Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: http://www.science-gate.com/IJAAS.html

Conceptualizing bioinformatics education in STEM literacy development for pre-service biology teachers

R. Ahmad Zaky El Islami [1], Indah Juwita Sari [2,*], Enggar Utari [2]

[1]*Department of Science Education, Faculty of Teacher Training and Education, Universitas Sultan Ageng Tirtayasa, Serang, Indonesia*
[2]*Department of Biology Education, Faculty of Teacher Training and Education, Universitas Sultan Ageng Tirtayasa, Serang, Indonesia*

ARTICLE INFO

Article history:
Received 18 June 2023
Received in revised form
11 November 2023
Accepted 9 December 2023

Keywords:
Bioinformatics education
STEM literacy
Pre-service biology teachers
Conceptual framework
Systematic review

ABSTRACT

This study aimed to create a basic plan for adding bioinformatics education into STEM (Science, Technology, Engineering, and Mathematics) learning, particularly for future biology teachers. By reviewing studies from 2019 to 2023 in the ERIC Database with the key terms "Bioinformatics Education" and "STEM Literacy," the research highlighted important areas in this subject. It organized the findings into four main themes related to bioinformatics education: levels of education, challenges faced, teaching methods, and methods for research or evaluation. Additionally, it identified three themes in STEM literacy: educational levels, challenges, and definitions or ways to measure it. The review pointed out a critical need for teaching materials, tools, and strategies in bioinformatics for future biology teachers at the college level. It also found a lack of research on STEM literacy at this level, with just three articles addressing it. These articles examined STEM literacy through skills such as general knowledge, career awareness, and communication skills. The suggested basic plan promotes combining bioinformatics education with real-world biological issues, career preparation, and addressing educational shortcomings. It recommends a bioinformatics module with specific curriculum content, tools, and teaching methods to improve STEM literacy, including knowledge, attitudes, and skills in STEM. This plan could guide future research in classrooms to improve STEM literacy among future biology teachers through bioinformatics education.

1. Introduction

All current biological problems lead to genomics and biological systems, which are solved through information technology and computational science, or what we call Bioinformatics (Magana et al., 2014). The existence of Bioinformatics is an indicator of the progress of biology because it integrates computer science, information technology, and biology. Bioinformatics greatly influences research patterns and educational strategies, and these continue to develop in efforts to improve human health and extend human life (Yang et al., 2008). It is essential to increase education to meet the need for competent scientists and technicians in bioinformatics (Hersh, 2007). In addition, to ensure successful education and training, we must better understand practical educational approaches and strategies for enhancing student learning in these areas (Magana et al., 2014).

Bioinformatics education can be defined as teaching and learning by using computers and information technology to solve biological problems (Sari et al., 2022; Koch and Fuellen, 2008). It means that bioinformatics education should include knowledge and skills from biology, mathematics, statistics, physics, chemistry, medicine, pharmacology, computer science, and information technology (Ranganathan, 2005). Efforts to integrate bioinformatics education effectively are a massive challenge (Brass, 2000). Pre-service biology teachers are an essential target in formally integrating bioinformatics education.

The boom in the use of bioinformatics has resulted in the emergence of research on bioinformatics education in recent decades, such as

* Corresponding Author.
Email Address: indah.juwitasari@untirta.ac.id (I. J. Sari)
https://doi.org/10.21833/ijaas.2023.12.021
Corresponding author's ORCID profile:
https://orcid.org/0000-0002-5810-2945

research conducted by Sari et al. (2022), which examined the use of bioinformatics in biology lessons to see the improvement in the computational thinking of high school students in Indonesia. Bain et al. (2022) also examined the success of a free bioinformatics workshop for Scottish secondary school biology students. Additionally, Bio-ITEST was created by Kovarik et al. (2013). The study examined the impact of developmental models on secondary school teachers' and students' views of cognitive attributes. These attributes include awareness, engagement, self-efficacy, and relevance. All are linked to fostering an interest in Science, Technology, Engineering, and Mathematics (STEM) careers. According to Kovarik et al. (2013), using real-world challenges in high school scientific courses effectively engages students' interest in STEM material and boosts self-efficacy. Students are better able to appreciate the significance of science material when ethical philosophy is included, and socio-scientific challenges coming from new genetic technologies are discussed.

STEM are content areas that are closely intertwined with one another. STEM integration is an excellent way to understand complex interrelationships in the context of solving real-world problems (Chai, 2019). So, increasing STEM literacy for pre-service biology teachers is a challenging endeavor for educators and researchers. Joyner and Parks' (2023) development goals of enhanced pedagogy to address the development of undergraduate STEM literacy are well recognized. Still, the methodologies and implementation for applying such lessons can take time and effort. STEM literacy involves effectively reading the latest scientific literature, developing studies, interpreting research results, and communicating scientific findings and theories. NRC (2014) mentioned more discussion about STEM literacy as one of the desired literacies that allows people to engage with society (NRC, 2014). STEM literacy has been defined as a student's sufficient understanding of ideas and processes in the four STEM fields and how they influence society to apply knowledge in using common technologies, critically evaluate STEM concepts in the news, and engage in solving everyday problems (Miller, 2022). The Next Generation Science Standards (NGSS, 2013) current science standards provide new education and training to bring STEM literacy to the mainstream of science education as they include extensive references to technology and engineering topics and practices across scientific fields. Such research conducted by Yang et al. (2022) to establish students' engagement in indigenous microbiology course-based undergraduate research experience model (CUREs) serves two purposes of scientific research and teaching, including students' scientific literacy skills and the role of the instructor, which can be further applied as a contribution for broader scientific knowledge and to carry out new research in their experience and future research career. The description of the problems mentioned leads us to create a conceptual framework for bioinformatics education towards STEM literacy for pre-service biology teachers. The conceptual framework designed comes from a systematic review of bioinformatics education for pre-service biology teachers and STEM literacy for pre-service biology teachers from the Scopus database for 2018-2023. The resulting conceptual framework can be widely used for pre-service biology teachers' bioinformatics courses to increase STEM literacy.

2. Method

To develop the conceptual framework of bioinformatics education towards STEM literacy for pre-service biology teachers, we need to understand the state of the art of the research on bioinformatics education for pre-service biology teachers and STEM literacy for pre-service biology teachers. We followed a systematic review of searching, categorizing, and analyzing the papers presented in this review (Magana et al., 2014). Initially, we conducted a search for empirical research within the ERIC database, which is recognized as the largest database in the field of education. We used broad search terms "Bioinformatics Education" and "STEM Literacy," covering the period from 2019 to 2023. This search resulted in the identification of six articles under "Bioinformatics Education" and 123 articles under "STEM Literacy." The criteria for including studies in our review were focused on journal articles that pertain to higher education.

We chose to employ a qualitative approach since the main objectives of this study were to determine how the literature depicts bioinformatics education and STEM literacy. This involved assessing the content of the abstracts in each category to find the themes. Based on the papers' main themes, we grouped them into four categories, including level, challenges, pedagogy, and educational research. In the level category, we included publications that described a particular program, degree, course, or set of courses. We considered any papers that discussed viewpoints regarding the necessity for bioinformatics education and STEM literacy, the opportunities and challenges of bioinformatics education and STEM literacy, and the problems. We considered all articles that discussed opinions regarding the necessity of bioinformatics education and STEM literacy, opportunities and challenges of bioinformatics education and STEM literacy, and problems relating to the interdisciplinary nature of bioinformatics education and STEM literacy when evaluating the challenges category. We considered publications in the pedagogy category that described a teaching strategy, multimedia tool, or strategy for disseminating bioinformatics knowledge. All works that examined bioinformatics education programs, resources, general knowledge, abilities, or attitudes were included in the category of educational research. The article abstracts were examined after deleting duplicate entries, and where in doubt, the entire article was read. Articles written in languages other than English, those that categorize teachers as belonging to the STEM fields (such as science and math teachers), and articles that utilize other than English as their primary language are excluded. In all, nine articles were retained for further analysis.

To find themes, we applied category analysis (Strauss and Corbin, 1990). Inductive analysis seeks out patterns and distinctions within the data to produce a series of interconnected themes (Glaser et al., 1967). In this method, we meticulously identified recurring themes within the abstracts, grouped these themes into categories, and selected terms that most effectively represented the subjects. To ensure a comprehensive and in-depth exploration of each identified theme, we revisited and thoroughly read all articles related to the same topic. In the results section, the articles are listed in alphabetical order, starting with the first author's last name followed by the year of publication. This review's scope is constrained by its reliance on the ERIC database, which, despite being the largest educational database globally, limits the breadth of sources considered. Future studies are encouraged to broaden the scope of literature review on bioinformatics education and STEM Literacy and to compare their findings with those of this study.

3. Results and discussion

3.1. Bioinformatics education for pre-service biology teachers

The six articles we got for further analysis have various keywords but have an exciting unity when presented in word cloud form. So, we construct a word cloud based on keywords often appearing in the analyzed articles. We can see in Fig. 1 that the big keywords are learning, bioinformatics, education, genomics, biology, curriculum, design and development, molecular genetics, proteomic, and data-driven, and these terms are part of the bioinformatics education definition. The definition made by Makolo et al. (2022) that bioinformatics education broadly is teaching and learning the use of computers and information technology, along with mathematical and statistical analysis to collect, store, analyze, convert, and integrate data to solve biological problems. The development of the bioinformatics curriculum aims to bring bioinformatics to multiple audiences, including undergraduate biology majors, pre-service biology teachers, and teaching faculty. Successful bioinformatics educational experience indicators include understanding students using bioinformatics tools with various data and making reasonable inferences (Greene and Donovan, 2005). Based on the word cloud and the definitions of several sources related to bioinformatics education, we can validate that the six articles analyzed represent the definition of bioinformatics education. Bioinformatics education is associated with developing and implementing curriculum, design, and learning tools meaningful for data-driven biology concepts such as molecular genetics, genomics, and proteomics. We present the results of the classification of the six articles in Table 1, which consists of the level of education and subjects analyzed in the article, the challenges the background or challenges faced in the article, the pedagogy includes the strategies, methods or teaching media developed by the author, and the evaluation consists of the skills or abilities of students studied in the article.

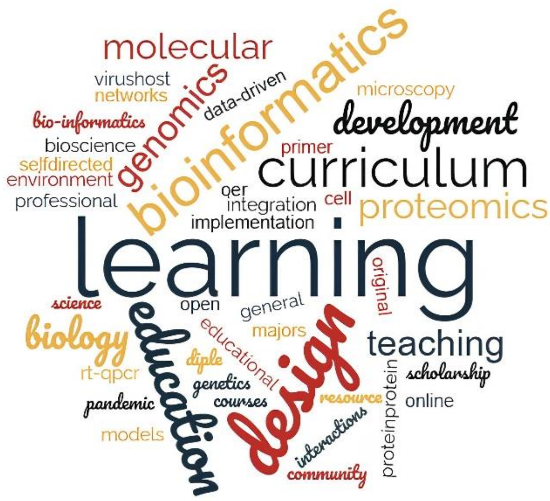

Fig. 1: Word cloud of bioinformatics education from keywords of articles

Our analysis revealed that half of the research articles on bioinformatics education focused on undergraduate programs, with the remainder addressing both undergraduate and graduate levels, including studies exclusively for graduate programs. Among these, five articles investigated the integration of bioinformatics into biology courses, such as genetics and molecular biology, within science departments. Remarkably, only one out of six articles explored bioinformatics education within a biology education major, as found in the ERIC database from 2019 to 2023. This observation underscores the significant role of bioinformatics education in the biology education department. An undergraduate level in biology education produces pre-service biology teachers at the high school level (NRC, 1990). They need to understand bioinformatics, which is closely related to concepts in Biology. They also need to understand how to teach bioinformatics to students. In addition, other skills arise with bioinformatics education at the undergraduate level of biology education (Sari et al., 2022; Kovarik et al., 2013; Welch et al., 2014).

The challenges that form the research background of the six articles are very important, interesting, and visionary for students' future. Bioinformatics skills are very useful in the career world of students; even the UK regularly includes the development of bioinformatics skills as one of its main goals (Gatherer, 2020). Bioinformatics is a multidisciplinary science that is needed by various groups and combines up-to-date educational resources (Ryder et al., 2019). Therefore, the need for training and practical guidance from other educators for biology instructors to apply effective pedagogical approaches to designing curricular tools and resources is increasing rapidly. Bioinformatics education is closely related to real-life activities, so learning biology, especially in molecular studies, can integrate social issues into the biology curriculum. Jones and Mellieon-Williams (2022) found that biology concepts related to social issues can be essential for students' future careers. Implementing bioinformatics learning, especially for pre-service biology teachers, is a direct and virtual scientific practice with collaborative engagement with teachers and colleagues. As stated by Laukens et al. (2019), the scientific approach requires direct training and collaborative engagement with instructors and peers, a challenging dimension of the learning environment to recreate online. The bioinformatics tools available on the website are free and easy to access, so they support in-person and online learning. Covey (2021) argued that computational biology and bioinformatics are inherent parts of most life science degrees that can encourage students to use various skills in practical research contexts. In addition, many essential concepts in molecular biology, gene expression, and nucleic acids create opportunities for spiral learning. Because this exercise requires only access to free web-based resources and does not require a laboratory, it can be used in most science education settings. The challenges and needs highlighted in the six articles led to the development of innovative and current bioinformatics education courses. Bioinformatics education is closely linked to advancements in artificial intelligence (AI). Zheng et al. (2022) have detailed how machine learning, a popular branch of AI, is dedicated to extracting meaningful and actionable insights from vast and complex datasets through various neural network models. Given that bioinformatics frequently deals with large data volumes, this connection is significant. Ezziane (2006) provided insights into the sophisticated use of AI in bioinformatics, with specific examples from immunology and vaccinology. This integration facilitates the introduction of bioinformatics to pre-service biology teachers, highlighting the field's relevance and application in modern scientific inquiry.

Teaching involves two critical elements: the methods used for instruction and an understanding of educational principles or strategies (Korthagen, 2017). Bioinformatics education demands a unique teaching strategy that stands apart from traditional subjects. Gatherer (2020) demonstrated this through the integration of bioinformatics into the undergraduate curriculum by creating specialized modules. This curriculum introduces bioinformatics in the first year, delves deeper into phylogenetics and structural bioinformatics in the second year, and applies these concepts to protein evolution in the third year, emphasizing the algorithmic basis of various bioinformatics techniques. In the first year, students engage with basic, interactive online bioinformatics tools; in the second, they progress to more advanced web-based resources and simple standalone software; by the third year, they use more complex tools tailored to specific protein evolution problems.

Contrastingly, Ryder et al. (2019) introduced a different pedagogical model for bioinformatics education through the NIBLSE Incubator, an online collaborative platform involving multiple stages, from the selection of learning resources to the dissemination of educational materials. This model aims to produce engaging, vetted resources that align with core bioinformatics competencies.

Similarly, Yu et al. (2022) employed an innovative online learning environment for molecular biosciences, covering Genetics, Cell Biology, Bioinformatics, and Advanced Microscopy, enabling students to use experimental techniques and laboratory tools remotely. This approach represents a novel strategy in the field, adapting to the evolving educational landscape by integrating online resources and home-based laboratory exercises.

The six articles we found related to bioinformatics education at the undergraduate level measure various skills and abilities, such as students' skills in using tools (Gatherer, 2020), scientific skills, including quantitative analysis, problem-solving, and handling "big data," (Ryder et al., 2019), learning outcomes (Laukens et al., 2019; Covey, 2021; Jones and Mellieon-Williams, 2022), practical lab skills, critical thinking skills, and proficiency with lab calculations (Yu et al., 2022), and also motivation and interest (Laukens et al., 2019). It means that bioinformatics education can enhance many skills and abilities of students.

3.2. STEM literacy for pre-service biology teachers

The word cloud in Fig. 2 shows that no big words can be taken as an understanding of STEM literacy, meaning that all have the same word size and no repetition of the same word. Some words that have the same scope are the concepts of physiology and ecology, originating from the subject of biology. Literacy, Science, Experience, and Career can also be keys to constructing a definition of STEM literacy. The National Research Council (NRC, 1996) defines STEM literacy as "knowledge and understanding of the mathematical and scientific processes and concepts necessary for personal decision-making, participation in cultural and civic affairs, and economic productivity." STEM literacy is the result of what is developed in students, the attitudes, skills, and knowledge they acquire through STEM education. Based on the word cloud and definitions from several sources related to STEM literacy, it can be validated that the fourth article analyzed represents the definition of STEM literacy. STEM literacy is a learning outcome consisting of knowledge, attitudes, and skills honed from science learning activities and programming experiences both in class and outside of school to support students' future careers.

Fig. 2: Word cloud of STEM literacy from keywords of articles

We present the results of the classification of three articles about STEM literacy in Table 2, which consists of the level of education and subjects analyzed in the article, the challenges containing the background or challenges faced, and the definitions or indicators used by the articles analyzed. We found that 100% of papers on STEM literacy in the ERIC database were at the undergraduate level from 2019–2023. There are two articles related to biology subject matter, such as physiology (Crawford et al., 2021), ecology (Wu et al., 2021), and one article related to the interdisciplinary course. Based on these findings, we can conclude that STEM literacy can be increased by activities in biology learning, especially for pre-service biology teachers. Research that measures STEM literacy in biology lessons has been conducted by Rahmi and Kaban (2021), and the result is that most students have achieved intermediate STEM literacy. Joyner and Parks (2023) researched to develop STEM literacy in microbiology courses through developing scaffolded assignments. Scaffolding assignments allow faculty to customize learning and assessment while facilitating students' conceptualization of big-picture concepts by constructing literacy-based projects. The results of this study indicate that the scaffolding approach facilitates the development of STEM literacy for undergraduate students.

Table 2 also provides information on key points of background research from three STEM literacy articles. Crawford et al. (2021) examined STEM literacy to build a strong foundation in STEM literacy, increase STEM diversity and inclusion, and prepare students to meet the demands of STEM careers. Wu et al. (2021) recognized that reforms in undergraduate science education are urgently needed to develop scientific literacy and STEM skills. Such skills can help students succeed in personal, professional, and civic life and are essential to the innovation and prosperity of the nation. Ahmed et al. (2020) studied STEM literacy to increase scientifically literate citizens and a STEM-capable workforce. Based on these three studies, we found that STEM literacy is important in supporting students' future careers, both for solving problems, making decisions, and using various skills to bring out the best innovations. Zollman (2012) stated that STEM literacy in learning can meet our social, economic, and personal needs.

The categories of definitions or indicators in the STEM literacy articles analyzed are the limits of STEM literacy studied, such as STEM literacy studied by Crawford et al. (2021), which used a questionnaire to capture general knowledge, appreciation, career awareness, and student career interests. Wu et al. (2021) examined STEM skills as part of STEM literacy from authentic inquiry experiences to improve skills in the scientific process using a questionnaire consisting of their rate of interest in ecology, ability to formulate testable hypotheses, understanding of how ecologists conduct research, and skills to evaluate the quality of scientific reports before and after the inquiry project. Ahmed et al. (2020) STEM working environment and students' skills, decision-making, and communication skills as STEM literacy were studied using confidence-related items questionnaires, such as skills in science writing, understanding how science thinks, collecting data, reading a textbook, working in a small group or team, and others. The three articles agreed that measuring STEM literacy was more effective using a scaled questionnaire.

Table 1: Bioinformatics education articles

No.	Reference	Level and course	Challenges	Pedagogy	Educational research or evaluation
1	Gatherer (2020)	Undergraduate biology	Biology graduates must have bioinformatics skills that will be very useful in their future careers. National initiatives in the United Kingdom to stimulate "Science, Technology, Engineering, and Mathematics" have regularly included the development of bioinformatics skills as one of their key goals	Bioinformatics curriculum: module	Bioinformatics skills
2	Ryder et al. (2019)	Undergraduate biology education	The need to create an inquiry-based curriculum in interdisciplinary fields. The need for the development and incorporation of up-to-date educational resources Lack of training and practical guidance from other educators for biology instructors to apply effective pedagogical approaches to designing curricular tools and resources	Online collaboration environment: incubators The NIBLSE incubator model	Scientific skills, including quantitative analysis, problem-solving, and handling big data
3	Jones and Mellieon-Williams (2022)	Undergraduate in genetics course	The need to include real-life activities by integrating social issues into the biology curriculum may encourage students to see biology concepts related to social issues that students can tackle in future careers.	Social justice service-learning project	Learning results related to STEM courses that use active learning
4	Yu et al. (2022)	Undergraduate- and graduate-level molecular bioscience labs	Scientific practice requires hands-on training and collaborative engagement with instructors and peers, dimensions of the learning environment that were challenging to recreate online	Online learning environment	Practical lab skills, analytical abilities, and competency with lab calculations
5	Laukens et al. (2019)	Graduate-level in biochemistry and biotechnology	Most life sciences degrees include computational biology and bioinformatics as a core component, which can allow students to apply a variety of abilities in real-world research settings	Using cytoscape and related computational network biology approaches is one way to help students develop practical skills through the data-driven analysis of complicated biomolecular datasets	Motivation and interest student learning outcomes
6	Covey (2021):	Undergraduate and degree specializing in biochemistry or molecular biology	Spiral learning is made possible by a few crucial ideas in molecular biology, gene expression, and nucleic acids. This activity can be done in most scientific education settings because it only calls for free online materials and doesn't require a lab	Students need to gain hands-on experience with primary design to gain familiarity with essential bioinformatics resources and a deeper theoretical understanding of the RT-qPCR approach and its potential limitations	Learning outcomes

Table 2: STEM literacy articles

No	Reference	Description	Challenges	Definition/ Indicators
1	Crawford et al. (2021)	Undergraduate in educational, scientific, and physiology-themed	Building a strong foundation for scientific and STEM literacy Increasing diversity and inclusion in STEM Improving students' readiness to fulfil the demand for STEM careers	STEM literacy: general knowledge, appreciation, career awareness, and career interest
2	Wu et al. (2021)	Undergraduate students: ecology course	Reforms in undergraduate science education are critically needed to develop science literacy and STEM skills for all students, which help individuals succeed in personal, professional, and civic life and are vital to the innovations and prosperity of the nation	STEM literacy in this article focusses on skills from authentic inquiry experiences to improve skill of the scientific process
4	Ahmed et al. (2020)	Undergraduate students EM course and working environment in scientific fields.	An interdisciplinary course for non-science majors was designed to address the needs of increasing scientifically literate citizens and the STEM-capable workforce	STEM literacy in this article focusses on STEM working environment and skills, decision-making, and communication skills

Zollman (2012) described STEM literacy into (1) literacy from science, technology, engineering, mathematics, and other related areas; (2) personal, social, and economic needs; and (3) the domain of cognitive, affective, and psychomotor learning. The ability to use scientific knowledge (in physics, chemistry, biological sciences, and earth and space sciences) and processes to understand and, in addition, to participate in decisions that affect science in life and health, earth and environment, and technology is described as each literacy in STEM literacy by some literature, such as OECD (2003). The ability to utilize, comprehend, and assess technology, as well as to comprehend the technological principles and techniques required to generate solutions and achieve goals, is what is meant by technology literacy, according to the NAGB (2010). Engineering literacy, according to the OECD (2003), is the capacity to apply scientific and mathematical principles systematically and creatively to practical objectives like designing, manufacturing, and operating efficient machinery.

Most STEM literacy definitions consider societal and economic needs but leave out individual needs. Economic demands for national security, societal needs for new technical and scientific advancements, and individual needs to become contented, useful, and informed citizens (Zollman, 2012). Physical abilities such as movement, coordination, manipulation, dexterity, grace, strength, speed, and activities that exhibit fine motor skills, such as precisely using precision tools or equipment, are examples of the psychomotor domain of STEM literacy (Zollman, 2012). However, there is less emphasis on the psychomotor domain than the cognitive and affective domains in STEM literacy. Technological advances are rapidly changing the psychomotor domain skills required. For example, instructional technology no longer covers keyboard skills but leads to using more advanced programming languages to solve problems. So, we conclude that the domain of STEM literacy consists of three domains, including STEM knowledge, STEM attitudes, and STEM skills.

3.3. A conceptual framework of STEM literacy-oriented bioinformatics education for pre-service biology teachers

STEM literacy is an essential ability for students as it helps them navigate the real world, and introducing bioinformatics education poses a significant challenge for the educational sector. It aims to harness all aspects of students' abilities, particularly those training to become biology teachers. In our systematic review, we developed a conceptual framework for STEM Literacy-Oriented Bioinformatics Education specifically designed for pre-service biology teachers, as illustrated in Fig. 3 of our findings. This framework highlights three critical needs for bioinformatics education for these future educators: 1) addressing biological problems that closely relate to everyday life; 2) encompassing cognitive, affective, and skill-based learning in bioinformatics, which is vital for their future roles as biology teachers; and 3) addressing the shortfall in bioinformatics training, with a specific focus on the context in Indonesia.

The findings of the six articles related to pedagogy in bioinformatics education for pre-service biology teachers consist of curriculum material, tools, and methods/models/strategies that support learning at the undergraduate biology education level. In Indonesia, biology education is a major that has a profile to produce a generation of biology teachers at the high school level. Subjects that can support the implementation of bioinformatics education include biochemistry and cell biology in the first year, genetics and biotechnology in the second year, and evolution in the third year. There still needs to be more bioinformatics education courses provided explicitly in the biology education department in Indonesia. This is one of the significant challenges for educators in Indonesia. The results of an analysis of the biology curriculum in a high school conducted by Sari et al. (2022) stated that the framework for the biology curriculum in Indonesia for senior high schools already contains molecular coverage for bioinformatics consisting of structural and functional relationships of genes, deoxyribonucleic acid (DNA), chromosomes, mutation, gene regulation, principles of biotechnology and its applications to improve human well-being (also known as DNA technology), and the theories, principles, and mechanisms of evolution and speciation.

Bioinformatics education for pre-service biology teachers requires knowledge of the instructor's pedagogical content and school readiness with a high-quality internet connection. The bioinformatics tools used in the study are widely available on the internet and are free of charge, like the research conducted by Sari et al. (2022), who used BLAST and Python in their bioinformatics learning. Clustal, FASTA, MEGA, BioConductor, Cytoscape, Chimera, and DataMonkey can also be used as bioinformatics tools in bioinformatics learning. Many learning strategies or methods have also been introduced that can support bioinformatics education for pre-service biology teachers, such as research-based projects and inquiry-based learning (Marques et al., 2014), computational inquiry-based teaching that has a relevant and straightforward activity in the scientific context, provide minds-on and hands-on activities (Sari et al., 2022), online learning environment (Yu et al., 2022), social justice service-learning project (Jones and Mellieon-Williams, 2022), and online collaboration environment: “incubators.” (Ryder et a., 2019). So, a bioinformatics module is needed to accommodate curriculum materials, tools, and methods or strategies used to implement bioinformatics education for pre-service biology teachers.

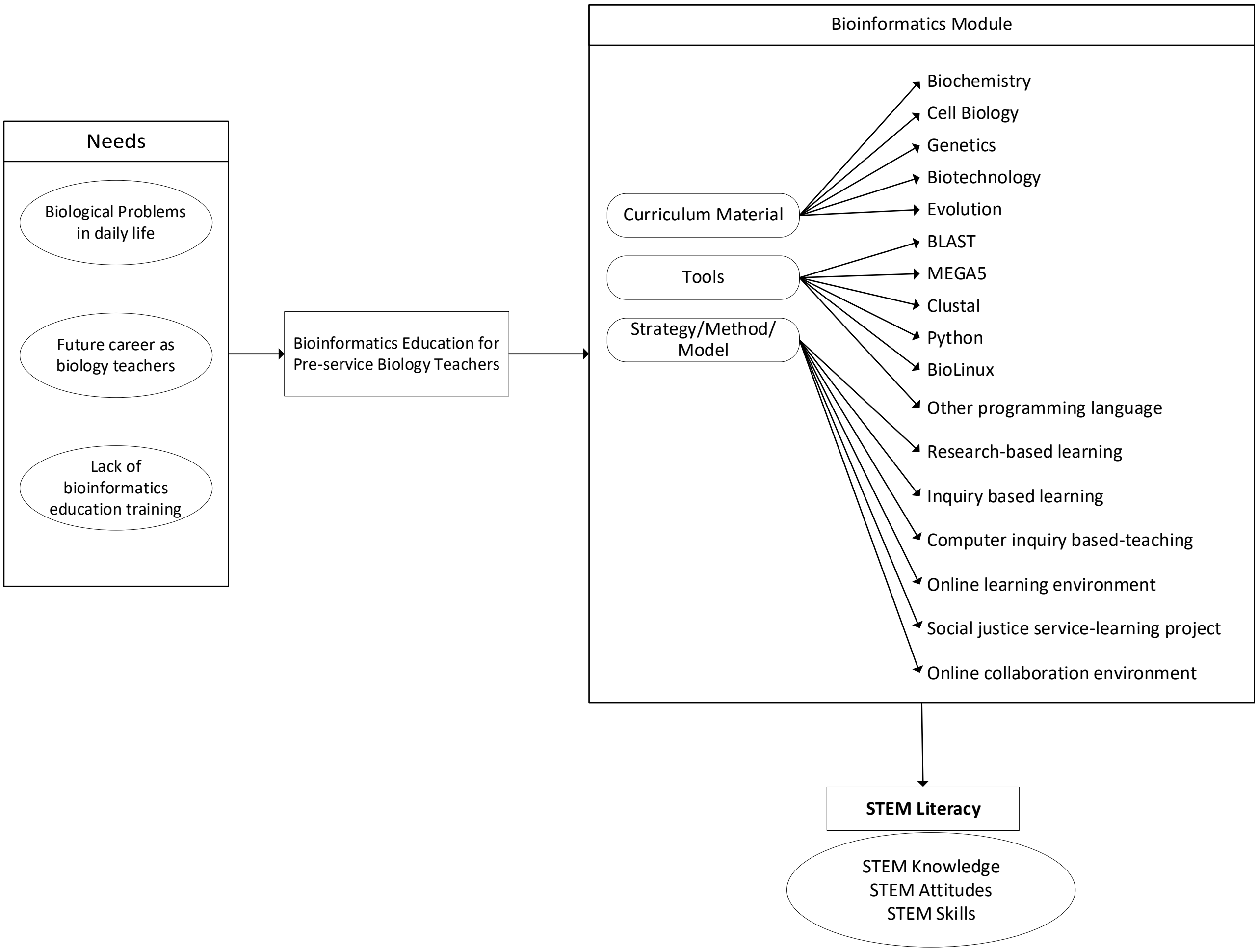

Fig. 3: A conceptual framework of bioinformatics education towards STEM literacy for pre-service biology teachers

This conceptual framework can be used to implement bioinformatics education for pre-service biology teachers using the bioinformatics module to initiate STEM Literacy for students. Research on bioinformatics education for pre-service biology teachers is still very limited, especially in Indonesia and when viewed from the ERIC Database. This is also reinforced by the absence of modules that support bioinformatics education for pre-service biology teachers. Based on the results of the systematic review, this conceptual framework is likely to become a benchmark in further developing bioinformatics education. Likewise, research that examines STEM literacy still needs to be improved. We need help finding STEM literacy research, especially in Indonesia at the undergraduate biology education students' level.

4. Conclusion

Bioinformatics education for future biology teachers should address real-life biological issues, prepare them for their future careers, and fill the gap in bioinformatics knowledge. To achieve this, bioinformatics education can be delivered through a module that includes curriculum content, tools, and teaching methods aimed at enhancing STEM literacy. This literacy encompasses knowledge in STEM fields, positive attitudes towards STEM, and practical STEM skills. Future research can utilize this conceptual framework to conduct classroom studies that aim to improve the STEM literacy of pre-service biology teachers through bioinformatics education.

Acknowledgment

The authors thank the LPPM Universitas Sultan Ageng Tirtayasa, which funded this research through the Internal Grant of the Research and Service Funding for the Year 2023 with the Penelitian Unggulan Untirta (PUU) Scheme.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

Ahmed MW, Anderson Y, Gerald-Goins T, Hollowell GP, Saliim ET, Sangutei T, and White SL (2020). Promoting STEM-literacy by designing decision-driven interdisciplinary courses for non-science majors. Journal of STEM Education: Innovations and Research, 21(3): 28-34.

Bain SA, Meagher TR, and Barker D (2022). Design, delivery and evaluation of a bioinformatics education workshop for 13-16-year-olds. Journal of Biological Education, 56(5): 570-580. https://doi.org/10.1080/00219266.2020.1858932

Brass A (2000). Bioinformatics education-A UK perspective. Bioinformatics, 16(2): 77–78. https://doi.org/10.1093/bioinformatics/16.2.77 **PMid:10842726**

Chai CS (2019). Teacher professional development for science, technology, engineering and mathematics (STEM) education: A review from the perspectives of technological pedagogical content (TPACK). The Asia-Pacific Education Researcher, 28(1): 5-13. https://doi.org/10.1007/s40299-018-0400-7

Covey SD (2021). An adaptable dry lab for SYBR based RT-qPCR primer design to reinforce concepts in molecular biology and nucleic acids. Biochemistry and Molecular Biology Education, 49(2): 262-270. https://doi.org/10.1002/bmb.21446 **PMid:32897640**

Crawford AJ, Hays CL, Schlichte SL, Greer SE, Mallard HJ, Singh RM, and Schiller AM (2021). Retrospective analysis of a STEM outreach event reveals positive influences on student attitudes toward STEM careers but not scientific methodology. Advances in Physiology Education, 45(3): 427-436. https://doi.org/10.1152/advan.00118.2020 **PMid:34124952**

Ezziane Z (2006). Applications of artificial intelligence in bioinformatics: A review. Expert Systems with Applications, 30(1): 2-10. https://doi.org/10.1016/j.eswa.2005.09.042

Gatherer D (2020). Reflections on integrating bioinformatics into the undergraduate curriculum: The Lancaster experience. Biochemistry and Molecular Biology Education, 48(2): 118-127. https://doi.org/10.1002/bmb.21320 **PMid:31793726**

Glaser BG, Strauss AL, and Strutzel E (1968). The discovery of grounded theory; strategies for qualitative research. Nursing Research, 17(4): 364. https://doi.org/10.1097/00006199-196807000-00014

Greene K and Donovan S (2005). Ramping up to the biology workbench: A multi-stage approach to bioinformatics education. Bioscene: Journal of College Biology Teaching, 31(1): 3-11.

Hersh WR (2007). The full spectrum of biomedical informatics education at Oregon Health and Science University. Methods of Information in Medicine, 46(1): 80-83. https://doi.org/10.1055/s-0038-1628138 **PMid:17224987**

Jones NN and Mellieon-Williams FM (2022). Social justice service-learning at an HBCU. Journal of College Science Teaching, 51(5): 5-9. https://doi.org/10.1080/0047231X.2022.12290575

Joyner JL and Parks ST (2023). Scaffolding STEM literacy assignments to build greater competence in microbiology courses. Journal of Microbiology and Biology Education, 24(1): e00218-22. https://doi.org/10.1128/jmbe.00218-22 **PMid:37089233 PMCid:PMC10117107**

Koch I and Fuellen G (2008). A review of bioinformatics education in Germany. Briefings in Bioinformatics, 9(3): 232-242. https://doi.org/10.1093/bib/bbn006 **PMid:18310676**

Korthagen F (2017). A foundation for effective teacher education: Teacher education pedagogy based on situated learning. The SAGE Handbook of Research on Teacher Education, 2: 528-544. https://doi.org/10.4135/9781526402042.n30

Kovarik DN, Patterson DG, Cohen C, Sanders EA, Peterson KA, Porter SG, and Chowning JT (2013). Bioinformatics education in high school: implications for promoting science, technology, engineering, and mathematics careers. CBE-Life Sciences Education, 12(3): 441-459. https://doi.org/10.1187/cbe.12-11-0193 **PMid:24006393 PMCid:PMC3763012**

Laukens K, Eyckmans M, De Neuter N, Naulaerts S, Meysman P, and Van Ostade X (2021). Preparing students for the data-driven life science era through a real-world viral infection case. Journal of Biological Education, 55(2): 178-187. https://doi.org/10.1080/00219266.2019.1667408

Magana AJ, Taleyarkhan M, Alvarado DR, Kane M, Springer J, and Clase K (2014). A survey of scholarly literature describing the field of bioinformatics education and bioinformatics educational research. CBE-Life Sciences Education, 13(4): 607-623. https://doi.org/10.1187/cbe.13-10-0193 **PMid:25452484 PMCid:PMC4255348**

Makolo AU, Smile O, Ezekiel KB, Destefano AM, McCall JL, and Isokpehi RD (2022). Leveraging H3Africa scholarly publications for technology-enhanced personalized bioinformatics education. Education Sciences, 12(12): 859. https://doi.org/10.3390/educsci12120859

Marques I, Almeida P, Alves R, Dias MJ, Godinho A, and Pereira-Leal JB (2014). Bioinformatics projects supporting life-sciences learning in high schools. PLOS Computational Biology, 10(1): e1003404. https://doi.org/10.1371/journal.pcbi.1003404 **PMid:24465192 PMCid:PMC3900377**

Miller KM (2022). Developing pedagogical content knowledge for STEM integration through data literacy: A case study of high school science teachers. Ph.D. Dissertation, University of Pennsylvania, Philadelphia, USA.

NAGB (2010). Technology and engineering literacy assessment and item specifications for the 2014. National Assessment of Educational Progress, Washington, D.C., USA.

NGSS (2013). Next generation science standards: For states, by states. Next Generation Science Standards, National Academies Press, Washington, D.C., USA.

NRC (1990). Fulfilling the promise: Biology education in the nation's schools. National Research Council, National Academies Press, Washington, D.C., USA.

NRC (1996). National science education standards. National Research Council, National Academies Press, Washington, D.C., USA.

NRC (2014). STEM integration in K-12 education: Status, prospects, and an agenda for research. National Research Council, National Academies Press, Washington, D.C., USA.

OECD (2003). Scientific literacy: The PISA 2003 assessment framework. Organization for Economic Cooperation and Development, Paris, France.

Rahmi YL (2023). A study investigation students' STEM literacy in biology learning. In the 3rd International Conference on Biology, Science and Education, Atlantis Press, Padang, Indonesia: 33-38. https://doi.org/10.2991/978-94-6463-166-1_6

Ranganathan S (2005). Bioinformatics education-Perspectives and challenges. PLOS Computational Biology, 1(6): e52. https://doi.org/10.1371/journal.pcbi.0010052 **PMid:16322761 PMCid:PMC1289384**

Ryder EF, Morgan WR, Sierk M, Donovan SS, Robertson SD, Orndorf HC, and Tapprich WE (2020). Incubators: Building community networks and developing open educational resources to integrate bioinformatics into life science education. Biochemistry and Molecular Biology Education, 48(4): 381-390. https://doi.org/10.1002/bmb.21387 **PMid:32585745 PMCid:PMC7496352**

Sari IJ, Vongsangnak W, and Pongsophon P (2022). The effect of bioinformatics module on molecular genetics concepts on senior high school students' computational thinking skills. Shanlax International Journal of Education, 10(2): 9-17. https://doi.org/10.34293/education.v10i2.4680

Strauss A and Corbin J (1990). Basics of qualitative research: Grounded theory, procedures, and techniques. SAGE, Thousand Oaks, USA.

Welch L, Lewitter F, Schwartz R, Brooksbank C, Radivojac P, Gaeta B, and Schneider MV (2014). Bioinformatics curriculum guidelines: toward a definition of core competencies. PLOS Computational Biology, 10(3): e1003496.

https://doi.org/10.1371/journal.pcbi.1003496
PMid:24603430 PMCid:PMC3945096

Wu XB, Sandoval C, Knight S, Jaime X, Macik M, and Schielack JF (2021). Web-based authentic inquiry experiences in large introductory classes consistently associated with significant learning gains for all students. International Journal of STEM Education, 8: 1-18.
https://doi.org/10.1186/s40594-021-00290-3

Yang JY, Yang MQ, Zhu MM, Arabnia HR, and Deng Y (2008). Promoting synergistic research and education in genomics and bioinformatics. BMC Genomics, 9(1): 1-5.
https://doi.org/10.1186/1471-2164-9-S1-I1
PMid:18366597 PMCid:PMC3226105

Yang Y, Wang M, Sang WL, Zhang YY, Liu W, and Wu SF (2022). Student-driven course-based undergraduate research experience (CUREs) projects in identifying vaginal microorganism species communities to promote scientific literacy skills. Frontiers in Public Health, 10: 870301.
https://doi.org/10.3389/fpubh.2022.870301
PMid:35570970 PMCid:PMC9096218

Yu A, Wisinski J, Osmundson T, Sanderfoot A, Cooper S, and Klein J (2022). Instructional innovations in college-level molecular bioscience labs during the pandemic-induced shift to online learning. Education Sciences, 12(4): 230.
https://doi.org/10.3390/educsci12040230

Zheng P, Wang S, Wang X, and Zeng X (2022). Artificial Intelligence in bioinformatics and drug repurposing: Methods and applications. Frontiers in Genetics, 13: 870795.
https://doi.org/10.3389/fgene.2022.870795
PMid:35368698 PMCid:PMC8969764

Zollman A (2012). Learning for STEM literacy: STEM literacy for learning. School Science and Mathematics, 112(1): 12-19.
https://doi.org/10.1111/j.1949-8594.2012.00101.x