (2018), Bay et al. (2017), & Georgiou and Kyza (2023)

Non-open access articles were eliminated from the data sources as we needed to access the article in the full-paper format. Finally, of the 177 articles screened using the criteria mentioned above, 33 original articles pertinent to the topic of this study were examined. To avoid bias in selecting articles for inclusion or exclusion, we employed several techniques, including translating articles into Indonesian, our native language, to facilitate comprehension and conducting the process of article inclusion and exclusion collaboratively with the team.

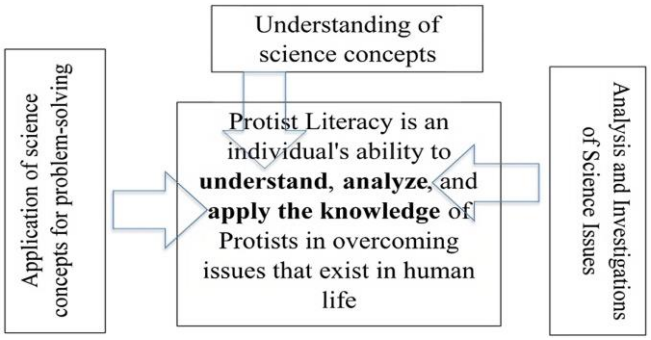

Figure 2. Process of defining protist literacy from various sources on scientific literacy (Source: Authors' own elaboration)

RESULTS

There were 33 Scopus articles analyzed in this SLR. These articles contain the scientific literacy definitions that we synthesized to develop the concept of protist literacy. We compiled diverse definitions of scientific literacy to use as a foundation for constructing the notion of protist literacy (**Table 1**).

The texts in bold are crucial terms used in formulating a definition for protist literacy (**Figure 2**). As a team, we examined three specific keywords, namely "understanding of science concepts," "analysis and investigation of science issues," and "application of science concepts for problem solving," in order to provide a clear definition of protist literacy. To clarify, we derived the idea of protist literacy by extrapolating from the concept of scientific literacy in prior studies.

Understanding concepts forms the fundamental foundation of scientific literacy. The following presents some viewpoints from researchers who incorporate the phrase "conceptual understanding" in their definition of scientific literacy.

> "Scientific literacy is based on an individual's ability to understand the scientific processes that occur in life to analyze information" (Stylos et al., 2023).

> "Scientific literacy refers to an individual's capacity to understand, convey, and use scientific knowledge to solve real-world problems" (Heliawati et al., 2022).

The results indicate that conceptual understanding is a fundamental component in the development of scientific literacy. Consequently, the protist literacy that we are cultivating necessitates an emphasis on comprehending the concept of protists, beginning with

Table 2. Concept of protists

Animal-like protists	Plant-like protists	Fungus-like protists	Content
-Phylum Sarcomastigophora	-Division Chlorophyta	-Division Myxomycota	-Protist definition
-Phylum Labyrinthomorpha	-Division Euglenophyta	-Division Oomycota	-Characteristics of protists
-Phylum Apicomplexa	-Division Pyrrophyta		-Position of protists
-Phylum Microspora	-Division Chrysophyta		-Evolution of protists
-Phylum Acetospora	-Division Phaeophyta		-Morphology of protists
-Phylum Myxozoa	-Division Rhodophyta		-Anatomy of protists
-Phylum Ciliophora			-Physiology of protists
			-Reproduction of protists
			-Classifications of protists
			-Habitat of protists
			-Benefits of protists to human

plant-like protists, fungus-like protists, and animal-like protists. This study's understanding of the protist concept was constrained to the protist materials presented at Universitas Negeri Malang, Indonesia (**Table 2**). Science concept analysis examines scientific literature that explores various scientific phenomena. Science concept analysis necessitates reliance on scientific literature or common usage. Science concept analysis aims to provide empirical evidence from real-world phenomena to validate scientific hypotheses.

> "Scientific literacy pertains to an individual's capacity to participate in scientific endeavors, including elucidating scientific phenomena and conducting analytical and strategic scientific inquiries" (Xie et al., 2023b).

The study of protists involves analyzing complex ideas essential for understanding various events related to protists. Scientific literacy emphasizes the comprehension and implications of scientific advancements for human survival through the application of scientific knowledge. Scientifically literate individuals can analyze the correlation between scientific principles and personal experiences.

> "Scientific literacy is the ability to apply scientific understanding in real life by involving scientific knowledge" (Chen & Liu, 2018).

> "Scientific literacy is the ability that students must have to analyze and apply scientific concepts in solving problems in everyday life" (Jufrida et al., 2019).

Protist literacy necessitates applying protist-related knowledge to facilitate the resolution of problematic protist-related issues that arise in daily life. As a result, "applying the concept of protists" is incorporated into the protist literacy definition.

> "Scientific literacy is about developing students' critical thinking so that they can discuss and consider the ethics, values and risks involved in science issues in society" (Georgiou & Kyza, 2023).

> "Scientific literacy is defined as an individual's ability to engage in scientific issues and generate ideas to overcome problems in society" (Wang et al., 2019).

We formulated the definition of protist literacy that pertains to societal concerns on protists, drawing inspiration from diverse definitions of scientific literacy that center on problem-solving in the realm of science. Most sources concur that scientific literacy is the capacity to comprehend, communicate, and apply scientific knowledge to solve everyday problems. The essence of scientific literacy is the application of scientific concepts to science problems. According to **Figure 2**, **protist literacy refers to an individual's ability to understand, analyze, and apply the knowledge of protists in overcoming issues that exist in human life.** Besides definition, we also attempted to formulate the dimensions that form protist literacy from various dimensions of scientific literacy suggested by past studies. **Figure 3** presents the dimensions of protist literacy based on SLR result. Seven dimensions of protist literacy (**Figure 3**). Concept knowledge, relation

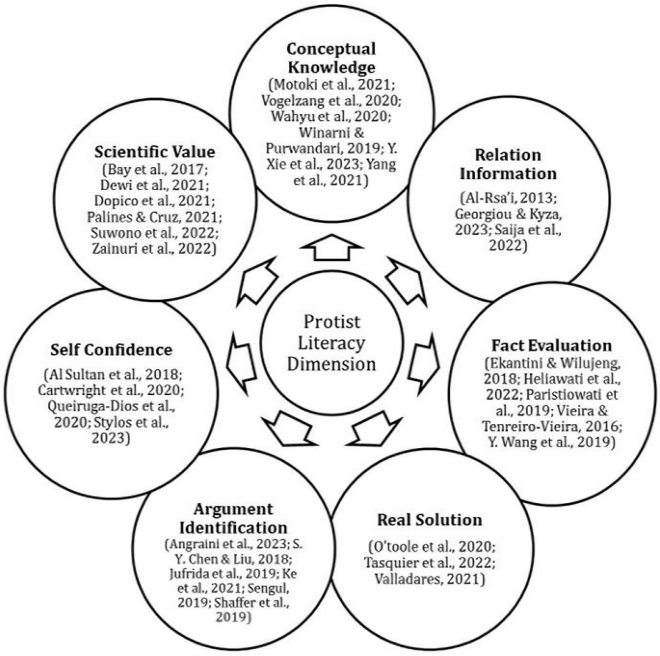

Figure 3. Dimensions of protist literacy (Source: Authors' own elaboration)

Table 3. Protist literacy dimension & its description

Dimension	Description
Conceptual knowledge	Know and understand the concept of protist
Relation information	Connect information/data to understand protist-related issues
Fact evaluation	Evaluate scientific facts about protists
Real solution	Choose the right solution regarding the problem of human interaction with protists
Argument identification	Identify scientific arguments about protists
Self confidence	Confidence in the skills and abilities possessed in understanding protists
Scientific value	Understand every value contained in the phenomenon of protist interaction with humans or the surrounding environment

information, fact evaluation, real solution, and argument identification belong to the cognitive domain of educational objectives in a protist course. In contrast, self-confidence and scientific value are parts of the affection domain of protist literacy. We concluded the definition of protist literacy from the results of reviewing various scientific articles (**Table 3**).

DISCUSSION

Protist Literacy

Protist literacy was developed in an effort to develop literacy principles from diverse branches of science, particularly biology. Biological literacy (Semilarski & Laius, 2021), genetic literacy (Maghfiroh et al., 2023), microbial literacy (Timmis et al., 2020), species literacy (Hooykaas et al., 2019), and many more types of scientific literacy have been established by researchers. As a result, we invented protist literacy because it did not exist previously, and we used previous research findings on scientific literacy as a foundation for constructing protist literacy. We obtained three keywords from the findings of a thorough literature review on scientific literacy.

Conceptual Understanding of Protist

Conceptual understanding is the current focus of attention to develop other cognitive skills in learning. Understanding concepts allows students to practice their problem-solving skills in the learning process (Hiebert, 2013). Someone who understands conceptual basics can generalize concepts to solve problems in the real world (Crooks & Alibali, 2014). The concept of protist is very complex because it has wide phylogenetic diversity. Protists are every aquatic food chain's primary producers, predators, food, and parasites (Weisse et al., 2016).

Protists include animal-like protists (Xie et al., 2023a), plant-like protists (Schwelm et al., 2018), and fungus-like protists (Xie & Wang, 2015), which are symbiotic with plants and animals. The classification of living entities currently dominates the study of protists (Asiloglu et al., 2021; Singer et al., 2021). The role of protist organisms in human existence that is most frequently discussed in scientific literature relates to the environment (Malard et al., 2022) and ecosystems (Burki et al., 2021). More emphasis is placed on protist morphology, anatomy, and reproduction (Singer et al., 2021). Therefore, the foundation of protist literacy includes understanding the concept of protist and associating it with life in general.

Analysis & Investigations of Protist-Related Issues in Human Life

Protist literacy promotes comprehension of the variety of living organisms and issues pertaining to related organisms. For instance, understanding the relationship between protists and their environment requires extensive knowledge of protists (Edgcomb, 2016; Massana et al., 2015; Singer et al., 2018). Analyzing and investigating the concept of protist literacy makes it simpler for students to communicate about various environmental issues caused by protist organisms.

Knowledge of protist organisms is associated with human positive attitudes towards protists (Bono-Lunn et al., 2016). Protist literacy enables students to value protists as more beneficial creatures. Protist literacy has the potential to make college students aware of their circumstances and aware of the benefits of protist organisms for humans. As an illustration, the use of brown algae as a food additive (Kadam et al., 2015). Protist literacy also facilitates university students' comprehension of protists as an integral component of daily life. Future sustainable development, such as producing biofuels from algae, will benefit from comprehending protist-related issues (Adeniyi et al., 2018; Milledge & Heaven, 2013).

Application of Concept of Protist in Solving Everyday Problems

We introduce protist literacy by highlighting the significance and potential of protist knowledge. Protist literacy requires not only knowledge of protist organisms, but also the relationship between protist organisms and human life. Positive (Wells et al., 2017) or negative (Pereda-Briones et al., 2019) interactions between humans and protist organisms are essential. In-depth knowledge of protists includes information about their function on the planet, such as being the primary producers of marine ecosystems. These autotrophic protists are called phytoplankton (Henson et al., 2021; Salmaso et al., 2015; Toseland et al., 2013).

Protists are very relatable to human existence because they are commonly found in human environments (Jex et al., 2013; Olive et al., 2020). The study of protists has the potential to arouse widespread curiosity and can provide examples of a variety of environmental biological problems. Many people are interested in protists because of their potential for conservation and public education about environmental threats such as blooming algae (Chen et al., 2015; Qi et al., 2017; Wang et al., 2017), red tide (Jeong et al., 2015; Zohdi & Abbaspour, 2019). Protists are also fascinating to study because of their relationship to human health, such as giardiasis caused by a protist organism called *Giardia duodenalis* (Cai et al., 2021). Therefore, by understanding protists, university students can comprehend the significance of protist organisms in their daily existence.

Protist Literacy Dimensions

A variety of scientific literacy concepts have been used to define protist literacy. In this paper, seven aspects of protist literacy are identified. The dimensions of protist literacy are as described below.

Conceptual knowledge

The notion of protist literacy has been derived from the framework of scientific literacy. It is anticipated that university students possessing a comprehensive understanding of protists will demonstrate proficiency in comprehending the intricacies of protist organisms. Concept knowledge refers to acquiring and comprehending information pertaining to protists within the context of higher education. Students must fully understand protists (Rossi et al., 2019; Weisse et al., 2016). Students need to comprehend and identify the diversity and classification of protists (Pawlowski, 2014). The concept of protist is crucial not only for protist education in universities, but for all humans in daily life. Concept knowledge refers to cognitive processes such as recollection, analysis, and comprehension (Ari, 2021). Concept knowledge entails integrating disparate pieces of information. Knowledge quality refers to how something is known and how well it can be understood (Chen et al., 2021; Förtsch et al., 2018). Concept knowledge involves principles and definitions.

Relation information

Relation information is the capacity to connect information/data to comprehend the issues posed by protist organisms to human life. Numerous problems are associated with protist organisms in human existence. For example, protist colonization causes variations in the microbiota of the human intestine (Partida-Rodríguez et al., 2017). Several studies have demonstrated that fungi, protists, and other microbiota in the human intestine have complex interrelationships. Linking diverse valuable information for solving or dealing with complex problems is important (Lanning & Mallek, 2017). Cultivating students' ability to effectively connect and synthesize crucial information is vital in addressing and mitigating the challenges they encounter in the learning process. The relational technique employed in this dimension commences by elucidating a phenomenon encountered. Connecting novel information with preexisting knowledge can foster problem-solving skills among university students (Magnuson, 2013).

Fact evaluation

Fact evaluation refers to critically assessing scientific information about protists. Scientific facts about protists might include the fact that protists provide significant potential for assessing the effects of pollution and human activities on the ecological integrity of biological systems (Anderson & Harvey, 2020; Cruaud et al., 2019). Evaluating issues about protist organisms within a community is important in pursuing truth. Scientific facts are empirical observations that have undergone rigorous validation through repeated confirmation (Dean et al., 2017). Repeated confirmation involves employing direct observation or drawing inferences, which serve as a basis for establishing factual information (Wolf-Chase, 2018). Scientific truth is inherently dynamic and subject to revision. It is possible for something that is currently acceptable to undergo modifications or even be subsequently rejected. The significance of assessing information about protists lies in acquiring scientific veracity derived from several sources of knowledge.

Real solution

The selection of an appropriate answer pertaining to the issue of human interaction with organisms holds significant importance in establishing a dimension of protist literacy. The ongoing issue under investigation pertains to the emergence of industrially manufactured nanoparticles and their potential to induce environmental toxicity (Vilas-Boas et al., 2020). The study of ciliated protists has received significant attention from ecotoxicologists due to their crucial function in regulating microbial populations and mitigating the effects of environmental toxicity (Gomiero et al., 2013). Extensive efforts have been made to identify and implement strategies to address environmental challenges associated with protist species. Utilizing the problem-solving process facilitates the development of independent learning skills among university students (Dent & Koenka, 2016). To effectively address a problem, university students must acquire relevant knowledge and collaborate with peers (Fairley et al., 2021).

Argument identification

College students' protist literacy can be assessed based on their ability to provide scientific arguments about protists. Students in higher education need more practice identifying valid arguments. Scientific argumentation skills assist students in reasoning (Zhu et al., 2017). In the classroom, argumentation can be used to explain a scientific process (Heng et al., 2015; Li et al., 2022). The inclusion of socio-scientific issues in the learning process can facilitate the development of students' argumentation skills (Ladachart & Ladachart, 2021). A scientific argument about protists could go something like "algae are eukaryotic organisms, unicellular or multicellular, but lack specialized organs and tissues, and lack vascularization". Scientific argumentation consists essentially of making claims supported by scientific evidence. Scientific argumentation aims to establish a connection between ideas and scientific evidence (Jones, 2014). To participate in scientific argumentation during the learning process, university students must have the ability to comprehend and apply theories, principles, laws, or models.

Self-confidence

Including affective domains such as self-confidence as a protist literacy dimension is essential. When university students have high confidence while studying, their academic performance improves (Izgi-Onbasili et al., 2022). Students have ample time to learn about protist organisms to present in the protist class. Lessons on protist contain a great deal of abstract material; therefore, it is necessary to train university students to comprehend and communicate the concept of protist confidently (Raharjo et al., 2018). Students' self-confidence can be boosted by listening to and responding to the ideas of their peers. Students' self-confidence in expressing their opinions in the classroom can increase their motivation to engage in active learning (Abaci & Okyay, 2013).

Scientific value

The importance of emphasizing scientific values remains crucial in protist literacy. Scientific values refer to inherent values in a scientific concept (Sickler et al., 2014). University students employ critical thinking and rationality to comprehend phenomena, refraining from subscribing to prevalent societal beliefs. All issues necessitate careful consideration and resolution through a logical and analytical cognitive process. An often encountered scenario with protist organisms pertains to a visually striking marine occurrence known as bioluminescence (Menghini & Aubry, 2021; Perin et al., 2022). Bioluminescence refers to the emission of light by marine algae through chemical reactions (Brodl et al., 2018). The values associated with science encompass various dimensions of its positive impact on human existence. Commonly observed in studies on protists are instances, where *Chlorella* sp. is employed as a dietary adjunct, purportedly enhancing stamina (Kotrbáček et al., 2015).

CONCLUSIONS

Literacy researchers have not carried out SLRs related to protist literacy. The concept of protist literacy was created from a scientific literacy framework that previous researchers have extensively researched. The definition of protist literacy was developed from three key words, namely "understanding the concept of protist", "analysis and investigation of protist-related issues", and "application of the concept of protist in human life". Protist literacy is very specific, because it only relates to protist organisms. The goal of protist literacy is for university students to have in-depth knowledge of protists and to apply knowledge of these concepts in everyday life.

The study of protists inside higher education institutions should aim to promote a comprehensive understanding of protist organisms. Hence, students can actively engage in solving community issues related to protists. The development of the protist literacy dimensions is crucial for students. These dimensions include

(1) concept knowledge,
(2) relation information,
(3) fact evaluation,
(4) real solution,
(5) argument identification,
(6) self-confidence, and
(7) scientific value.

Limitations

The researchers acknowledge certain limitations inherent in this study. The present study only focused on elucidating protist literacy's definition and its various associated dimensions. The investigation of protist literacy is an intriguing avenue for further scholarly exploration. Another limitation of this study is that the literature search was restricted to the Scopus database and a small number of papers, 33 in total. Besides, the current study only employed "scientific literacy" in the database search. As a result, in the future, researchers can use additional phrases or combine several literacy concepts, such as "science literacy" or "biology literacy," to make search results more thorough and intriguing. This SLR incorporated articles from the last ten years, allowing for previously unavailable information. Future scholars must consider this to acquire additional knowledge. Since we only understand English as a second language, the articles we studied were exclusively in English. Meanwhile, valuable information

may be found in publications in languages other than English.

Author contributions: All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: This study was supported by the Directorate of Research, Technology and Community Service (DRTPM), Ministry of Education, Culture, Research and Technology, INDONESIA under Grant 140/E5/PG.02.00.PL/2023 & 20.6.23/UN32.20.1/LT/2023.

Ethical statement: The authors stated that the present work does not necessitate the approval of an ethics committee, as it primarily constitutes a literature review that integrates several theories or concepts.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Abaci, R., & Okyay, B. (2013). A comparation of self confidence levels and personal growth initiative skills between managers and employees. *Procedia-Social and Behavioral Sciences, 106*, 39-44. https://doi.org/10.1016/j.sbspro.2013.12.006

Adeniyi, O. M., Azimov, U., & Burluka, A. (2018). Algae biofuel: Current status and future applications. *Renewable and Sustainable Energy Reviews, 90*(2018), 316-335. https://doi.org/10.1016/j.rser.2018.03.067

Adl, S. M., Bass, D., Lane, C. E., Lukeš, J., Schoch, C. L., Smirnov, A., Agatha, S., Berney, C., Brown, M. W., Burki, F., Cárdenas, P., Čepička, I., Chistyakova, L., del Campo, J., Dunthorn, M., Edvardsen, B., Eglit, Y., Guillou, L., Hampl, V., …, & Zhang, Q. (2019). Revisions to the classification, nomenclature, and diversity of eukaryotes. *Journal of Eukaryotic Microbiology, 66*(1), 4-119. https://doi.org/10.1111/jeu.12691

Adl, S. M., Simpson, A. G. B., Lane, C. E., Lukeš, J., Bass, D., Bowser, S. S., Brown, M. W., Burki, F., Dunthorn, M., Hampl, V., Heiss, A., Hoppenrath, M., Lara, E., Gall, L. Le, Lynn, D. H., McManus, H., Mitchell, E. A. D., Mozley-Stanridge, S. E., Parfrey, L. W., …, & Spiegel, F. W. (2012). The revised classification of eukaryotes. *Journal of Eukaryotic Microbiology, 59*(5), 429-514. https://doi.org/10.1111/j.1550-7408.2012.00644.x

Al Sultan, A., Henson, H., & Fadde, P. J. (2018). Pre-service elementary teachers' scientific literacy and self-efficacy in teaching science. *IAFOR Journal of Education, 6*(1), 25-42. https://doi.org/10.22492/ije.6.1.02

Alneyadi, S. S. (2019). Virtual lab implementation in science literacy: Emirati science teachers' perspectives. *EURASIA Journal of Mathematics, Science and Technology Education, 15*(12), em1786. https://doi.org/10.29333/ejmste/109285

Al-Rsa'i, M. S. (2013). Promoting scientific literacy by using ICT in science teaching. *International Education Studies, 6*(9), 175-186. https://doi.org/10.5539/ies.v6n9p175

Anderson, S. R., & Harvey, E. L. (2020). Temporal variability and ecological interactions of parasitic marine syndiniales in coastal protist communities. *MSphere, 5*(3). https://doi.org/10.1128/msphere.00209-20

Angraini, E., Zubaidah, S., & Susanto, H. (2023). TPACK-based active learning to promote digital and scientific literacy in genetics. *Pegem Egitim ve Ogretim Dergisi* [*Pegem Education and Training Magazine*], *13*(2), 50-61. https://doi.org/10.47750/pegegog.13.02.07

Archibald, J. M., Simpson, A. G. B., & Slamovits, C. H. (2017). Handbook of the protists. In *Handbook of the protists*. Springer. https://doi.org/10.1007/978-3-319-32669-6

Ari, O. (2021). Undergraduates as interdisciplinary researchers: Gains in competencies and conceptual knowledge. *College Teaching, 69*(4), 218-230. https://doi.org/10.1080/87567555.2020.1860888

Asiloglu, R., Samuel, S. O., Sevilir, B., Akca, M. O., Acar Bozkurt, P., Suzuki, K., Murase, J., Turgay, O. C., & Harada, N. (2021). Biochar affects taxonomic and functional community composition of protists. *Biology and Fertility of Soils, 57*(1), 15-29. https://doi.org/10.1007/s00374-020-01502-8

Bay, J. L., Vickers, M. H., Mora, H. A., Sloboda, D. M., & Morton, S. M. (2017). Adolescents as agents of healthful change through scientific literacy development: A school-university partnership program in New Zealand. *International Journal of STEM Education, 4*(1). https://doi.org/10.1186/s40594-017-0077-0

Berney, C., Ciuprina, A., Bender, S., Brodie, J., Edgcomb, V., Kim, E., Rajan, J., Parfrey, L. W., Adl, S., Audic, S., Bass, D., Caron, D. A., Cochrane, G., Czech, L., Dunthorn, M., Geisen, S., Glöckner, F. O., Mahé, F., Quast, C., … de Vargas, C. (2017). UniEuk: Time to Speak a Common Language in Protistology! *Journal of Eukaryotic Microbiology, 64*(3), 407-411. https://doi.org/10.1111/jeu.12414

Bono-Lunn, D., Villeneuve, C., Abdulhay, N. J., Harker, M., & Parker, W. (2016). Policy and regulations in light of the human body as a 'superorganism' containing multiple, intertwined symbiotic relationships. *Clinical Research and Regulatory Affairs, 33*(2-4), 39-48. https://doi.org/10.1080/10601333.2016.1210159

Brodl, E., Winkler, A., & Macheroux, P. (2018). Molecular mechanisms of bacterial bioluminescence. *Computational and Structural Biotechnology Journal, 16*, 551-564. https://doi.org/10.1016/j.csbj.2018.11.003

Buonanno, F., Dolan, J. R., Esteban, G. F., Hines, H. N., Kamra, K., Kosakyan, A., Miceli, C., Samaritani, E., Vannini, C., & Warren, A. (2020). Protistological science dissemination. *European Journal of Protistology, 76*, 125729. https://doi.org/10.1016/j.ejop.2020.125729

Burki, F., Sandin, M. M., & Jamy, M. (2021). Diversity and ecology of protists revealed by metabarcoding. *Current Biology, 31*(19), R1267-R1280. https://doi.org/10.1016/j.cub.2021.07.066

Cai, W., Ryan, U., Xiao, L., & Feng, Y. (2021). Zoonotic giardiasis: An update. *Parasitology Research, 120*(12), 4199-4218. https://doi.org/10.1007/s00436-021-07325-2

Cartwright, N. M., Liddle, D. M., Arceneaux, B., Newton, G., & Monk, J. M. (2020). Assessing scientific literacy skill perceptions and practical capabilities in fourth year undergraduate biological science students. *International Journal of Higher Education, 9*(6), 64-76. https://doi.org/10.5430/ijhe.v9n6p64

Chen, O., Woolcott, G., & Kalyuga, S. (2021). Comparing alternative sequences of examples and problem-solving tasks: The case of conceptual knowledge. *Educational and Developmental Psychologist, 38*(1), 158-170. https://doi.org/10.1080/20590776.2021.1915098

Chen, S. Y., & Liu, S. Y. (2018). Reinforcement of scientific literacy through effective argumentation on an energy-related environmental issue. *EURASIA Journal of Mathematics, Science and Technology Education, 14*(12), em1625. https://doi.org/10.29333/ejmste/95171

Chen, S., Gao, K., & Beardall, J. (2015). Viral attack exacerbates the susceptibility of a bloom-forming alga to ocean acidification. *Global Change Biology, 21*(2), 629-636. https://doi.org/10.1111/gcb.12753

Čipková, E., Karolčík, Š., Sládková, K., & Ušáková, K. (2018). What is the level of scientific literacy among geography students studying bachelor's studies in natural sciences? *International Research in Geographical and Environmental Education, 27*(4), 295-310. https://doi.org/10.1080/10382046.2017.1389044

Crooks, N. M., & Alibali, M. W. (2014). Defining and measuring conceptual knowledge in mathematics. *Developmental Review, 34*(4), 344-377. https://doi.org/10.1016/j.dr.2014.10.001

Cruaud, P., Vigneron, A., Fradette, M. S., Dorea, C. C., Culley, A. I., Rodriguez, M. J., & Charette, S. J. (2019). Annual protist community dynamics in a freshwater ecosystem undergoing contrasted climatic conditions: The Saint-Charles River (Canada). *Frontiers in Microbiology, 10*. https://doi.org/10.3389/fmicb.2019.02359

Dean, A. K., Ellis, N., & Wells, V. K. (2017). Science 'fact' and science 'fiction'? Homophilous communication in high-technology B2B selling. *Journal of Marketing Management, 33*(9-10), 764-788. https://doi.org/10.1080/0267257X.2017.1324895

Delanka-Pedige, H. M. K., Munasinghe-Arachchige, S. P., Abeysiriwardana-Arachchige, I. S. A., Zhang, Y., & Nirmalakhandan, N. (2020). Algal pathway towards meeting United Nation's sustainable development goal 6. *International Journal of Sustainable Development and World Ecology, 27*(8), 678-686. https://doi.org/10.1080/13504509.2020.1756977

Dent, A. L., & Koenka, A. C. (2016). The relation between self-regulated learning and academic achievement across childhood and adolescence: A meta-analysis. *Educational Psychology Review, 28*(3), 425-474. https://doi.org/10.1007/s10648-015-9320-8

Dewi, C. A., Erna, M., Martini, Haris, I., & Kundera, I. N. (2021). Effect of contextual collaborative learning based ethnoscience to increase student's scientific literacy ability. *Journal of Turkish Science Education, 18*(3), 525-541. https://doi.org/10.36681/tused.2021.88

Dopico, E., Ardura, A., Borrell, Y. J., Miralles, L., & García-Vázquez, E. (2021). Boosting adults' scientific literacy with experiential learning practices. *European Journal for Research on the Education and Learning of Adults, 12*(2), 223-238. https://doi.org/10.3384/RELA.2000-7426.OJS1717

Edgcomb, V. P. (2016). Marine protist associations and environmental impacts across trophic levels in the twilight zone and below. *Current Opinion in Microbiology, 31*, 169-175. https://doi.org/10.1016/j.mib.2016.04.001

Ekantini, A., & Wilujeng, I. (2018). The development of science student worksheet based on education for environmental sustainable development to enhance scientific literacy. *Universal Journal of Educational Research, 6*(6), 1339-1347. https://doi.org/10.13189/ujer.2018.060625

Etten, J. Van, Keddis, R., Lisa, J., & Rauschenbach, I. (2022). The diverse world of protists–An ideal community with which to introduce microscopy in the microbiology teaching laboratory. *Journal of Microbiology & Biology Education, 23*(1), 23-25. https://doi.org/10.1128/jmbe.00142-21

Fairley, N., Fernandez, V., Richard-Plouet, M., Guillot-Deudon, C., Walton, J., Smith, E., Flahaut, D., Greiner, M., Biesinger, M., Tougaard, S., Morgan, D., & Baltrusaitis, J. (2021). Systematic and collaborative approach to problem solving using X-ray photoelectron spectroscopy. *Applied Surface Science Advances, 5*, 100112. https://doi.org/10.1016/j.apsadv.2021.100112

Förtsch, C., Werner, S., von Kotzebue, L., & Neuhaus, B. J. (2018). Effects of high-complexity and high-cognitive-level instructional tasks in biology

lessons on students' factual and conceptual knowledge. *Research in Science and Technological Education, 36*(3), 353-374. https://doi.org/10.1080/02635143.2017.1394286

Fu, X., Ou, Z., Zhang, M., Meng, Y., Li, Y., Wen, J., Hu, Q., Zhang, X., Norbäck, D., Deng, Y., Zhao, Z., & Sun, Y. (2021). Indoor bacterial, fungal and viral species and functional genes in urban and rural schools in Shanxi Province, China–Association with asthma, rhinitis and rhinoconjunctivitis in high school students. *Microbiome, 9*, 138. https://doi.org/10.1186/s40168-021-01091-0

Gallagher, K. E., Kadokura, E., Eckert, L. O., Miyake, S., Mounier-Jack, S., Aldea, M., Ross, D. A., & Watson-Jones, D. (2016). Factors influencing completion of multi-dose vaccine schedules in adolescents: A systematic review. *BMC Public Health, 16*, 172. https://doi.org/10.1186/s12889-016-2845-z

Geisen, S., Hu, S., dela Cruz, T. E. E., & Veen, G. F. (Ciska. (2021). Protists as catalyzers of microbial litter breakdown and carbon cycling at different temperature regimes. *ISME Journal, 15*(2), 618-621. https://doi.org/10.1038/s41396-020-00792-y

Geisen, S., Mitchell, E. A. D., Adl, S., Bonkowski, M., Dunthorn, M., Ekelund, F., Fernández, L. D., Jousset, A., Krashevska, V., Singer, D., Spiegel, F. W., Walochnik, J., & Lara, E. (2018). Soil protists: A fertile frontier in soil biology research. *FEMS Microbiology Reviews, 42*(3), 293-323. https://doi.org/10.1093/femsre/fuy006

Georgiou, Y., & Kyza, E. A. (2023). Fostering chemistry students' scientific literacy for responsible citizenship through socio-scientific inquiry-based learning (SSIBL). *Sustainability, 15*(8), 6442. https://doi.org/10.3390/su15086442

Gomiero, A., Dagnino, A., Nasci, C., & Viarengo, A. (2013). The use of protozoa in ecotoxicology: Application of multiple endpoint tests of the ciliate E. Crassus for the evaluation of sediment quality in coastal marine ecosystems. *Science of the Total Environment, 442*, 534-544. https://doi.org/10.1016/j.scitotenv.2012.10.023

Gu, X., Wang, C., & Lin, L. (2019). Examining scientific literacy through new media. *EURASIA Journal of Mathematics, Science and Technology Education, 15*(12), em1785. https://doi.org/10.29333/ejmste/109948

Guler, B. A., Saglam-Metiner, P., Deniz, I., Demirel, Z., Yesil-Celiktas, O., & Imamoglu, E. (2022). Aligned with sustainable development goals: Microwave extraction of astaxanthin from wet algae and selective cytotoxic effect of the extract on lung cancer cells. *Preparative Biochemistry and Biotechnology, 53*(5), 565-571. https://doi.org/10.1080/10826068.2022.2116455

Hammarsten, M., Askerlund, P., Almers, E., Avery, H., & Samuelsson, T. (2019). Developing ecological literacy in a forest garden: Children's perspectives. *Journal of Adventure Education and Outdoor Learning, 19*(3), 227-241. https://doi.org/10.1080/14729679.2018.1517371

Heliawati, L., Lidiawati, L., Adriansyah, P. N. A., & Herlina, E. (2022). Ethnochemistry-based adobe flash learning media using indigenous knowledge to improve students' scientific literacy. *Jurnal Pendidikan IPA Indonesia* [*Indonesian Science Education Journal*], *11*(2), 271-281. https://doi.org/10.15294/jpii.v11i2.34859

Heng, L. L., Surif, J., & Seng, C. H. (2015). Malaysian students' scientific argumentation: Do groups perform better than individuals? *International Journal of Science Education, 37*(3), 505-528. https://doi.org/10.1080/09500693.2014.995147

Henson, S. A., Cael, B. B., Allen, S. R., & Dutkiewicz, S. (2021). Future phytoplankton diversity in a changing climate. *Nature Communications, 12*, 5372. https://doi.org/10.1038/s41467-021-25699-w

Hiebert, J. (Ed.) (2013). *Conceptual and procedural knowledge: The case of mathematics*. Routledge. https://doi.org/10.4324/9780203063538

Hooykaas, M. J. D., Schilthuizen, M., Aten, C., Hemelaar, E. M., Albers, C. J., & Smeets, I. (2019). Identification skills in biodiversity professionals and laypeople: A gap in species literacy. *Biological Conservation, 238*, 108202. https://doi.org/10.1016/j.biocon.2019.108202

Husamah, H., Suwono, H., Nur, H., & Dharmawan, A. (2022). The development and validation of environmental literacy instrument based on spirituality for prospective science teachers. *EURASIA Journal of Mathematics, Science and Technology Education, 18*(12), em2206. https://doi.org/10.29333/EJMSTE/12732

Izgi-Onbasili, U., Avsar-Tuncay, A., Sezginsoy-Seker, B., & Kiray, S. A. (2022). An examination of pre-service teachers' experiences in creating a scientific digital story in the context of their self confidence in technological pedagogical content knowledge. *Journal of Baltic Science Education, 21*(2), 207-223. https://doi.org/10.33225/jbse/22.21.207

Jeong, H. J., Lim, A. S., Franks, P. J. S., Lee, K. H., Kim, J. H., Kang, N. S., Lee, M. J., Jang, S. H., Lee, S. Y., Yoon, E. Y., Park, J. Y., Yoo, Y. Du, Seong, K. A., Kwon, J. E., & Jang, T. Y. (2015). A hierarchy of conceptual models of red-tide generation: Nutrition, behavior, and biological interactions. *Harmful Algae, 47*, 97-115. https://doi.org/10.1016/j.hal.2015.06.004

Jex, A. R., Koehler, A. V., Ansell, B. R., Baker, L., Karunajeewa, H., & Gasser, R. B. (2013). Getting to the guts of the matter: The status and potential of

"omics" research of parasitic protists of the human gastrointestinal system. *International Journal for Parasitology, 43*(12-13), 971-982. https://doi.org/10.1016/j.ijpara.2013.06.005

Jones, L. (2014). Developing deaf children's conceptual understanding and scientific argumentation skills: A literature review. *Deafness and Education International, 16*(3), 146-160. https://doi.org/10.1179/1557069X13Y.0000000032

Jufrida, J., Basuki, F. R., Kurniawan, W., Pangestu, M. D., & Fitaloka, O. (2019). Scientific literacy and science learning achievement at junior high school. *International Journal of Evaluation and Research in Education, 8*(4), 630-636. https://doi.org/10.11591/ijere.v8i4.20312

Kadam, S. U., Tiwari, B. K., & O'Donnell, C. P. (2015). Extraction, structure and biofunctional activities of laminarin from brown algae. *International Journal of Food Science and Technology, 50*(1), 24-31. https://doi.org/10.1111/ijfs.12692

Kathiraven, T., Sundaramanickam, A., Shanmugam, N., & Balasubramanian, T. (2015). Green synthesis of silver nanoparticles using marine algae Caulerpa racemose and their antibacterial activity against some human pathogens. *Applied Nanoscience, 5*(4), 499-504. https://doi.org/10.1007/s13204-014-0341-2

Ke, L., Sadler, T. D., Zangori, L., & Friedrichsen, P. J. (2021). Developing and using multiple models to promote scientific literacy in the context of socio-scientific issues. *Science and Education, 30*(3), 589-607. https://doi.org/10.1007/s11191-021-00206-1

Kirmizigul, A. S., & Kizilay, E. (2020). Investigation of the pre-service science teachers' perceptions of protists. *Pedagogical Research, 5*(4), em0081. https://doi.org/10.29333/pr/9132

Kotrbáček, V., Doubek, J., & Doucha, J. (2015). The chlorococcalean alga chlorella in animal nutrition: A review. *Journal of Applied Phycology, 27*(6), 2173-2180. https://doi.org/10.1007/s10811-014-0516-y

Ladachart, L., & Ladachart, L. (2021). Preservice biology teachers' decision-making and informal reasoning about culture-based socioscientific issues. *International Journal of Science Education, 43*(5), 641-671. https://doi.org/10.1080/09500693.2021.1876958

Lanning, S., & Mallek, J. (2017). Factors influencing information literacy competency of college students. *Journal of Academic Librarianship, 43*(5), 443-450. https://doi.org/10.1016/j.acalib.2017.07.005

Li, X., Wang, W., & Li, Y. (2022). Systematically reviewing the potential of scientific argumentation to promote multidimensional conceptual change in science education. *International Journal of Science Education, 44*(7), 1165-1185. https://doi.org/10.1080/09500693.2022.2070787

Liang, S. W., Fang, W. T., Yeh, S. C., Liu, S. Y., Tsai, H. M., Chou, J. Y., & Ng, E. (2018). A nationwide survey evaluating the environmental literacy of undergraduate students in Taiwan. *Sustainability, 10*(6), 1730. https://doi.org/10.3390/su10061730

Loy, I., Carnero-Sierra, S., Acebes, F., Muñiz-Moreno, J., Muñiz-Diez, C., & Sánchez-González, J.-C. (2021). Where association ends. A review of associative learning in invertebrates, plants and Protista, and a reflection on its limits. *Journal of Experimental Psychology: Animal Learning and Cognition, 47*(3), 234-251. https://doi.org/10.1037/xan0000306

Maghfiroh, H., Zubaidah, S., Mahanal, S., & Susanto, H. (2023). A systematic review of genetic literacy interventions in secondary schools. *AIP Conference Proceedings, 2569*(1), 020030. https://doi.org/10.1063/5.0112439

Magnuson, M. L. (2013). Web 2.0 and information literacy instruction: Aligning technology with ACRL standards. *Journal of Academic Librarianship, 39*(3), 244-251. https://doi.org/10.1016/j.acalib.2013.01.008

Mahanal, S., Zubaidah, S., & Setiawan, D. (2020). The potential of RICOSRE to enhance university students' science literacy in biology. *International Conference on Biology, Sciences and Education, 10*, 282-287. https://doi.org/10.2991/absr.k.200807.056

Mahanal, S., Zubaidah, S., Setiawan, D., Maghfiroh, H., & Muhaimin, F. G. (2022). Empowering college students' problem-solving skills through RICOSRE. *Education Sciences, 12*(3), 196. https://doi.org/10.3390/educsci12030196

Malard, L. A., Mod, H. K., Guex, N., Broennimann, O., Yashiro, E., Lara, E., Mitchell, E. A. D., Niculita-Hirzel, H., & Guisan, A. (2022). Comparative analysis of diversity and environmental niches of soil bacterial, archaeal, fungal and protist communities reveal niche divergences along environmental gradients in the Alps. *Soil Biology and Biochemistry, 169*, 108674. https://doi.org/10.1016/j.soilbio.2022.108674

Massana, R., Gobet, A., Audic, S., Bass, D., Bittner, L., Boutte, C., Chambouvet, A., Christen, R., Claverie, J. M., Decelle, J., Dolan, J. R., Dunthorn, M., Edvardsen, B., Forn, I., Forster, D., Guillou, L., Jaillon, O., Kooistra, W. H. C. F., Logares, R., …, & de Vargas, C. (2015). Marine protist diversity in European coastal waters and sediments as revealed by high-throughput sequencing. *Environmental Microbiology, 17*(10), 4035-4049. https://doi.org/10.1111/1462-2920.12955

Menghini, D., & Aubry, S. (2021). De novo transcriptome assembly data of the marine bioluminescent dinoflagellate pyrocystis lunula [De novo

transcriptome assembly data of the marine bioluminescent dinoflagellate pyrocystis lunula]. *Data in Brief, 37*, 107254. https://doi.org/10.1016/j.dib.2021.107254

Merlo, S., Gabarrell Durany, X., Pedroso Tonon, A., & Rossi, S. (2021). Marine microalgae contribution to sustainable development. *Water, 13*(10), 1373. https://doi.org/10.3390/w13101373

Milledge, J. J., & Heaven, S. (2013). A review of the harvesting of micro-algae for biofuel production. *Reviews in Environmental Science and Biotechnology, 12*(2), 165-178. https://doi.org/10.1007/s11157-012-9301-z

Motoki, K., Saito, T., & Takano, Y. (2021). Scientific literacy linked to attitudes toward COVID-19 vaccinations: A pre-registered study. *Frontiers in Communication, 6*. https://doi.org/10.3389/fcomm.2021.707391

Nurwidodo, N., Amin, M., Ibrohim, I., & Sueb, S. (2020). The role of eco-school program (adiwiyata) towards environmental literacy of high school students. *European Journal of Educational Research, 9*(3), 1089-1103. https://doi.org/10.12973/EU-JER.9.3.1089

O'toole, J. M., McKoy, K., Freestone, M., & Osborn, J. A. (2020). 'Scientific literacy': An exercise in model building. *Education Sciences, 10*(8), 204. https://doi.org/10.3390/educsci10080204

Olive, M., Gan, C., Carratalà, A., & Kohn, T. (2020). Control of waterborne human viruses by indigenous bacteria and protists is influenced by temperature, virus type, and microbial species. *Applied and Environmental Microbiology, 86*, e01992-19. https://doi.org/10.1128/AEM.01992-19

Palines, K. M. E., & Cruz, R. A. O. Dela. (2021). Facilitating factors of scientific literacy skills development among junior high school students. *Lumat, 9*(1), 546-569. https://doi.org/10.31129/LUMAT.9.1.1520

Paristiowati, M., Cahyana, U., & Bulan, B. I. S. (2019). Implementation of problem-based learning–Flipped classroom model in chemistry and its effect on scientific literacy. *Universal Journal of Educational Research, 7*(9A), 56-60. https://doi.org/10.13189/ujer.2019.071607

Partida-Rodríguez, O., Serrano-Vázquez, A., Nieves-Ramírez, M. E., Moran, P., Rojas, L., Portillo, T., González, E., Hernández, E., Finlay, B. B., & Ximenez, C. (2017). Human intestinal microbiota: Interaction between parasites and the host immune response. *Archives of Medical Research, 48*(8), 690-700. https://doi.org/10.1016/j.arcmed.2017.11.015

Pawlowski, J. (2014). Protist evolution and phylogeny. In *eLS* (pp. 1-9). John Wiley & Sons Ltd. https://doi.org/10.1002/9780470015902.a0001935.pub2

Pereda-Briones, L., Terrados, J., & Tomas, F. (2019). Negative effects of warming on seagrass seedlings are not exacerbated by invasive algae. *Marine Pollution Bulletin, 141*, 36-45. https://doi.org/10.1016/j.marpolbul.2019.01.049

Perin, L. S., Moraes, G. V., Galeazzo, G. A., & Oliveira, A. G. (2022). Bioluminescent dinoflagellates as a bioassay for toxicity assessment. *International Journal of Molecular Sciences, 23*(21), 13012. https://doi.org/10.3390/ijms232113012

Pitman, S. D., Daniels, C. B., & Sutton, P. C. (2018). Characteristics associated with high and low levels of ecological literacy in a western society. *International Journal of Sustainable Development and World Ecology, 25*(3), 227-237. https://doi.org/10.1080/13504509.2017.1384412

Purssell, E., & McCrae, N. (2020). How to perform a systematic literature review. In *How to perform a systematic literature review*. Springer. https://doi.org/10.1007/978-3-030-49672-2

Putri, R. T. H., Raharjo, & Rachmadiarti, F. (2021). Practicing creative thinking skills: Inquiry base activity sheets development in protists learning material. *Jurnal Pendidikan Biologi* [*Journal of Biology Education*], *6*(1), 1-11. https://doi.org/10.31932/jpbio.v6i1.847

Qi, L., Hu, C., Wang, M., Shang, S., & Wilson, C. (2017). Floating algae blooms in the East China Sea. *Geophysical Research Letters, 44*(22), 11501-11509. https://doi.org/10.1002/2017GL075525

Queiruga-Dios, M. Á., López-Iñesta, E., Diez-Ojeda, M., Sáiz-Manzanares, M. C., & Dorrío, J. B. V. (2020). Citizen science for scientific literacy and the attainment of sustainable development goals in formal education. *Sustainability, 12*(10), 4283. https://doi.org/10.3390/su12104283

Raharjo, D., Ramli, M., & Rinanto, Y. (2018). Misconception protist in high school biology textbooks. In *Proceedings of the International Conference on Mathematics and Science Education* (pp. 85-90).

Rossi, A., Bellone, A., Fokin, S. I., Boscaro, V., & Vannini, C. (2019). Detecting associations between ciliated protists and prokaryotes with culture-Independent single-cell macrobiotics: A proof-of-concept study. *Microbial Ecology, 78*(1), 232-242. https://doi.org/10.1007/s00248-018-1279-9

Saija, M., Rahayu, S., Fajaroh, F., & Sumari. (2022). Enhancement of high school students' scientific literacy using local-socioscientific issues in Oe3C instructional strategies. *Jurnal Pendidikan IPA Indonesia* [*Indonesian Science Education Journal*], *11*(1), 11-23. https://doi.org/10.15294/jpii.v11i1.33341

Salmaso, N., Naselli-Flores, L., & Padisák, J. (2015). Functional classifications and their application in

phytoplankton ecology. *Freshwater Biology, 60*(4), 603-619. https://doi.org/10.1111/fwb.12520

Schwelm, A., Badstöber, J., Bulman, S., Desoignies, N., Etemadi, M., Falloon, R. E., Gachon, C. M. M., Legreve, A., Lukeš, J., Merz, U., Nenarokova, A., Strittmatter, M., Sullivan, B. K., & Neuhauser, S. (2018). Not in your usual top 10: Protists that infect plants and algae. *Molecular Plant Pathology, 19*(4), 1029-1044. https://doi.org/10.1111/mpp.12580

Seers, K. (2012). What is a qualitative synthesis? *Evidence Based Nursing, 15*(4), 101-101. https://doi.org/10.1136/ebnurs-2012-100977

Semilarski, H., & Laius, A. (2021). Exploring biological literacy: A systematic literature review of biological literacy. *European Journal of Educational Research, 10*(4), 1907-1918. https://doi.org/10.12973/eu-jer.10.3.1181

Semilarski, H., Laius, A., & Rannikmäe, M. (2019). Development of Estonian upper secondary school students' biological conceptual understanding and competences. *Journal of Baltic Science Education, 18*(6), 955-970. https://doi.org/10.33225/jbse/19.18.955

Sengul, O. (2019). Linking scientific literacy, scientific argumentation, and democratic citizenship. *Universal Journal of Educational Research, 7*(4), 1090-1098. https://doi.org/10.13189/ujer.2019.070421

Shaffer, J. F., Ferguson, J., & Denaro, K. (2019). Use of the test of scientific literacy skills reveals that fundamental literacy is an important contributor to scientific literacy. *CBE Life Sciences Education, 18*(3). https://doi.org/10.1187/cbe.18-12-0238

Sharon, A. J., & Baram-Tsabari, A. (2020). Can science literacy help individuals identify misinformation in everyday life? *Science Education, 104*(5), 873-894. https://doi.org/10.1002/sce.21581

Sickler, J., Cherry, T. M., Allee, L., Smyth, R. R., & Losey, J. (2014). Scientific value and educational goals: Balancing priorities and increasing adult engagement in a citizen science project. *Applied Environmental Education and Communication, 13*(2), 109-119. https://doi.org/10.1080/1533015X.2014.947051

Sihombing, M. S. G., & Pranoto, H. (2021). Analysis of students' learning difficulties in protist material. *Jurnal Pelita Pendidikan* [*Pelita Pendidikan Journal*], *9*(3), 143-148. https://doi.org/10.24114/jpp.v9i3.24436

Singer, D., Kosakyan, A., Seppey, C. V. W., Pillonel, A., Fernández, L. D., Fontaneto, D., Mitchell, E. A. D., & Lara, E. (2018). Environmental filtering and phylogenetic clustering correlate with the distribution patterns of cryptic protist species. *Ecology, 99*(4), 904-914. https://doi.org/10.1002/ecy.2161

Singer, D., Seppey, C. V. W., Lentendu, G., Dunthorn, M., Bass, D., Belbahri, L., Blandenier, Q., Debroas, D., de Groot, G. A., de Vargas, C., Domaizon, I., Duckert, C., Izaguirre, I., Koenig, I., Mataloni, G., Schiaffino, M. R., Mitchell, E. A. D., Geisen, S., & Lara, E. (2021). Protist taxonomic and functional diversity in soil, freshwater and marine ecosystems. *Environment International, 146*, 106262. https://doi.org/10.1016/j.envint.2020.106262

Stylos, G., Siarka, O., & Kotsis, K. T. (2023). Assessing Greek pre-service primary teachers' scientific literacy. *European Journal of Science and Mathematics Education, 11*(2), 271-282. https://doi.org/10.30935/scimath/12637

Suwono, H., Maulidia, L., Saefi, M., Kusairi, S., & Yuenyong, C. (2022). The development and validation of an instrument of prospective science teachers' perceptions of scientific literacy. *EURASIA Journal of Mathematics, Science and Technology Education, 18*(1), em2206. https://doi.org/10.29333/EJMSTE/12732

Tasquier, G., Knain, E., & Jornet, A. (2022). Scientific literacies for change making: Equipping the young to tackle current societal challenges. *Frontiers in Education, 7*. https://doi.org/10.3389/feduc.2022.689329

Timmis, K., Timmis, J., & Jebok, F. (2020). The urgent need for microbiology literacy in society: Children as educators. *Microbial Biotechnology, 13*(5), 1300-1303. https://doi.org/10.1111/1751-7915.13619

Toseland, A., Daines, S. J., Clark, J. R., Kirkham, A., Strauss, J., Uhlig, C., Lenton, T. M., Valentin, K., Pearson, G. A., Moulton, V., & Mock, T. (2013). The impact of temperature on marine phytoplankton resource allocation and metabolism. *Nature Climate Change, 3*(11), 979-984. https://doi.org/10.1038/nclimate1989

Valladares, L. (2021). Scientific literacy and social transformation: Critical perspectives about science participation and emancipation. *Science and Education, 30*, 557-587. https://doi.org/10.1007/s11191-021-00205-2

Vanier, G., Stelter, S., Vanier, J., Hempel, F., Maier, U. G., Lerouge, P., Ma, J., & Bardor, M. (2018). Alga-made anti-hepatitis B antibody binds to human fcγ receptors. *Biotechnology Journal, 13*(4), 1700496. https://doi.org/10.1002/biot.201700496

Vieira, R. M., & Tenreiro-Vieira, C. (2016). Fostering scientific literacy and critical thinking in elementary science education. *International Journal of Science and Mathematics Education, 14*(4), 659-680. https://doi.org/10.1007/s10763-014-9605-2

Vilas-Boas, J. A., Senra, M. V. X., & Dias, R. J. P. (2020). Ciliates in ecotoxicological studies: A minireview. *Acta Limnologica Brasiliensia, 32*. https://doi.org/10.1590/s2179-975x6719

Virtič, M. P. (2022). Teaching science & technology: Components of scientific literacy and insight into the steps of research. *International Journal of Science Education, 44*(12), 1916-1931. https://doi.org/10.1080/09500693.2022.2105414

Vogelzang, J., Admiraal, W. F., & Van Driel, J. H. (2020). Effects of scrum methodology on students' critical scientific literacy: The case of green chemistry. *Chemistry Education Research and Practice, 21*(3), 940-952. https://doi.org/10.1039/d0rp00066c

Wahyu, Y., Suastra, I. W., Sadia, I. W., & Suarni, N. K. (2020). The effectiveness of mobile augmented reality assisted STEM-based learning on scientific literacy and students' achievement. *International Journal of Instruction, 13*(3), 343-356. https://doi.org/10.29333/iji.2020.13324a

Wang, L., Wang, X., Jin, X., Xu, J., Zhang, H., Yu, J., Sun, Q., Gao, C., & Wang, L. (2017). Analysis of algae growth mechanism and water bloom prediction under the effect of multi-affecting factor. *Saudi Journal of Biological Sciences, 24*(3), 556-562. https://doi.org/10.1016/j.sjbs.2017.01.026

Wang, Y., Lavonen, J., & Tirri, K. (2019). An assessment of how scientific literacy-related aims are actualized in the national primary science curricula in China and Finland. *International Journal of Science Education, 41*(11), 1435-1456. https://doi.org/10.1080/09500693.2019.1612120

Weisse, T., Anderson, R., Arndt, H., Calbet, A., Hansen, P. J., & Montagnes, D. J. S. (2016). Functional ecology of aquatic phagotrophic protists–Concepts, limitations, and perspectives. *European Journal of Protistology, 55*, 50-74. https://doi.org/10.1016/j.ejop.2016.03.003

Wells, M. L., Potin, P., Craigie, J. S., Raven, J. A., Merchant, S. S., Helliwell, K. E., Smith, A. G., Camire, M. E., & Brawley, S. H. (2017). Algae as nutritional and functional food sources: Revisiting our understanding. *Journal of Applied Phycology, 29*(2), 949-982. https://doi.org/10.1007/s10811-016-0974-5

Winarni, E. W., & Purwandari, E. P. (2019). The effectiveness of turtle mobile learning application for scientific literacy in elementary school. *Journal of Education and E-Learning Research, 6*(4), 156-161. https://doi.org/10.20448/journal.509.2019.64.156.161

Wolf-Chase, G. A. (2018). New worlds, new civilizations? From science fiction to science fact. *Theology and Science, 16*(4), 415-426. https://doi.org/10.1080/14746700.2018.1525221

Xiao, Y., & Watson, M. (2019). Guidance on conducting a systematic literature review. *Journal of Planning Education and Research, 39*(1), 93-112. https://doi.org/10.1177/0739456X17723971

Xie, J., Tan, B., & Zhang, Y. (2023a). A large-scale study into protist-animal interactions based on public genomic data using DNA barcodes. *Animals, 13*(14), 2243. https://doi.org/10.3390/ani13142243

Xie, Y., & Wang, G. (2015). Mechanisms of fatty acid synthesis in marine fungus-like protists. *Applied Microbiology and Biotechnology, 99*(20), 8363-8375. https://doi.org/10.1007/s00253-015-6920-7

Xie, Y., Wang, J., Li, S., & Zheng, Y. (2023b). Research on the influence path of metacognitive reading strategies on scientific literacy. *Journal of Intelligence, 11*(5), 78. https://doi.org/10.3390/jintelligence11050078

Xuan, X., Jin, Q., Jo, I., Duan, Y., & Kim, M. (2019). The potential contribution of geography curriculum to scientific literacy. *Journal of Geography, 118*(5), 185-196. https://doi.org/10.1080/00221341.2019.1611906

Yang, Y., Cai, S., Wen, Y., Li, J., & Jiao, X. (2021). AR learning environment integrated with EIA inquiry model: Enhancing scientific literacy and reducing cognitive load of students. *Sustainability, 13*(22), 12787. https://doi.org/10.3390/su132212787

Yunanda, I., Susilo, H., & Ghofur, A. (2019). Misconceptions identification on biodiversity and protist using multiple choice open reason (MCOR). *Biosfer: Jurnal Pendidikan Biologi* [*Biosphere: Journal of Biology Education*], *12*(2), 170-181. https://doi.org/10.21009/biosferjpb.v12n2.170-181

Zainuri, A., Sukarno, S., & Huda, M. (2022). Understanding scientific literacy and pedagogy competence: A critical insight into religious integration thinking skills Miftachul Huda. *Journal of Educational and Social Research, 12*(1), 273-281. https://doi.org/10.36941/jesr-2022-0022

Zhu, M., Lee, H. S., Wang, T., Liu, O. L., Belur, V., & Pallant, A. (2017). Investigating the impact of automated feedback on students' scientific argumentation. *International Journal of Science Education, 39*(12), 1648-1668. https://doi.org/10.1080/09500693.2017.1347303

Zohdi, E., & Abbaspour, M. (2019). Harmful algal blooms (red tide): A review of causes, impacts and approaches to monitoring and prediction. *International Journal of Environmental Science and Technology, 16*(3), 1789-1806. https://doi.org/10.1007/s13762-018-2108-x