International Journal of Biology Education Towards Sustainable Development
Vol.2, No.2, 2022, pp. 87-98
e-ISSN 2809-5073. DOI. 10.52889/ijbetsd.v2i2.164

Implementation of Bioinformatics Learning in Senior High School: A Systematic Review

Submitted 12 August 2022, Revised 31 December 2022, Accepted 31 December 2022

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Abstract

This study aimed to analyze the implementation of bioinformatics learning in senior high school from research articles. A systematic review was conducted in this study and showed the findings of relevant studies about the implementation of bioinformatics learning in senior high school. Three journals used for a systematic review: PLOS Computational Biology, Briefing Bioinformatics, and CBE-Life Science Education. A total of nine papers were included in the systematic review from 166 articles screened by criteria; bioinformatics learning or bioinformatics education at the senior high school level, published from 2010 to 2019. The result of this study is the trend of learning outcomes of bioinformatics learning at senior high school is to increase cognitive or knowledge in the Biology field, especially molecular biology (67%). The trend for the type of assessment in bioinformatics learning at senior high school is the observation to assess the learning outcome (44%). The trend of contents in bioinformatics learning used Biology, computer science, and information technologies (100%). The trend of bioinformatics tools in bioinformatics learning at senior high school is BLAST (44%). The trend of teaching strategy to implement bioinformatics learning at senior high school is inquiry and problem-based learning (each teaching strategy is 22%). The last is the trend of the period in implementing bioinformatics learning at senior high school is three periods in each topic (33%). For further study, the trend of implementation of bioinformatics learning can be integrated to design the new framework for implementing bioinformatics learning at senior high school. These findings recommended that science teachers or science educators promote bioinformatics learning at senior high schools.

Kata Kunci: bioinformatics learning, senior high school, systematic review

INTRODUCTION

Bioinformatics is interdisciplinary biology, computer science, and information technology that is useful for storing complex life science data. According to NCBI (2007), bioinformatics is something new in Biology subject for senior high school, and three categories design the scientific field; biology, computer science, and information technology, whose role is to facilitate data analysis and storage. Huerta et al. (2000) state that bioinformatics is used for research and development by applying computational tools to grow the utilize of organic, therapeutic, behavioral, or wellbeing information by getting, putting away, organizing, documenting, analyzing, or visualizing that information. Furthermore, Kovarik et al. (2013) state that bioinformatics is the use of computer science for biomedicine and biology, so the incorporation of information technology, software engineering, and biology to analyze the large data sets produced in biology.

Scientists need help to keep up with current research trends and keep science curricula current by teaching bioinformatics at undergraduate and graduate levels (Bloom, 2001). Bioinformatics in instruction brings logical examination and addresses key activities in bioinformatics-integrated inquire about through true hands-on and minds-on exercises. Coordination bioinformatics into tall school educational module with the genuine setting is key to cultivating students' realization of the real-life commitment of bioinformatics, advancing their understanding, and expanding their intrigued. Meaning the basic concepts, thoughts, information, and competencies (or hones) of each teach, such as science, computer sciences, science, etc., ought to be associated and coordinates. The real context for bioinformatics education should be relevant scientific concepts, ideas, and practices (Machluf and Yarden, 2013).

In the last decade, some researchers have done a study to implement bioinformatics learning in senior high school. For example, Marques et al. (2014) developed and implemented multi-activity investigate ventures outlined to empower inquiry-based learning in tall schools, called "Bioinformatics@-school". Appraisal of this venture has appeared that understudies discover it pleasant, and instructors accept it is valuable as a educating help. Objective assessment of information securing uncovered an clear positive impact both within the information and certainty of the understudies. Moreover, Lark et al. (2018) implemented Avida-ED, a research-based stage for computerized advancement, as a bioinformatics instrument that overcomes numerous of the challenges related with utilizing organic show life forms within the classroom. The result of this think about is that Avida-ED impacts understudy understanding and acknowledgment of advancement.

However, the systematic review to analyze bioinformatics learning in senior high school could have been more extensive. This is important to know the trend on how to implement bioinformatics learning, especially for educators and researchers. So, this study aimed to investigate the trend of the implementation of bioinformatics learning in senior high school by analyzing studies in journals from 2010 to 2019.

METHOD

A systematic review was conducted in this study to identify, evaluate and summarize the findings of relevant studies about bioinformatics learning in senior high school. This study used five steps in systematic reviews from Khan et al. (2003), which we can see in Figure 1.

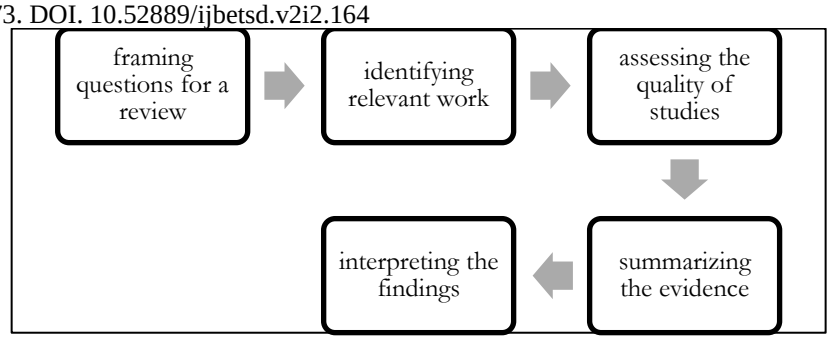

Figure 1. Five steps in the systematic review

1) The first step in this study is framing questions for a review. The research question in this study is "What is the trend of the implementation of bioinformatics learning in senior high school from analyzing studies of journals in the period of 2010–2019?"
2) The second step is identifying relevant work with identifying articles which needed to investigate the implementation of bioinformatics learning in senior high school. We used four journals that have bioinformatics learning and bioinformatics education within the most recent ten years (2010-2019) in the Scopus database with Q1 quality journals. That Journals are PLOS Computational Biology (n = 86), Briefing Bioinformatics (n = 53), and CBE-Life Science Education (n = 27).
3) The third step is assessing the quality of studies. We identified articles which published in the journal the implementation of bioinformatics learning in senior high school students, and we limited the articles that the sample in the research is senior high school students (n = 9 articles) consists of five articles from PLOS Computational Biology, one from Briefing Bioinformatics, and three from CBE-Life Science Education.
4) The fourth step is to summarize the evidence of these nine articles. To summarize the evidence, we use Tables 1 to 3. The detail will be described on results, and discussion part of this article that have six categories consist of learning outcome of implement the bioinformatics learning; type of assessment; content of bioinformatics learning; program and tool for bioinformatics learning; teaching strategy; and period of bioinformatics learning.
5) The fifth step is to interpret the findings from nine articles on implementing of bioinformatics learning in senior high school.

RESULTS AND DISCUSSION

Nine research articles consisted on the implementation of bioinformatics learning for senior high schools from three journals were investigated based on six categories consisting of the learning outcome of implementing the bioinformatics learning; type of assessment; content of bioinformatics learning; program and tool for bioinformatics learning; teaching strategy; and

period of bioinformatics learning. All components investigated in each research article can be seen in Table 1, Table 2, and Table 3.

Table 1. Learning outcome and assessment type of implement the bioinformatics learning in senior high schools

Authors (Year)	Learning outcome of implement the bioinformatics learning	Type of assessment
Rueda et al (2019)	to realize the potential of acquiring programming skills, giving them a tool not only for understanding and experiencing science but also for developing strategies to help solve different challenges of their future professional life.	Observation
Marques et al (2014)	to motivate a discussion about evolution, molecular mechanisms, and disease, all inferred from bioinformatics analysis, while helping teachers and students engage with specific topics of the Life Sciences curriculum via the individual bioinformatics activities.	- Questionnaire - A simple test on the concepts
Gallagher et al (2011)	to know how computation is used in biology and why a basic understanding of computation is necessary for research in many fields of biology.	Observation
Schneider and Jimenez (2012)	to understand how data integration works are fundamental to empowering to see the limitations as well as the possibilities when exploring, retrieving, and analyzing biological data from databases.	Not fit with this criteria
Wood and Gebhardt (2013)	to introduce bioinformatics, databases, and data-intensive biology	Observation
Machluf et al (2017)	to assess the cognitive and affective outcomes of bioinformatics education in senior high school.	- Questionnaires - Observation - interviews
Kovarik et al (2013)	to increase student understanding of the application of information technologies to the biological sciences; the ethical implications of the acquisition and use of biological information; and the career possibilities in the fields of bioinformatics, computational biology, and related STEM careers	- Pre-post surveys
Bokor et al (2014)	to increase student understanding of phylogenetics and coevolution of plants and pollinators.	- A survey of science content knowledge - Rubric - Short follow up survey

Authors (Year)	Learning outcome of implement the bioinformatics learning	Type of assessment
VanMeter-Adams et al (2014)	to know the experiences attract students to pursue an education and career in science, technology, engineering, and mathematics (STEM)	Questionnaires

Based on Table 1, we can see that the trend of learning outcomes from bioinformatics learning in senior high school that leads to an increase in students' understanding of concepts in molecular biology such as genetic testing, evolution, molecular mechanisms, disease, phylogenetics and coevolution (Schneider and Jimenez, 2012; Gallagher et al, 2011; Wood and Gebhardt, 2013; Machluf et al, 2017; Kovarik et al, 2013; and Bokor et al, 2014). However, learning outcomes from bioinformatics learning in senior high school not only for increasing the cognitive but also attitude. Marques et al. (2014) implemented the "Bioinformatics@school" Program in senior high school to motivate a discussion about evolution, molecular mechanisms, and disease, all inferred from bioinformatics analysis. Machluf et al. (2017) also measure affective learning outcomes of bioinformatics education in senior high school. Rueda et al. (2019) measured programming skills through smartphones to introduce Python for bioinformatics in high schools. Kovarik et al. (2013) and VanMeter-Adams et al. (2014) surveyed to analyze students' perception of a future career, especially in STEM, after learning bioinformatics in the classroom. Moreover, the type of assessment from nine research articles almost uses observation to assess the learning outcome of implementing bioinformatics learning (Rueda et al, 2019; Gallagher et al, 2011; Wood and Gebhardt, 2013; and Machluf et al, 2017) and other use questionnaires (Marques et al., 2014; Kovarik et al., 2013; VanMeter-Adams et al., 2014), interview (Machluf et al., 2017), and concept test (Machluf et al., 2017).

Implementing bioinformatics learning is very important for students at the senior high school level because, at this level, students have to apply the biology concept to a real-world problem. Porter et al. (2007) state that schools have responded to challenges by developing education programs in bioinformatics. According to Incantalupo et al. (2014), senior high schools have used technology to help improve the learning gains of students in Biology and other disciplines. Based on the analysis of nine research articles, the trend of learning outcomes of bioinformatics learning in senior high school is to increase cognitive or knowledge in the Biology field, especially molecular biology (67%). Machluf and Yarden (2007) state that bioinformatics learning in senior high school is suitable for a cognitive level because the activities are relevant to the scientific context of students' interests and have a clear connection between principle and technique in the biology field, and also the representation of diverse organisms and different molecules (DNA, RNA, and Protein). According to NCBI (2007), the

extreme objective of bioinformatics 'is to empower the disclosure of modern natural experiences as well as to make a worldwide viewpoint from which binding together standards in science can be discerned'.

The trend for the type of assessment in bioinformatics learning in senior high school is the observation to assess the learning outcome (44%). Gallagher et al. (2011) used observation to evaluate students' lessons in bioinformatics learning. The instructors detailed to the colleagues their perceptions almost which portion of the lessons the understudies had delighted in, which parts they had battled with, and whether or not understudies might interface these lessons to other lessons from science course.Howard et al. (2017) state that the assessment for bioinformatics learning has to see the achievement of student learning processes see students' perceptions of learning, and evaluate the specific bioinformatics content achievement.

Table 2. The content, program and tools of Bioinformatics in senior high school

Authors (Year)	The content of Bioinformatics in senior high school	Program and tool for Bioinformatics Learning
Rueda et al (2019)	- basic operations in mathematics - understanding of logical operators - knowledge of the classical perspective on the molecular basis of information flow from DNA to proteins.	Python programming
Marques et al (2014)	- Biological databases, accession numbers/identifiers - Gene structure, sequence motifs, gene finding - Genetic code, ORFs, homology - Protein structure (2ry and 3ry), structural coordinate files (.pdb) - Genetic variation (mutation, SNP), karyotype, allelic frequencies, homo/heterozygosity	Bioinformatics@school program - GeneCards, UniProt/Swiss-Prot, PubMed, OMIM, Human Gene Mutation Database - GeneMark, WWWPromoterScan - NCBI's ORF finder, BLAST - Clustalw, PDB site, Rasmol - Ensembl, OMIM
Gallagher et al (2011)	- introduction to algorithms, - a basic discussion of the BLAST algorithm - algorithms to construct phylogenetic trees	BLAST
Schneider and Jimenez (2012)	Data integration consist of Genome, gene annotation, protein sequence, protein structure, pathways, gene expression, protein identifications	DAS (Distributed Annotation System) Game - ELLS programme - EBI databases programmatic
Wood and Gebhardt (2013)	- molecular basis of genetic/infectious diseases, evolutionary relationships - biological sequences	LearningLAB on Bioinformatics - ELLS programme

Authors (Year)	The content of Bioinformatics in senior high school	Program and tool for Bioinformatics Learning
	- genome organisation, and structure–function relationships	
Machluf et al (2017)	- introduction to biotechnology, genetic engineering, molecular biology and biochemistry - advanced laboratories - industrial fermentation processes, immunodiagnostics and immunotherapy, tissue culture, environmental biotechnology, bio-nanotechnology and an inquiry project	The bioinformatics learning environment - Entrez - Blast-N - Blast-P - ClustalW - ORF Finder - Primer3Plus - Prosite and Jmol
Kovarik et al (2013)	- Using Bioinformatics: Genetic Testing, - Genetic and molecular consequences of a mutation in the Breast Cancer susceptibility 1 (BRCA1) gene - Compare DNA and protein sequences from patients with those of the BRCA1 reference sequence. - Visualize molecular structures and the impact of mutations on protein structures. - Mitochondrial DNA. - DNA barcoding	Bio-ITEST program - NCBI - BLAST - Cn3D - BOLD - ORF finder
Bokor et al (2014)	- observation of morphological characteristics, DNA extraction, amplification, and verification of polymerase chain reaction (PCR) product, immersing them in an authentic experience consistent with current laboratory research practices - coevolution of plants and their pollinator species and how morphological and molecular phylogenetic trees	The plant phylogenetics module - PCR and DNA electrophoresis - FASTA import into MEGA5
VanMeter-Adams et al (2014)	create awareness about STEM	Not fit with this criteria

Based on Table 2, we can see that the trend of contents in bioinformatics learning was used in Biology, computer science, and information technologies (100%). For example, Gallagher et al. (2011) implemented bioinformatics learning by introducing BLAST to senior high school in the classroom, consisting of knowledge of phylogenetic trees as biology content, using BLAST to construct phylogenetic trees as computer science content, and introduction to algorithms as information. Moreover, All of the researchers use free programs and tools for

bioinformatics learning in senior high school, such as Python programming (Rueda et al., 2019), BLAST (Gallagher et al., 2011; Machluf et al., 2017; Kovarik et al. (2013), MEGA5 (Bokor et al., 2014), etc.

Based on the result of analyzing nine research articles about content in bioinformatics learning at senior high school, the trend of content in bioinformatics learning was used in Biology, computer science, and information technologies (100%). It means that bioinformatics is a modern interdisciplinary field. According to Stevens & Boucher (2015), bioinformatics is an developing multidisciplinary field that applies standards of computer sciences and data innovations to form the tremendous, assorted, and complex life sciences information more understandable and important and to assist realize its full potential. Wefer and Sheppard (2008) classified bioinformatic content into nine areas: Human Genome Project (HGP) / genomics; Forensic; Evolution; Classification; Medicine; Computer use; Agriculture and food technology; and Science, Technology and Society, and SSI.

BLAST is the most widely used bioinformatics tool; four out of nine articles use BLAST for bioinformatics learning (44%). Syngai et al. (2013) state that BLAST is an perfect early on device for understudies to bioinformatics applications and open to any analyst over the web, and is routinely utilized to relegate arrangements into useful and ordered categories. Many free bioinformatics tools can be used to facilitate academics, especially educators, to be implemented in secondary school. The most important thing is that the school has a computer (Kovarik et al., 2013). The free bioinformatics tools such as Blast-N, Blast-P, ClustalW, MEGA5, and Jmol are fundamental. They are accessible on the website and updated frequently to support scientists, teachers, and students (Machluf et al., 2017). Learning bioinformatics uses many online resources. There are modules, data sets, and programming languages constantly developing to be used by teachers and students for learning bioinformatics. Research about programming languages for bioinformatics learning still needs to be completed. At the same time, there are so many programming languages for bioinformatics, such as Python (http://biopython.org/wiki/Main_Page), R (http://www.rstudio.com/), Genomics Education Partnership (GEP, http://gep.wustl.edu) (Chen et al., 2017).

Table 3. Teaching strategies and periode to implement bioinformatics learning in senior high school

Authors (Year)	Teaching strategies	Periods
Rueda et al (2019)	Problem based learning	3 periods
Marques et al (2014)	Enquiry-based learning	5 periods

Gallagher et al (2011)	Problem based learning	3 periods
Schneider and Jimenez (2012)	Game-based learning	3 periods
Wood and Gebhardt (2013)	Computer-based activity	Not fit with this criteria
Machluf et al (2017)	Computer based scientific-inquiry	5 periods
Kovarik et al (2013)	Think pair share and Jigsaw	10 periods
Bokor et al (2014)	Module based learning	4 periods
VanMeter-Adams et al (2014)	Not fit with this criteria	Not fit with this criteria

Based on Table 3, we can see that the various teaching strategies used in bioinformatics learning, such as problem-based learning (Rueda et al., 2019; Gallagher et al., 2011), inquiry-based learning (Marques et al., 2014), game-based learning (Schneider and Jimenez, 2012), computer-based learning (Wood and Gebhardt, 2013), module-based learning (Bokor et al. (2014), and the other used combine strategy such as Machluf et al. (2017) used computer-based scientific-inquiry and Kovarik et al. (2013) used Think pair share and a jigsaw for implementing bioinformatics learning in senior high school. Additionally, the trend of the period to implement bioinformatics learning is ten periods (Kovarik et al., 2013), and the shorters' period is three periods (Rueda et al., 2019; Schneider and Jimenez, 2012; Gallagher et al., 2011).

The selection of learning strategies for bioinformatics needs to be considered. The trend of teaching strategy to implement bioinformatics learning at senior high school is inquiry and problem-based learning (each teaching strategy is 22%). Machluf & Yarden (2013) state that through the request prepare, understudies are required to facilitate between diverse sorts of information from diverse logical disciplines, review earlier substance information, apply specialized abilities in utilizing bioinformatics instruments, reason deductively, make choices taking after a key arrange and to assess and legitimize the logical handle and its steps. Prince and Felder (2006) state that problem-based learning (PBL) starts when understudies are stood up to with an true issue and work in groups to distinguish learning needs and create a practical arrangement, with teaches acting as facilitators instead of essential sources of data.

The trend of the period in implementing bioinformatics learning at senior high school is three periods for each topic (33%). Three periods include the introduction of the bioinformatics topic, focusing on biology material, and the application of bioinformatics to biology content. Gallagher et al. (2011) state that teachers must be mindful of the time it would take to learn

bioinformatics because of the limitations students' computational techniques used in biology problems simultaneously.

CONCLUSION

The trend of learning outcomes of bioinformatics learning at senior high school is to increase cognitive or knowledge in the Biology field, especially molecular biology (67%). The trend for the type of assessment in bioinformatics learning at senior high school is the observation to assess the learning outcome (44%). The trend of contents in bioinformatics learning used Biology, computer science, and information technologies (100%). The trend of bioinformatics tools in bioinformatics learning at senior high school is BLAST (44%). The trend of teaching strategy to implement bioinformatics learning at senior high school is inquiry and problem-based learning (each teaching strategy is 22%). The last is the trend of the period in implementing bioinformatics learning at senior high school is three periods in each topic (33%). For further study, the trend of implementation of bioinformatics learning can be integrated to design the new framework for implementing bioinformatics learning at senior high school. These findings were recommended to science teachers or educators to promote bioinformatics learning at senior high schools.

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