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The use of simple spectrophotometer in STEM education: A bibliometric analysis

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Abstract

This study aims to provide a bibliometric analysis on the topic of the simple spectrophotometer. By using the VOSviewer software, bibliometric analysis methods from 128 articles were used in this study. The articles were selected based on the inclusion and exclusion criteria predefined. The results of this study indicate that several simple spectrophotometer instruments have been used for teaching and learning in chemistry and other STEM areas, such as UV-Vis and photometers. This instrument was built by replacing the main components in the spectrophotometer, such as the light source and detector, to be simpler. The development of other types of spectrophotometers that involve students in building them can be a potential research alternative in Chemistry and other STEM areas. This research is expected to provide a better understanding of the challenges and opportunities of using a simple spectrophotometer for teaching and learning purposes.

Keywords: *Bibliometrics, Simple Spectrophotometer, STEM Education.*

1. Introduction

One of the instruments often used in chemistry is the spectrophotometer. A spectrophotometer is an instrument for analysing a compound qualitatively and/or quantitatively by measuring the transmittance and/or absorbance of a sample as a function of concentration [1-3]. These spectrophotometers have several types of instruments with their respective ways of working and functions, such as UV-Vis, Infra-Red, and Atomic Absorption Spectrophotometers [4]. Spectrophotometers are generally sold at prices ranging from 3,000 to more than 20,000 USD [5]. The relatively high price for this analysis instrument makes it rarely owned and used for teaching and learning purposes in schools and universities in developing countries such as Indonesia [4, 6, 7]. Even though it has a spectrophotometer instrument, students usually only see demonstrations or only send samples to their instructor for analysis due to its limited number [8]. This traditional learning will make students dependent on the information provided by the teacher or instructor. Besides that, it also causes students to lack understanding and mastery of technical analysis using this spectrophotometer instrument [9].

This problem has attracted the attention of researchers in the field of chemistry education. As a solution offered by the researchers, the analytical chemistry lessons especially topics related to spectrophotometer instruments, are taught using a simple spectrophotometer instrument [2, 8, 10, 11]. This method can force students to think higher, learn independently, and create different and meaningful experiences [8]. In addition, by providing a STEM-based project for making a simple spectrophotometer instrument, students can think fundamentally. They think about how a spectrophotometer instrument works to critically evaluate the quality of the data generated from the instrument [12].

Many researchers have conducted research on the use and development of simple spectrophotometer instruments [1, 10, 13, 14]. Such as research on making a simple photometer to introduce analytical instruments [15], research on the use of a low-cost absorption spectrophotometer [16], and research on demonstrating the principles of Spectrophotometry by making a simple spectrophotometer using a light sensor on a smartphone [13]. The large amount of literature that discusses this issue shows that this topic is one of the focuses of researchers in the field of chemistry and STEM education. A review of the extent of research and publications using this simple spectrophotometer is needed to understand this domain better. Therefore, this study aims to provide a bibliometric literature review to analyze the literature on the topic of simple spectrophotometers. The novelties obtained from study include providing a better understanding of the challenges and opportunities of using a simple spectrophotometer for teaching and learning purposes, applicable as a guideline for further insight and research opportunity in the area of chemistry and STEM education, and shows connectivity data between authors as well as data distribution of institutions that have conducted research on the topic of simple spectrophotometers.

2. Simple Spectrophotometer

The development of simple spectrophotometer instrument is usually inseparable from its main components, namely a light source, monochromator, and detector [12]. Parts of the spectrophotometer instrument are replaced using simple household tools that are easy to find but have almost the same functions as those of a commercial spectrophotometer [15, 17, 18]. Some of them have even used and compared cheap detectors like LED [10, 19] and built-in sensor in smartphone [3, 20]. An example of the results of developing a simple spectrophotometer using a smartphone detector is shown in Figure 1.

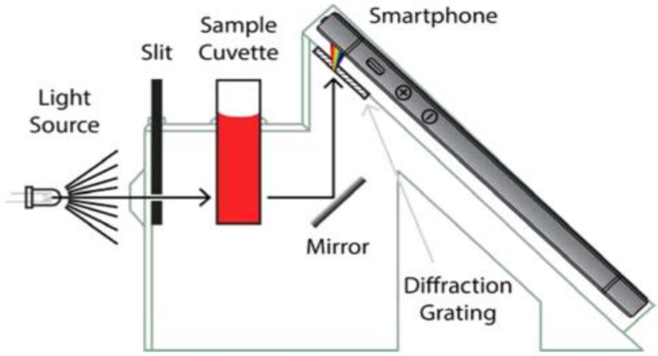


Figure 1. Schematic of a simple UV-Vis spectrophotometer using a smartphone detector [3]

Based on Figure 1. The UV-Vis spectrophotometer instrument is designed with simple materials but has almost the same function as components in commercial UV-Vis. Light sources that use LED lights emit light which then passes through a narrow slit. The light that has been selected through the slit is then passed through a cuvette containing a sample of a colored solution. The light that is not absorbed by the sample is then reflected by the mirror and travels through the diffraction grating. This diffraction grating functions as a prism to diffract white light beams into the color spectrum of their components. The camera smartphone will then detect this color spectrum [3].

The example of this simple UV-Vis instrument uses the basic principles of the Lambert-Beer Law. This law also underlies the development of other simple spectrophotometer instruments. This law is formulated as follows:

$$A = \varepsilon . b . C \qquad (1)$$

A is absorbance with molar absorptivity (ε; L/mol.cm); *b* (cm), is the path length of light in the sample, and *C* (mol/L) concentration. Then, when the correlation above involves light transmission (*T*) and light intensity (*I*), absorption (*A*) is defined as follows [5, 7, 21, 22]:

$$A = -\log(T) = \log \frac{I}{I_0} \qquad (2)$$

I is the intensity of light transmitted through the sample and I_0 is the intensity of the light transmitted through the blank.

Researchers in chemistry and other fields often use Lambert-beer's law and commercial spectrophotometers to support research data. Such as the use of UV-Vis to determine the absorption efficiency [23], the use of Atomic Absorption Spectrophotometer to determine the concentration of Cu(II) and Pb(II) metals [24], and the use of IR to determine the characterization of complex formation [25]. Not unlike commercial spectrophotometers, simple spectrophotometers can also be used as research databases. Such as using simple UV-Vis to detect mercury ions [26], simple photometer to determine sodium concentration in drinks [27], and determine the sugar content in sugarcane using an LED Spectrophotometer [28]. With various evidence of using simple spectrophotometers for learning and research purposes [29-32], it is important to review the various results of the development of simple spectrophotometers [33-36]. These results can be helpful for exploring opportunities for the development of other types of simple spectrophotometers.

3. Methods

In this study, the bibliometric literature review method was used [37-39]. In this method, five stages are used to process the literature so that the reviews are carried out systematically and the data obtained are valid [40, 41]. These stages are presented in Figure 2.

Figure 2. Literature data processing stages

3.1. Determine the keyword

The general keywords used in this research are "simple spectrophotometer" OR "low-cost spectrophotometer" OR "spectrophotometer modification" These keywords are then used to obtain literature data in the Google Scholar database. This search uses PoP 7 software (Publish or Perish 7).

3.2. Initial literature data mining

The results of data mining using the above keywords with PoP 7 software on the Google Scholar database were obtained as many as 454 articles. The initial data mining obtained is shown in Table 1.

Table 1. Initial data mining metrics

No	Initial literature data mining	Results
1	Publication years	2011-2021
2	Papers	454
3	Citations	7674
4	Authors/paper	2.78
5	H-index	33

3.3. Literature data selection

The selection of literature data is made manually by reading the title related to the research topic, namely "simple spectrophotometer" or "Low-cost spectrophotometer". In the initial search results, there is a lot of literature that is not in accordance with the research topic. Further investigation is needed on the Google Scholar web to ensure the suitability of the literature data with the research topic. After obtaining and confirming the data on the Google Scholar website, 128 relevant articles were obtained. Metrics data after the selection process are shown in Table 2.

Table 1. Literature data selection results

No	Literature data selection	Results
1	Publication years	2011-2021
2	Papers	128
3	Citations	372
4	Authors/paper	3.18
5	H-index	11

3.4. Final data mining

All selected articles will be collected and then used as a source of data analysis at this stage. Detailed information of each article related to year of publication, volume, journal name, and publisher is completed at this stage [42, 43].

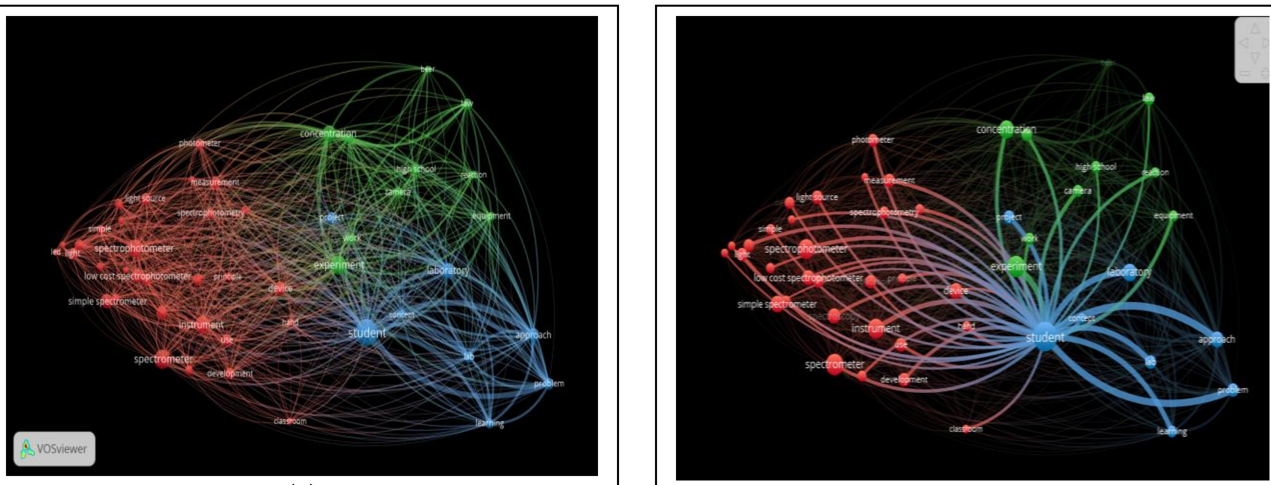
3.5. Literature data extraction and analysis

Bibliometric analysis was carried out with VOS viewer using complete data from the previous stage. At this stage, the analysis is focused on network, overlay, and density visualization, author and co-author relationship, author affiliation mapping and pedagogical aspect and equipment used

4. Results and Discussions

4.1. Network overlay and density visualization results

Network, overlay, and density visualization analysis were used to map the relationship between keywords that most often appeared in the 128 articles obtained about "simple spectrophotometer." From this visualization, the pattern of interrelationships between keywords that appear, and which are most often used by researchers can be seen. The results of the network visualization are presented in Figure 2. Based on the visualization results obtained in Figure 2. Various keywords are related to one another. There are three groups of data that are distinguished by color. The results of the further analysis show that the green color reflects research that emphasizes the field of research and how it works; this can be reflected by the words “high school and experiment.’ The blue data group reflects research that emphasizes the approach used; this is reflected in words “approach, problem, and learning.” The third group, marked in red, is classified into the research group that emphasizes the resulting product. This data set is denoted by the words "simple spectrometer, low-cost spectrophotometer, and photometer."

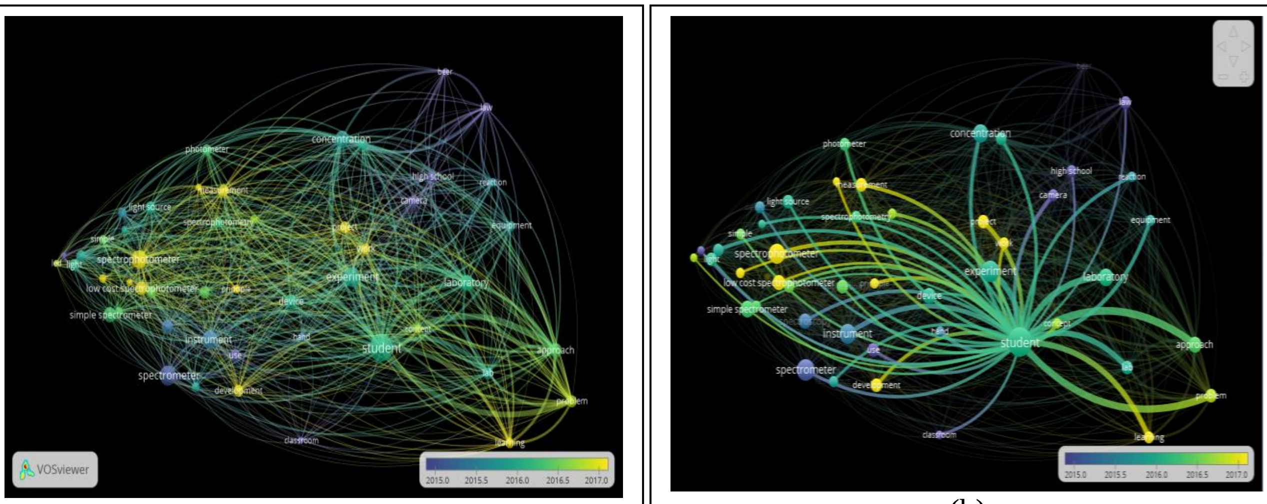


(a) (b)

Figure 2. (a) Visualization network**,** (b) focused visualization network

Table 2 shows that students are the center of the entire data group. This indicates that students as research subjects are essential [44, 45]. In addition, previous studies also suggest that the development of a simple spectrophotometer should involve students more in the development process because this can have a good impact on them [4, 7].

Similar to network visualization, the results are shown in the overlay visualization also indicate the relationship between keywords. However, the overlay visualization prioritizes the keyword relationship with the year of publication. The results of the overlay visualization are shown in Figure 3.



(a) (b)

Figure 3. (a) Overlay visualization, (b) focused Overlay visualization

In Figure 3, there are different color degradations for each keyword that is displayed, starting from purple to bright yellow. The more purple the color of the displayed keyword indicates that the word is from an older publication. In contrast, keywords in yellow indicate keywords that come from newer publications. The search results from Figure 3 show that the keywords leading to the low-cost spectrophotometer, project, and learning are newer keywords compared to the others. This shows that research trends using project-based learning to produce low-cost spectrophotometers are indeed being carried out by many researchers [29, 46].

In line to network and overlay visualization, density visualization shows the frequency with which these keywords appear in articles. The more often these keywords appear in the article, the thicker the density of these words. The results of the density analysis are shown in Figure 4.

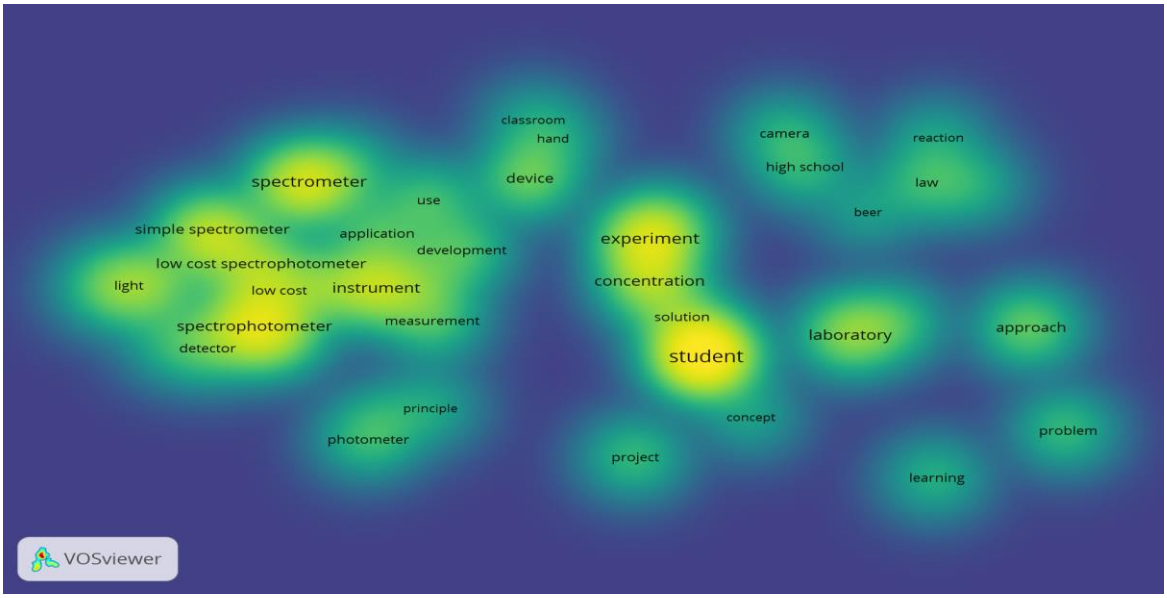


Figure 4. Density Visualization

From Figure 4 knows that the words student and experiment have a high density, likewise, with a low-cost spectrophotometer and simple spectrometer. These four keywords show the most frequently occurring keywords in the 128 articles analyzed.

4.2. Author and co-author relationship

One of the important data obtained from bibliometric analysis is the relationship between authors. This analysis makes it possible to see the interrelationships between authors and how they cite each other. The results of the author's analysis are shown in Figure 5.

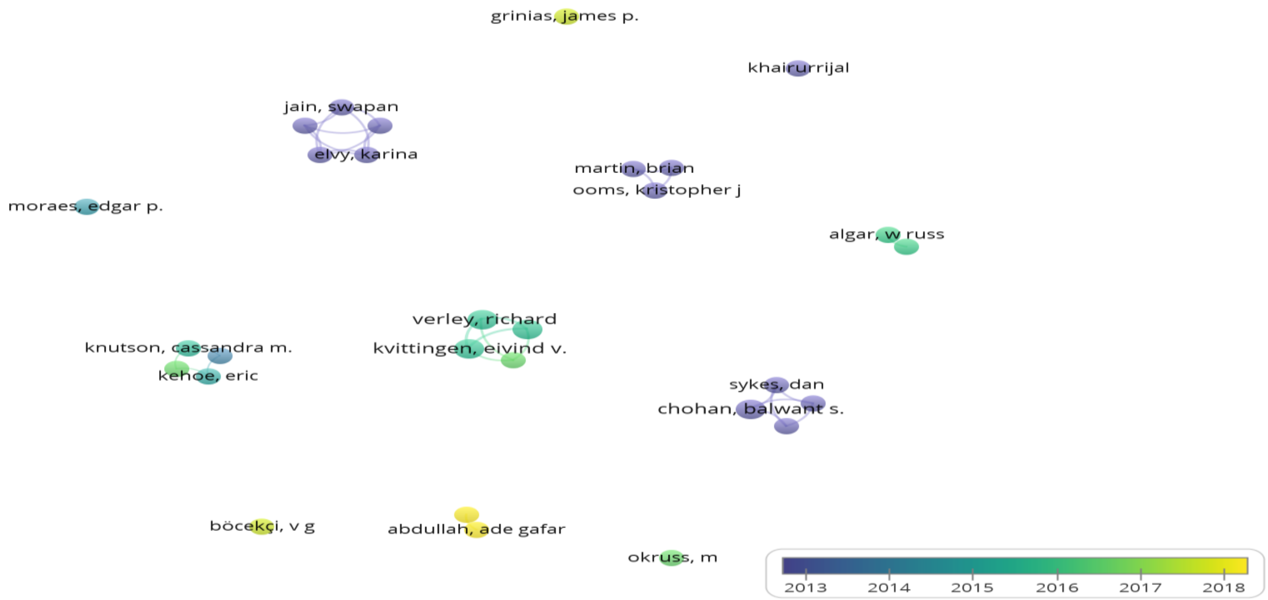


Figure 5. Author’s relationship visualization

From the visualization in Figure 5, several authors work together to research the topic of simple spectrophotometers. The Jain Swapan group carried out research on the development of a simple photometer [47], the Kvittingen Eivind V. group developed the simple UV-photometer, lego calorimeter, and fluorimeter [2, 10, 11], the Chohan, Balwant S. group developed the LED fluorimeter and colorimeter [8, 48, 18], the Knutson, Theodore R. group developed handled camera colorimetry and smartphone colorimetry [49, 50], and there was also a group of researchers from Indonesia, namely Nandiyanto, Asep Bayu Dani and Abdullah, Ade Gafar who developed an Arduino-based spectrophotometer [22, 51].

4.3. Author affiliation mapping

Analysis of the authors' affiliation was carried out using a gpsvisualizer.com. The primary data obtained were analyzed and separated based on the first author's affiliation; the results obtained 72 points of first author affiliation. This number includes several institutions conducting more than one study. The mapping results are shown in Figure 6.

Figure 6. Authors' Affiliation mapping

Based on Figure 6. Universities in America still dominate the author's affiliation. Indonesia's affiliates, namely the Indonesian University of Education (UPI) [5, 28], Bandung Institute of Technology (ITB) [52, 53], and Gadjah Mada University (UGM) [54]. In this affiliation, research is dominated by spectrophotometer with Arduino and LED. In addition, researchers from Indonesia are focusing on developing a simple UV-Vis spectrophotometer. There have not been many developments of other types of simple spectrophotometers.

4.4. Pedagogical aspect and equipment used

Chemistry teaching and learning using spectrophotometer instruments in Indonesia have been carried out using ordinary practicum methods and demonstrations [4, 7]. Not all students can try to operate every spectrophotometer instrument that is practiced. This makes students have a weakness in understanding the constituent parts of each spectrophotometer instrument that is practiced, the theoretical basis used, and how to operate the instrument [6, 8]. Therefore, an approach is needed that can overcome the problems faced by students in practicum and learning chemistry instrumentation using a spectrophotometer. The Science, Technology, Engineering, and Mathematics (STEM) approach is a learning approach that allows it to be applied to practicum and learning chemistry instrumentation [55]. This approach emphasizes the integration of each STEM field with engineering design through a project [38]. Thus, students can have their own experience in designing a simple spectrophotometer practicum instrument by evaluating the parts, workings, and operation of the instrument through a given project [44].

Based on the review and bibliometric analysis that has been done, various types of simple spectrophotometers have been developed [19, 56, 57]. This development focuses on three main parts of the spectrophotometer, namely the light source, monochromator, and detector [4, 6]. A light source serves to determine the wavelength. The function of the monochromator is to select the light emitted from the light source, and the detector serves to measure the intensity of light and or light absorbance [6, 53, 58]. Each of these characteristics is used as the basis for selecting a tool that will be used as a component of a simple spectrophotometer instrument [4].

In this study, various types of simple equipment were identified that researchers used to develop a simple spectrophotometer instrument. A simple alternative equipment that can be used as a light source include: LED [48, 59], digital camera [60], laser pointer [53], dan flame [30, 61, 62]. While some simple equipment that can be used as detectors include: smartphone camera [61, 63], arduino [12, 64], and photodiode [16, 30, 12]. Besides that,

construction of instrument developed also has various variations, such as the use of 3D plastic printing [3, 65], lego [10, 11], shoe boxes [13], and wood [66].

The use and development of simple spectrophotometer instruments are also inseparable from the pedagogical aspects used. It is known from the results of the analysis that the pedagogical approach used by researchers to develop a simple spectrophotometer instrument is quite varied. The experimental method is the most commonly used [20,51]. In addition, project-based learning methods have also been used to improve students' various skills [12, 44]. This method allows students to build their version of the spectrophotometer. In addition, the development and use of this simple spectrophotometer have been successfully carried out at various levels of education. This proves that at the high school level, they can receive lessons and spectrophotometer experiments [30]. This is one of the advantages of developing a simple spectrophotometer to be developed independently by teachers and students in high school.

5. Conclusion

The use and development of a simple spectrophotometer instrument is an alternative that teachers can do to carry out teaching and learning related to chemical instrumentation. The similarity of characteristics between the components that build the commercial spectrophotometers and simple spectrophotometers can make students better understand the basic principles and how these tools work. The bibliometric analysis provides an overview of the pattern of relationships between one study and another on the topic of simple spectrophotometers. The analysis of this pattern of interrelationships shows that the photometer and UV-Vis instruments are the two most widely developed instruments. This pattern provides an opportunity to develop other simple spectrophotometer instruments such as AAS and IR. In addition, there are not many studies that use the STEM pedagogical approach to teach students related to the topic of simple spectrophotometers. These results are expected to provide a better understanding of the challenges and opportunities of using a simple spectrophotometer for teaching and learning purposes.

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