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Trend and Opportunity of Science Education Research Related Optical Waves: A Systematic Literature Network Analysis

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ABSTRACT
Understanding the profile or trend of a research topic is very important and is the first step in starting research. The purpose of this study is to describe the profile of science education research related to wave optics learning. The systematic Literature Network Analysis (SLNA) method was used in this study. Article data during the last ten years (2012-2021) was collected from the Google Scholar database using the Publish or Perish (PoP) application. There were 109 eligible articles which were analyzed to find out research trends related to wave optics learning. The analysis results show that the number of studies and research citations has increased in the last ten years. The dominant waves optical materials studied are polarization and diffraction of light. This research is useful in finding further research opportunities related to wave optic learning. Further research related to the application of innovative media and inquiry learning strategies has the opportunity to be developed on wave optics (dispersion and interference). Further research can be focused on conceptual understanding and developing process skills and 21st-century skills for students through wave optics learning.

INTRODUCTION

One of the main goals of studying physics is to understand the nature of light [1]. Light can act as a particle or a wave, and in some situations, it must be studied by considering its wave nature explicitly [2]. Optical effects that depend on the wave properties of light are grouped under physical optics, sometimes called wave optics [3], which covers the topics of dispersion, interference, diffraction and polarization of light [4]. The development of optics will not only be based on theory but also on greater breakthroughs in practice in the 21st century. Therefore, this requires students (optical students) to have a more solid foundation in physical optics [5].

The optical waves subject at the high school level is studied in the third science class. While at the higher education level, the basics of wave optics are studied in introductory physics, optics, or optical waves courses [6] [7]. One of the learning outcomes of optics courses for prospective physics teacher-

students is being able to explain and apply the concepts of physical optics, including dispersion, interference, diffraction and polarization of light and be able to carry out investigations of these concepts through experiments in the laboratory independently and measured with a sense of responsibility [8]. Optics is a useful subject through practice to deepen understanding of theory [9].

Various studies continue to be carried out to overcome various obstacles for students studying wave optics. Understanding the nature of light is not easy to achieve because of its complex nature of light [1]. Traditional wave optics learning also often fails to develop a functional mental model of wave optical phenomena for students [10]. Even people who work in optics, such as Opticianry, have a common understanding of wave optics [11]. Many students find it difficult to understand the basic knowledge of wave optics because the physical optical system is strict and requires a strong logical reasoning model and original reason [12]. In addition, wave optics learning materials have strong theoretical characteristics and abstract physics situations [13]. It has more complex formulas and involves much mathematical knowledge, thus bringing difficulties to practical teaching [5]. Suppose memorization is used as a teaching approach. In that case, it will not only be difficult for students to understand the material, but the teacher will also find it very difficult to teach wave optics material because of the complex characteristics.

Although various previous researchs have been carried out on wave optics from the pedagogical and material aspects, the opportunity to conduct innovative research can still be carried out according to the objectives and problems in current wave optics learning. The way to find new innovative research opportunities is to conduct a systematic literature review of what has been researched by previous researchers [14]. A systematic literature review or secondary study aims to find and identify all material relevant to the topic to be studied systematically or following a set of established procedures [15]. Systematic reviews identify where little or no relevant research has been done so that new primary research is needed [16]. Traditionally in education, a literature review can be used to make claims about what we know and do not know about a particular phenomenon, subject or topic, thereby opening up new research opportunities in education and teaching [17]. Systematic literature review plays an important role in academic research to build a body of knowledge and check further research's novelty [18].

Systematic literature review can be sharpened by visualization by Bibliometric Analysis [19]. Bibliometric analysis is the most common approach involving statistical methods to analyze bibliographic data. The analysis from an analytical and quantitative point of view coordinates expertise in a particular field of study [20]. Systematic literature review and Bibliometric Analysis can be integrated to describe research trends and find new research opportunities [21] [22]. Both systematic literature review and Bibliometric Analysis integrated into a quantitative-based methods namely Systematic Literature Network Analysis (SLNA) [23], and it relies on objective measures and algorithms to perform quantitative literature-based detection of emerging topics [24]. With this aim, we undertook Systematic Literature Network Analysis (SLNA), which consists of a new literature review method based on a dynamic approach that allows us to uncover how academics have tackled various problems in wave optics learning over time. In other words, the SLNA results will complement the existing systematic literature review on wave optics learning in that they provide the reader with a synthesis of the dynamic developments of the field and a set of developmental themes of wave optics learning research based on objective measurements.

Publications that use a systematic literature review or Bibliometric Analysis in the field of science or physics education have been carried out, including research trends in physics education [25], physics e-modules [26], science and physics-based learning STEM [27] [28] [29], STEAM in science education [30], history of science (physics) [31], scientific literacy in science education [32], critical thinking skills [33], physics problem solving [34], quantum physics education [35], astrophysics [36], linking behavior in the physics education research [37], online physics learning during the Covid-19 Pandemic [38], misconceptions in science [39], augmented reality in physics education [40], ethnoscience [41]. However, based on our data collection and best knowledge, publications that discuss systematic literature network analysis (SLNA) by combine systematic literature reviews and

bibliometric analysis in the learning optics field, especially physical optics or wave optics, have never been done.

However, this opens up opportunities to conduct secondary studies of research results on the topic of wave optics both at the high school and university levels. This study aims to describe research trend data related to learners and wave optics, especially in the matter of dispersion, interference, diffraction and light polarization. The results of this publication will contribute to finding topics that have been researched and new things that still need to be developed through innovative research in wave optics learning.

METHOD

The article data analyzed in this study were taken from the google scholar database. Google Scholar is a digital database with the largest collection level [42], which can be accessed openly (open source), covers various languages [43] and is an established data source complementing the two sources. Traditional commercial data, Scopus and the Web of Science [44]. Article data in Google Scholar can be easily collected through a reference manager application program such as Publish or Perish [45]. The google scholar database can be used to identify the most prominent themes in the process of clustering bibliometric analysis literature [46].

The analytical method used in this research is Systematic Literature Network Analysis (SLNA). According to Figure 1, the SLNA methodology stages are carried out in two main stages, namely the Systematic Literature review stage and the Bibliometric analysis stage [23].

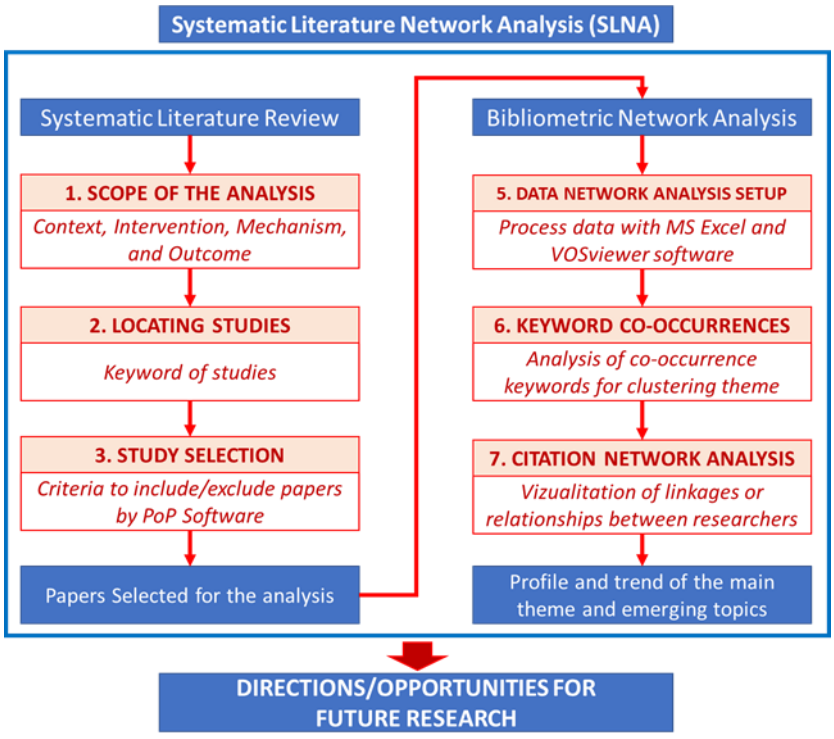

Fig 1. *SLNA Methodology in Current Research*

The first stage in the SLNA (Left side of figure 1) is the Systematic Review of Literature (SLR), which includes stages; 1) Scope of the analysis, to formulate research questions and frame the correct literature review, 2) Locating Study (keyword of studies) using google scholar database used as a data source and collected using Publish or Perish, 3) Study selection and evaluation using criteria for

using/not using articles (include time, document type, language and relevant topics). The literature review was carried out directly through Publish or Perish (PoP), according to the chosen topics. The output of this stage is a collection of selected articles to be analyzed in the second stage.

The second stage in SLNA is Bibliometric analysis. Paper data are tabulated using Microsoft Excel and prepared in CSV (comma delimited) format so they can be input into the VOSviewer software. The bibliometric analysis in SLNA [24] includes; 1) analysis of co-occurrence keywords for clustering theme. Theme clusters show the relationship between topics, the topics that are most often researched or have the most influence in the span of the research period; 2) citation network analysis, which show linkages or relationships between researchers [47]. Bibliometric analyses are visualized using VOSviewer software [32] [48] [49].

RESULTS AND DISCUSSIONS

Results of First Phase: Systematic Literature Review

1. Scope of the analysis

This step is important to avoid ambiguity in the review by defining the scope of the analysis [50]. To determine the scope of the literature review, the following approaches are used: 1) Context: the context in which research partners will be reviewed is research in the field of science education or physics education, especially on wave optics. 2) Intervention: the scope of intervention in the articles analyzed is pedagogical strategies to teach wave optics material (applying learning models or methods, learning media or teaching materials and other relevant pedagogical strategies). 3) Mechanisms: mechanisms according to the treatment given and closely related to the learning strategies in the reviewed articles. 4) Outcome: the selected articles are articles that impact various knowledge and skills of students, such as conceptual understanding, thinking skills, and process skills, including various 21st-century skills needed by students.

2. Locating studies

Data was collected using the Publish or Perish (*PoP*) application using the Google Scholar database. Data collection uses titles related to wave optics, namely: "light dispersion", "light interference", "light diffraction", and "light polarization". The focus of searching for data in the field of education or learning is then added with the keyword's "student" and "learning". The data search was carried out in the last ten years (2012-2021) because research on wave optics is relatively rare compared to other physics materials, so the research of the last ten years in wave optics is still considered up-to-date.

3. Study Selection and Evaluation

At the beginning of the search, 996 documents were obtained, and then further data were selected with a complete publication year identity (958 documents were obtained). The type of document was only journals and proceedings publications and skipped the selection of documents in the form of books, citations, patents and theses (649 documents were obtained). Then the final selection stage is choosing articles relevant to wave optics in physics or science learning so that 109 eligible articles are obtained. Metric data from eligible articles are shown in Table 1.

Tabel 1. Data Citation Metrics from Eliglible Papers

Description	Value	Description	Value
Citations	634	g_index	22
Years	10	hc_index	14
Cites_Year	63.4	hI_index	3.43
Cites_Paper	5.82	hI_norm	8
Cites_Author	240.03	AW_index	13.22
Papers_Author	53.25	e_index	16.16
Authors_Paper	2.85	hm_index	7.07
h_index	12	hA	6

Table 1 shows the metric data for 109 eligible articles from a systematic analysis to select articles that are appropriate for the study of wave optics. There were over 500 citations over the last ten years from articles. Data for the last ten years shows that 2-3 authors more often write articles related to the study of optical wave learning in an article, with citations 5-6 times in each paper.

Fig 2. *Number of Documents Relevant to the Topic of Wave Optics every year for a period of 10 years (2012-2021)*

The trend in the number of relevant articles (Figure 2) shows an increase over ten years. In 2016 there were only three publications of articles relevant to the study of wave optics. Meanwhile, in 2019-2021 the number of publications on wave optics material has increased dramatically. It is surprising that the Covid-19 pandemic that occurred within that year did not hamper the productivity of publications on wave optics learning. The publications that dominated in the last ten years have been dominated by the Journal of Physics: Conference Series (IOP Science Publisher), Physics Education (IOP Science Publisher), Physical Review Physics Education Research (APS Publisher) and The Physics Teacher (AAPT Publisher). These journals are relevant to the field of study in physics education and teaching. Other journals, namely the Journal of Chemical Education (ACS Publisher), publish material on wave optics learning.

Results of Second Phase: Bibliometric Analysis

1. Network Analysis of the Keyword Cooccurrences

Network analysis uses the overall word count to identify influential title words, and each word is counted once no matter how many times it appears in the same article [51].

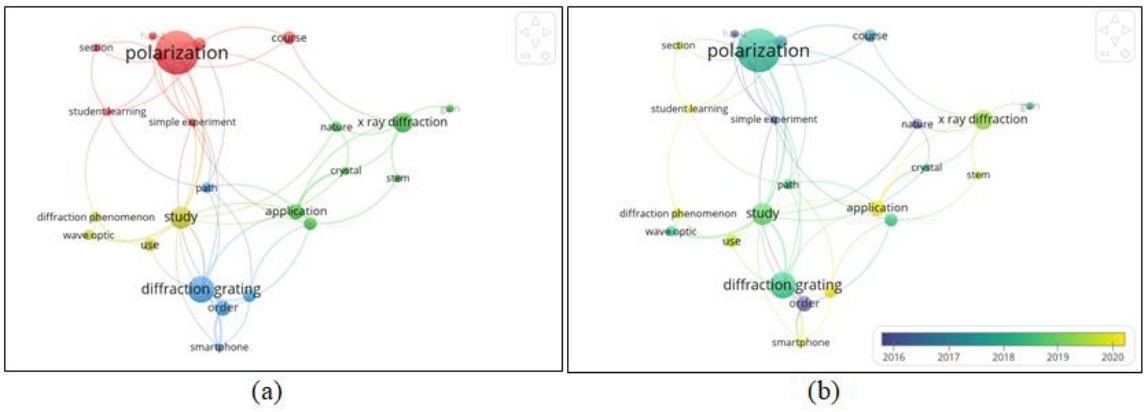

Fig 3. (a) *Network visualization, and (b) Overlay visualization of network plot of keyword data/research title related to wave optics subject matter*

Based on Figure 3, it is known the relationship of keywords that are the topic of wave optics material. The co-word analysis in Figure 3a shows four main clusters in research on wave optics. The first cluster (red colour) includes words such as polarization, student learning, and simple experiment. The second cluster (blue colour) includes the words diffraction grating and smartphone. The third cluster (green colour) includes words such as x-ray diffraction, STEM, application, optical diffraction and crystal. The fourth cluster (yellow colour) includes the words diffraction phenomena and wave optics. Figure 3b shows some of the words that are the latest topics to be researched in 2020: x-ray diffraction, STEM, student learning, application and smartphone.

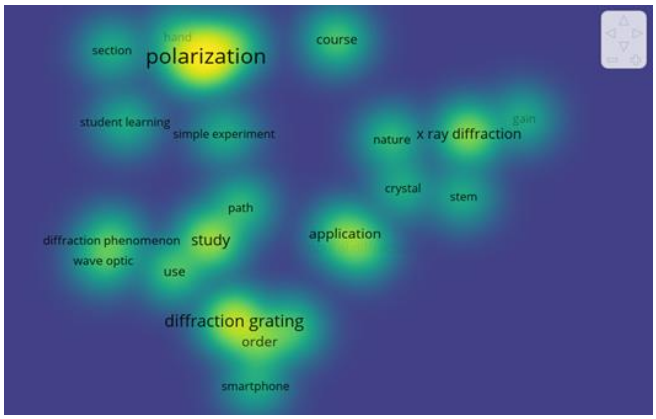

Fig 4. *Density visualization of network plot of keyword data/research title related to wave optics subject matter*

The topic of polarization of light is the most studied, as shown in Figure 4, and the top two relevant research titles are in Table 2. Then the topics that appear the next are lattice diffraction and x-ray diffraction. The topic of x-ray diffraction is widely studied in the field of material physics (non-educational research). However, in this analysis, only the topic of x-ray diffraction is used in educational research, especially for college students, using various media and certain learning methods.

Table 2. Top Ten Relevant Articles (Rank) from 109 Eligible Articles (2012-2021)

No.	GS Rank	Cites	Authors	Title	Year	Source	Publisher
1	2	3	M Michelini, A Stefanel	A path to build basic Quantum Mechanics ideas in the context of light polarization and learning outcomes of secondary students	2021	Journal of Physics: Conferenc e Series	Institute of Physics (IOP) Science
2	3	5	KM Cvenic, L Ivanjek, M Planinic, K Jelicic, A Susac, M Hopf	Analyzing high school students' reasoning about polarization of light	2021	Physical Review Physics Education Research	American Physical Society (APS)
3	5	6	A Susac, M Planinic, A Bubic, K Jelicic, L Ivanjek, KM Cevic, M Palmovic	Effect of students' investigative experiments on students' recognition of interference and diffraction patterns: An eye-tracking study	2021	Physical Review Physics Education Research	American Physical Society (APS)

4	6	1	I Chuasontia, T Sirirat	Designing an instructional module to teach light diffraction by a grating to secondary students applying a STEM-integrated approach	2021	Physics Education	Institute of Physics (IOP) Science
5	9	7	A Susac, M Planinic, A Bubic, L Ivanjek & M Palmovic	Student recognition of interference and diffraction patterns: An eye-tracking study	2020	Physical Review Physics Education Research	American Physical Society (APS)
6	12	3	E Pratidhinaa, W Sunu Brams Dwandarua, H Kuswanto	Exploring Fraunhofer diffraction through Tracker and spreadsheet: An alternative lab activity for distance learning	2020	Revista Mexicana de F´ısica E	Sociedad Mexicana de Física, A. C.
7	15	6	PI Nursuhud, DA Oktavia, MA Kurniawan, I Wilujeng, Jumadi, H Kuswanto	Multimedia learning modules development based on android assisted in light diffraction concept	2019	Journal of Physics: Conferenc e Series	Institute of Physics (IOP) Science
8	17	20	A Coetzee, SN Imenda	Alternative conceptions held by first year physics students at a South African university of technology concerning interference and diffraction of waves	2012	Research in Higher Education Journal	AABRI Publisher
9	18	3	A Stefanel, M Michelini, L Santi	Upper secondary students face optical diffraction using simple experiments and on-line measures	2014	Proceedin gs of Science, Frontiers of Fundamen tal Physics 14	Aix Marseille University (AMU) Saint-Charles Campus, Marseille
10	22	5	J Lehmann, C Tzschaschel, M Fiebig, T Weber	Microdisplays as a versatile tool for the optical simulation of crystal diffraction in the classroom	2019	Journal of Applied Crystallog raphy	Internation al Union of Crystallogr aphy (IUCR), Wiley

Table 2 shows the ten most relevant articles based on the title and search keywords in the database of data sources related to research in wave optics learning material (light dissertation, light interference, light diffraction or light polarization). Michelini & Stefanel's article (No.1 in Table 2) on students' ideas about basic quantum mechanics in the context of light polarization is the most relevant article in the database of data sources using the Publish or Perish (PoP) data collection application. Then, the article by Cvenic et al. (No.2 in Table 2) on the analysis of students' reasoning on the material of light polarization. Interestingly, the fourth most relevant article by Chuasontia & Sirirat about designing a

STEM-based learning module for lattice diffraction material for high school students, but the article only got one citation. Several articles have not been cited even in the top 15 most relevant of the 109 articles analyzed. Colicchia [24] explained that quotes alone could not perfectly represent the field. An article may be excluded from analysis because no other work has cited it, regardless of the relevance of its content, or the article may have received a limited number of citations because it was recently published. Therefore, other tools such as keyword analysis and citation score analysis can complement and reduce these limitations.

2. Citation Network Analysis (CNA)

A citation network is a network with nodes (nodes/circle) indicating the article and links (dashing lines) indicating citations [52]. Based on Figure 5, it is known that the relationship between articles and topics is still relatively small. This relationship shows that the published articles are less connected with other articles.

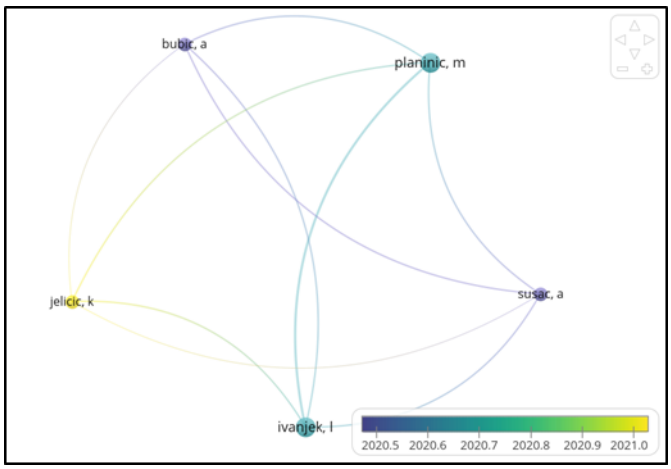

Fig 5. *The relationship between authors in the study of wave optics material from 109 eligible articles*

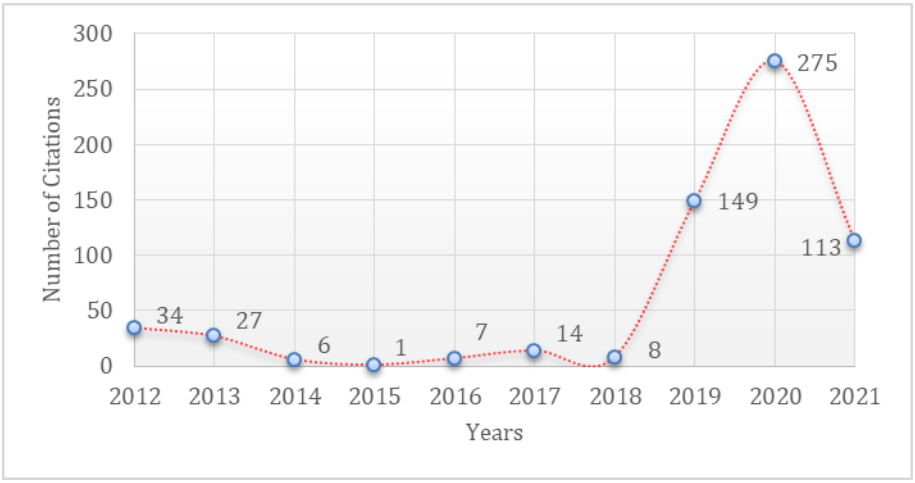

Fig 6. *Number of article citations on the topic of wave optics every year for a period of 10 years (2012-2021)*

The trend analysis of the number of article citations from 2012 to 2018 was relatively stable or did not show a significant increase/decrease (Figure 6). However, in 2019-2021 there was a very drastic increase. It may happen in 2019-2020, and many articles were published about learning related to wave optics material (Figure 2), so citations to support research related to wave optics material were also widely carried out that year.

The citation network analysis performed on linked components did not consider isolated papers as they were not linked via citations to other articles [24]. So, in the bibliometric analysis, it is necessary to analyze the ranking of citation scores as presented in Table 3.

Table 3. Top ten articles with the most citations from 109 Eligible Articles (2012-2021)

No.	Cites	Authors	Title	Year	Source	Publisher
1	20	A Coetzee, SN Imenda	Alternative conceptions held by first year physics students at a South African university of technology concerning interference and diffraction of waves	2012	Research in Higher Education Journal	AABRI Publisher
2	16	PAE Piunno	Teaching the operating principles of a diffraction grating using a 3D-printable demonstration kit	2017	Journal of Chemical Education	American Chemical Society (ACS) Publications
3	13	S Saprudin, S Liliasari, AS Prihatmanto,	Pre-service physics teachers' thinking styles and its relationship with critical thinking skills on learning interference and diffraction	2019	Journal of Physics: Conference Series	Institute of Physics (IOP) Science
4	8	A Velentzas	Teaching diffraction of light and electrons: Classroom analogies to classic experiments	2014	The Physics Teacher	American Association of Physics Teachers (AAPT) Physics Education
5	8	TD Varberg, K Skakuj	X-ray diffraction of intermetallic compounds: A physical chemistry laboratory experiment	2015	Journal of Chemical Education	American Chemical Society (ACS) Publications
6	7	A Susac, M Planinic, A Bubic, L Ivanjek,	Student recognition of interference and diffraction patterns: An eye-tracking study	2020	Physical Review Physics Education Research	American Physical Society (APS)
7	6	ML Hulien, JW Lekse, KA Rosmus,	An Inquiry-Based Project Focused on the X-ray Powder Diffraction Analysis of Common Household Solids	2015	Journal of Chemical Education	American Chemical Society (ACS) Publications
8	6	MJ Taltavull	Transmitting knowledge across divides: optical dispersion from classical to quantum physics	2016	Historical Studies in the Natural Sciences	online.ucpress.edu
9	6	PI Nursuhud, DA Oktavia, MA Kurniawan,	Multimedia learning modules development based on android assisted in light diffraction concept	2019	Journal of Physics: Conference Series	Institute of Physics (IOP) Science
10	6	V Mešić, A Vidak, E Hasović,	University students' ideas about the role of the aperture and laser beam dimensions in formation of diffraction patterns	2019	European Journal of Physics	Institute of Physics (IOP) Science

Table 3 displays the ten most cited articles in science-physics education or learning related to wave optics or physical optics. It can be seen that the article by Coetzee & Imenda, (No.1 Table 3, 20 citations) on alternative conceptions in interference material and wave diffraction has the most citations. They were then followed by Piunno's article (No.2 Tabel 3, 16 citations) about the use of 3D-printable Demonstration Kits in lattice diffraction learning and Saprudin et al.'s article (No.3 Table 3, 13 citations) about the thinking styles of prospective teacher students. Physics and its relation to critical thinking skills on interference and diffraction materials. So, it can be said that the three studies contributed the most to further research on wave optics learning. It is widely recognized that citations can measure publication relevance, even though a widely cited article may not necessarily represent impactful and world-class research [53]. It is assumed that citations represent how the cited article influences a new study [54].

Discussion: Further research opportunities on wave optics

The analysis results show that the number of studies and research citations on the study of wave optics material has increased in number since the last ten years and has increased drastically starting in 2019. The drastic increase in the number of studies shows a high interest among researchers [55] in the study of wave optics material. Based on the analysis cluster, it is known that the material of wave optics which has been widely studied and published is the material of polarization and diffraction. Meanwhile, the interference and diffraction material has not yet appeared in the co-occurrence keyword analysis. Likewise, the impact measured in learning is more focused on efforts to improve students' understanding of concepts in wave optics.

Light dispersion material is an important material. The material is closely related to student life, such as the rainbow phenomenon, which contains many concepts of light dispersion [56]. Likewise, light interference material is essential but more complex for students to understand. Some students still do not understand the concepts of light dispersion and interference and even tend to experience misconceptions [57]. It is necessary to develop innovative studies to teach students about light dispersion subjects and incredibly complex light interference materials. Simulation and experimental media development can help students better understand the phenomenon of light interference.

Innovative studies were carried out to teach wave optics, such as using simple ways to teach wave optics phenomena [58], using the model of CDIO (*conceive*, *design*, *implement*, *operate*) [5] [9], design of innovative media to enhance the conceptual understanding [59], and using of spreadsheet excel as alternative media in optic learning [60]. It also uses complex media such as Spatial Light Modulator (SLM) Educational Kit [61]. Wave optics experiments have also been developed by researchers using a virtual wave optics laboratory [62] and Remotely Controlled Laboratory (RCL) [63]. Several previous studies have used various software applications to explain wave optical phenomena, such as MATLAB GUIs [64], Python and GeoGebra [65], LabVIEW Software [66], and Igor Software [67]. These media can be developed and integrated with various learning strategies in learning wave interference material.

Of course, this research is not only looking for opportunities for something that has not been or is rarely studied in wave optics. The results of this analysis will improve understanding so that it becomes a guide for the successful implementation of further research, especially related to wave optics learning. Not only focusing on conceptual understanding, but wave optics learning is also at least able to train students to have science process skills, scientific literacy and 21st-century skills. Based on cluster analysis, many learning strategies still have the opportunity and are relevant in developing the quality of wave optics learning, namely inquiry-based and project-based learning.

Integrating the scientific inquiry approach in learning helps construct the knowledge learned [68] and develops students' scientific literacy [69] [70]. The inquiry approach can increase students' understanding of the nature of scientific inquiry [71] and assist in understanding abstract scientific concepts such as the concept of light interference. Inquiry learning emphasizes critical thinking skills that can improve students' science process skills [72]. Science process skills are an important goal in

science learning [73], not only helping students access knowledge but also determining knowledge [74]. Critical thinking skills can be trained by inquiry-based learning.

One of the levels of inquiry learning that can be developed in wave optics learning is based on the real-world application of inquiry learning. It is relevant because the phenomenon of wave optics is found in real life. Real-world application of inquiry learning can be made collaboratively through project-based and problem-based learning approaches to find answers to authentic, real-world problems [75]. Project-inquiry-based learning is constructivism learning which, in its implementation, is based on investigation and investigation that includes gathering information from various sources [76].

In addition, various 21st Century skills are also very important in training students to prepare for tough global competition [77] [78] [79]. 21st-century skills such as communication, collaboration, critical thinking, and creative thinking can be developed through inquiry-based project-based wave optics learning. Through project activities that begin with inquiry activities, students can gradually learn wave optics material and develop various skills such as communication, collaboration, critical thinking, and creative thinking after passing the project's final phase. So, the following research in optical waves can be developed to increase students' skills by driven by inquiry-project-based learning.

CONCLUSION AND SUGGESTION

Systematic Literature Network Analysis (SLNA) has been carried out and found 109 eligible articles discussing learning wave optics. The analysis shows that the number of studies and citations on research on wave optics learning materials has increased in the last ten years. Network analysis of the relationship between articles is still relatively few, and topics that often appear only include polarization and diffraction materials. In contrast, research has not widely studied interference and light dispersion materials. It opens up opportunities to conduct innovative research on wave optics, especially on the topic of light interference and dispersion. Project-based and inquiry-based learning models and relevant visual media can be alternative solutions in optical wave learning. Science learning is not only focused on conceptual understanding but also trains students' scientific process and 21st-century skills. Further research can be focused on analysis of conceptual understanding and developing process skills and 21st-century skills for students through wave optics learning.

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