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Development of UV-VIS Spectrophotometer Virtual Laboratory Media for Instrumental Analytical Chemistry Digital Practicum

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Abstract: The demands of 21st Century learning are now in the Industrial Revolution Era 4.0 with 4C learning characters. Educators must develop their creativity to improve the quality of learning so that students can be more creative in learning. *Instrumental Analytical Chemistry* is a course that studies modern instrumentation for chemical analysis. The instrumentation is unavailable in the laboratory because it is costly. This research aims to develop a virtual laboratory media UV-Vis Spectrophotometer that can be used in the digital practicum of the Instrumental Analytical Chemistry Course. The method used is development research (R & D) by adapting the multimedia model ID Hannafin & Peck, using Macromedia flash applications. This research shows that the UV-Vis Spectrophotometer virtual lab developed provides excellent feasibility results and is also effective for use in lectures and digital practicum of Instrumental Analytical Chemistry lectures.

Keywords: Laboratorium Virtual, Spektrofotometer UV-Vis, praktikum digital
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INTRODUCTION

Learning in the 21st century is a learning that prepares generations to be able to develop their skills and abilities in mastering information and communication technology so that they can face the challenges of globalization in the future (Daggett, 2010; Kay & Greenhill, 2010; Noor, 2013; Alismail & McGuire, 2015; Malik, 2018). The framework for 21st-century learning states that the need for learning skills in this era of globalization is oriented to an increasingly challenging future and can be successful with 4C criteria: critical thinking and problem-solving, communication, collaborative, and creativity (Trilling & Fadel, 2009; NEA, 2014; Ahmad, 2020; Panggabean, et al., 2021; Susanti, Rangga, & Nasution, 2021). Responding to these challenges, it is necessary to carry out educational renewal in a planned, directed, and sustainable manner, one of which is through development research and renewal (innovation) in implementing learning in the classroom.

The Instrumental Analytical Chemistry lecture at the Chemistry Education Study Program FKIP Jambi University studies how to analyze chemical elements and compounds in samples using chemical instrumentation with devices that use computer programs with more sensitive, accurate results and shallow detection limits. Many things affect learning outcomes according to the learning objectives that have been formulated and the minimum standards of learning outcomes that are set. Many factors are likely to cause gaps, one of which is for the chemistry learning process in terms of the unmet process standards, both in face-to-face lectures in class and learning in the laboratory.

The results of the needs analysis, the author's observation of the Instrumental Analytical Chemistry lecture, one of the conditions that require the implementation of the learning process to be developed for the better, is caused by the lack of availability of instrumentation facilities or equipment that supports practicum learning in the laboratory. This is mainly because the equipment is costly. So far, in the laboratory's Instrumental Analytical Chemistry practicum lecture, the material or subject matter that can be practised and the equipment is available. Only one instrumentation unit out of 12 instrumentation is needed. This fact certainly affects the learning outcomes obtained by students.

An effort to overcome the problem of instrumentation limitations is the development of Virtual Laboratories, which support media as a substitute for expensive instrumentation. This Virtual Lab has become an alternative that describes the process of electronic learning using computer simulation. Ultra Violet-Visible (UV-Vis) Spectrophotometer is the most widely used instrumentation in the topic or title of Instrumental Analytical Chemistry practicum because this instrumentation can analyze elements and compounds in the ultraviolet wavelength region to visible light visible, for samples of coloured and colourless (clear) solutions, for example for the analysis of alcohol, caffeine, metal ions, and others.

With the background of the description above, researchers have developed an actual Instrumental Analytical Chemistry practicum to digital practicum, especially the development of virtual laboratory media for UV-Vis Spectrophotometer instrumentation, which can also meet the demands of digital native 21st-century learning with 4C characteristics and the development of digital technology that can also meet the educational challenges of the Industrial Revolution 4.0 era.

The focus of the problem in research is the development of virtual laboratory media for the practicum Instrumental Analytical Chemistry Course, which refers to the 4C characteristics of 21st Century learning following the educational demands of the Revolution Era 4.0 to improve the quality of practicum learning through the digital practicum. The research was conducted on developing virtual laboratory media UV-Vis Spectrophotometer, feasibility and effectiveness of the results of developing virtual laboratory media UV-Vis Spectrophotometer for Instrumental Analytical Chemistry practicum.

METHODS

This research was carried out and tested in the Chemistry Education Study Program S1 FKIP Jambi University. The method used in this study is a educational research and development (Borg & Gall, 2007), with a systems approach, developing virtual laboratory learning media UV-Vis Spectrophotometer for digital practicum Instrumental Analytical Chemistry. The Multimedia Design Model that became a reference in this study was adapted from the Multimedia Design Model of Hannafin & Peck (1988). The steps that must be passed in the development of this learning model are:

1. Preliminary Research (Needs Analysis)
2. Virtual Laboratory Media Development Planning
3. Validation, Evaluation and Revision of Virtual Laboratory Media
4. Virtual Laboratory Media Trials as digital practicum activities

Research Procedural Flow

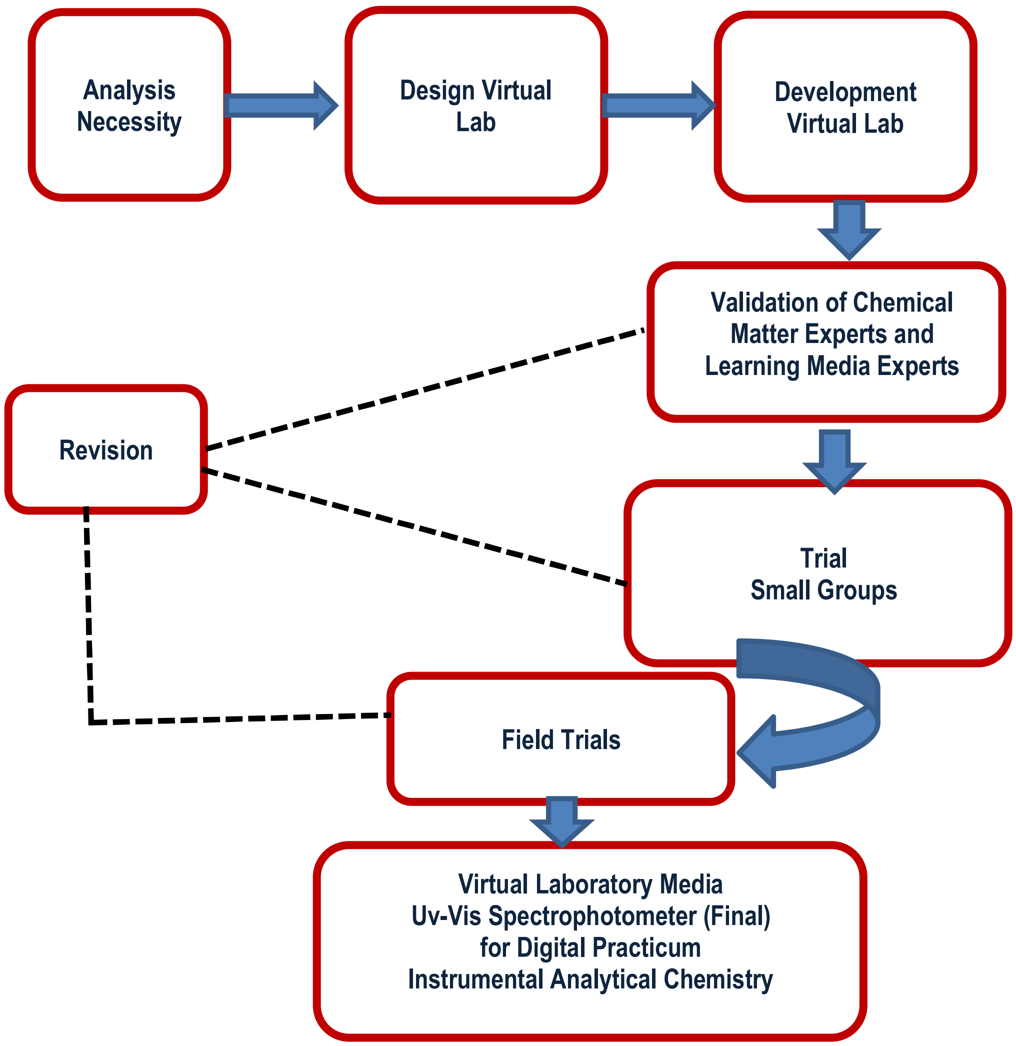

Figure 1. Laboratory Media Development Research Procedure UV-Visible Virtual Spectrophotometer

UV-Visible Spectrophotometry

This spectrophotometry is a combination of UV and Visible spectrophotometry. It uses two different light sources, a UV light source and a visible light source. Although more sophisticated tools already use only one light source as a UV and Vis source, namely a photodiode equipped with a monochromator. UV-Vis is the most widely available and most popularly used for spectrophotometric systems. The convenience of this method is that it can be used both for colour and colourless samples. Ultraviolet-visible or Ultraviolet-visible (UV-Vis) spectrophotometry involves the spectroscopy of photons within the UV-visible region. This means using light in visible and close proximity. Absorption in the visible range directly affects the colour of the chemicals involved. In this region of the electromagnetic spectrum, molecules undergo electronic transitions. Absorption of UV-Visible light by molecules, through 3 processes, namely:

a. Absorption by bonding electron transitions and anti-bonding electrons.
b. Absorption by d and f electron transitions of complex molecules
c. Absorption by charge transfer.

The interaction between light energy and molecules can be described as follows:

$$\mathbf{E} = \boldsymbol{hv}$$

Where, E = energy (joules/second)
h = plank constant
v = photon frequency

UV-Vis light absorption is limited to several functional groups/chromophore groups (clusters with unsaturated bonds) containing valence electrons with low excitation levels, involving three types of electrons: sigma, phi and phi and non-bonding electron. Organic chromophores such as carbonyls, alkenes, azo, nitrates and carboxyls can absorb ultraviolet and visible light. Its maximum wavelength can change according to the solvent used. Auxochromes are functional groups with independent electronics, such as hydroxyl, methoxy and amines. The binding of the autochrome group to the chromophore group will result in a shift in the absorption band towards a larger wavelength (bathochromic) accompanied by an increase in intensity (hyperchromic). UV-Vis spectrophotometry is routinely used to quantitatively determine solutions of ionic transition metals and highly conjugated organic compounds.

a. Solutions of transition metal ions can be coloured (e.g., absorb light) because electrons in metal atoms can be attracted from one electronic state to another. The presence of other species, such as certain anions or ligands, strongly influences the colour of solutions of metal ions. For example, the colour of an aqueous solution of copper sulfate is a very bright blue; adding ammonia increases and colour changes wavelength maximum absorption (λ_{max}).
b. Organic compounds, especially those with high conjugation levels, also absorb light in the UV or visible regions of the electromagnetic spectrum. The solvent for this determination is often water for water-soluble compounds or ethanol for soluble organic compounds. (Organic solvents may have significant UV light absorption; not all solvents are suitable for use in UV spectroscopy. Ethanol absorbs very weakly at most wavelengths.) The polarity of the solvent and pH can affect the absorption spectrum of organic compounds. Tyrosine, for example, increases the maximum absorption and molar coefficient of extinction when the pH increases from 6 to 13 or when the polarity of the solvent decreases.
c. While complex cost transfers also give rise to colour, colour is often too strong to be used in quantitative measurements. The Beer-Lambert law states that the absorbance of a solution is directly proportional to the concentration of absorbing species in the solution and the length of the path. So, to keep a long way to go, UV/VIS spectroscopy can be used to determine concentrations in absorbent solutions. It is necessary to find out how quickly the absorbance changes with concentration. It can be taken from a reference (table of molar coefficients of extinction) or, instead, determined from the calibration curve.

UV-Vis Instrumentation

UV-VIS spectroscopy has instrumentation consisting of five main components, namely:

1. Radiation Source
   The usual source of light energy for the visible regions of the spectrum and the near ultraviolet and near-infrared regions is an incandescent lamp with a wire made of tungsten. Under ordinary operating conditions, the output of this tungsten lamp is adequate from about 235 or 350 nm to about three μm. The energy emitted by the heated wire varies according to its wavelength. The heat from tungsten lamps can be troublesome; Sometimes, the lamp housing is covered in water or cooled with a wind blower to prevent samples or other components of the instrument from getting warm.
2. Sample Place
   Generally, spectrophotometry involves solutions, most of which are cells for putting liquids into the spectrophotometer's light beam. The cell must transmit light energy in the spectral region of interest: so glass cells absorb in the visible region; quartz cells or high silica glass are special for ultraviolet regions. In analytical chemistry instrumentation, cylindrical test tubes are sometimes used as sample containers. It is essential that such tubes are placed reproducibly by affixing a mark on one side of the flower and that the mark always remains in its direction each time it is placed in the instrument. Cells are better when the optical surface is flat. The cells must be filled so the light beam penetrates the solution, with the meniscus located entirely above the beam. Generally, the cells are held in position by the kinematic design of the holder or by spring-loaded clasps that ensure that the tube's position in the instrumentation cell chamber is reproducible.
3. Monochromator
   This monochromator is an optical device for isolating a radiation beam from a continuous source, which beam has a high spectral purity with the desired wavelength. Radiation from the source is focused into the entrance gap and then aligned by a lens or mirror so that a parallel beam falls onto the dispersing element, a prism or a diffraction lattice. By rotating the prism or lattice mechanically, the various portions of the spectrum produced by the disperse ensure concentration in the exit gap; from there, the portions encounter the sample by other optical means.
4. Detector
   Detectors can respond to radiation at various wavelengths. There are several ways to detect substances that have passed through a column. A standard method that is easy to use to explain is the use of ultra-violet absorption. Many organic compounds absorb UV light of some wavelength. If you shine UV light on a solution coming out through a column and a detector on the opposite side, you will get a direct reading of how much light is absorbed. The amount of light absorbed will depend on the amount of a particular compound passing through the beam. You will wonder why the solvent used does not absorb UV light. The solvent absorbs it! However, different compounds will absorb different parts of the UV spectrum very strongly. Methanol, for example, absorbs at wavelengths below 205 nm and water at waves below 190 nm. If you are using a methanol-water mixture as a solvent, you should use wavelengths greater than 205 nm to prevent incorrect readings of the solvent.
5. Rekorder/Readout
   A recorder is a component of instrumentation that records the results of the chemical sample analysis process. The signal is recorded as a spectrum in the form of peaks. The absorption spectrum is a plot between absorbance as an ordinate at sub Y and wavelength as abscissa at source X.

Working Principle of UV-Visible Spectrophotometer Instrumentation

In principle, UV-Vis spectroscopy uses Light as the energy that affects the substance of chemical compounds to cause light. The Light used is a photon that vibrates and travels straight and is an electric and magnetic force that both pose straight to each other. When it affects chemical compounds, photon energy will cause a response (response), while the response that arises for organic compounds is only a physical response or physical event. However, when it comes to decomposing chemical compounds, these compounds can be broken into smaller molecules or radicals called chemical events or Chemical events.

UV-Vis spectroscopy is used for coloured liquids. So the sample to be identified must be altered in a complex compound. Analysis of elements derived from plant, animal, and human tissues must be transformed into solutions, e.g. destruction of acid mixtures (H_2SO_4+HNO_3+$HclO_4$) at elevated temperatures. The sample solution obtained is carried out in the next stage of preparation with specific reagents to separate elements from one another, for example, Pb analysis with dithizone extraction at a certain pH. The Pb sample was reacted with ammonium citrate and natrium phosphate, pH adjusted by adding ammonium hydroxide, KCN and NH_2OH—HCl and extraction with dithizone.

The way the UV-Vis spectrophotometer works is that the Light from the radiation source is forwarded to the monochromator, Light from the monochromator is directed separately through the sample with a rotating mirror, The detector receives Light from the sample alternately repeatedly, The electrical signal from the detector is processed, converted to digital and the results are viewed, the calculation is done with a computer that has been programmed.

RESULTS & DISCUSSION

Results

Results of Needs Analysis

Identifying the characteristics of students in this study used questionnaires and observations. The results of course identification for students show that students like to study Instrumental Analytical Chemistry courses. Lecturers also prepare lectures well. Furthermore, the lecture process has routine and less varied methods and strategies. Students have participated in chemistry competition activities several times at the provincial and national levels.

The results of the identification of lectures followed by practicum as support for lectures show that practicum equipment is minimal, with minimal laboratory facilities, so there are no practicum activities.

The results of the initial characteristics of students who attend Instrumental Analytical Chemistry courses show that students have good motivation to attend lectures. Students have computer skills shown by the information that almost all students have laptops.

The results of the Needs Analysis obtained from the questionnaire to students are as shown at table 1.

Table 1. Results of Needs Analysis on Student Characteristics

No	Questionnaire Indicators	Data Analysis Results
1.	Information about student activity in lectures	71.20% of students stated that the Instrumental Analytical Chemistry course in the category was quite good. 70.83% of students stated that they were less challenged in Instrumental Analytical Chemistry courses. 64.03% stated that Instrumental Analytical Chemistry lectures are useful for extra-curricular activities in the field of Chemistry such as olympiade, etc.
2.	Readiness of lecturers to carry out lectures	79.14% stated that lecturers had preparation before carrying out lectures
3.	The learning process carried out by lecturers	87.50% stated that lecture methods and strategies were less varied. 83.33% stated that lecturers are quite concerned about student responses
4.	Information about Instrumental Analytical Chemistry practicum in the Chemistry laboratory	87.50% stated that students were quite enthusiastic about participating in practicum activities. 95.83% stated that Instrumental Analytical Chemistry practicum equipment was very lacking 87.50% stated that laboratory facilities and infrastructure were not available and did not support the implementation of Instrumental Analytical Chemistry lectures. 87.50% stated that only 2-3 subjects of learning material could be practiced from the twelve titles in the practicum guide.

Results of Virtual Laboratory Media Development UV-Visible Spectrophotometer

The following is the form of display (lay out) of the results of the development of virtual laboratory media UV-Vis Spectrophotometer:

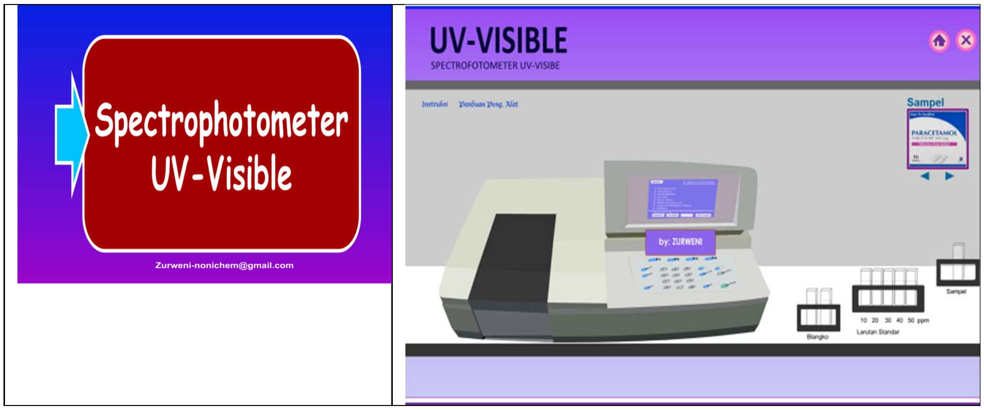

Figure 2. Lay out Multimedia Lab Virtual Spectrophotometer UV-Vis

1. Results of Formative Evaluation by Spectrophotometer Analytical Chemistry Experts. The evaluation results from the Analytical Chemistry Expert Instrumental Spectrophotometry for chemistry learning of the S1 Chemistry Education Study Program following the Virtual Laboratory media for the Instrumental Analytical Chemistry Course after revision, gave an average evaluation percentage of 91.90% as follows:

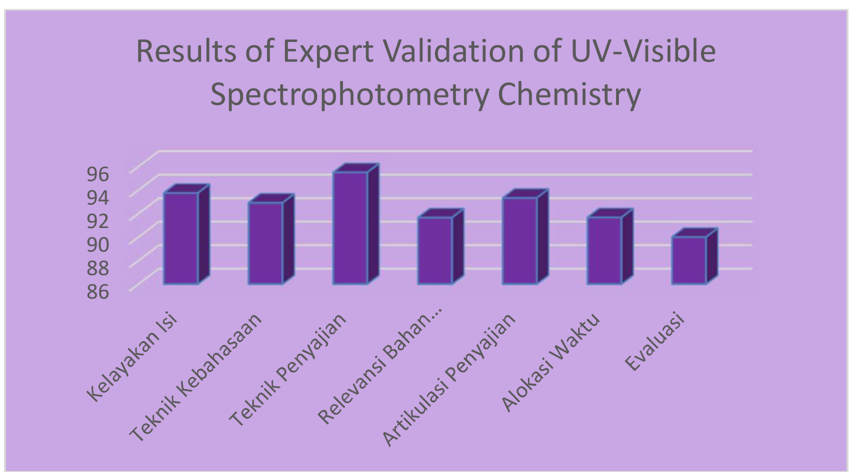

Figure 3. Results of Formative Evaluation of Instrumental Analytical Chemistry Experts

These results show that the learning media developed for the practicum of the Instrumental Analytical Chemistry course is in accordance with the UV-Vis Spectrophotometry Analysis material and can be continued to the next trial.

2. Results of Formative Evaluation of Learning Media
After revision, the evaluation results from Media Experts for Virtual Laboratory learning for the development of UV-Vis Spectrophotometer for the Instrumental Analytical Chemistry Course gave an average evaluation percentage of 90.84%. These results show that the UV-Vis Spectrophotometer virtual laboratory media developed and, after improvement, is feasible to be tested on students as a continuation of the development research stage. The percentage of evaluation and valuation results of this virtual laboratory media is shown in the following graph.

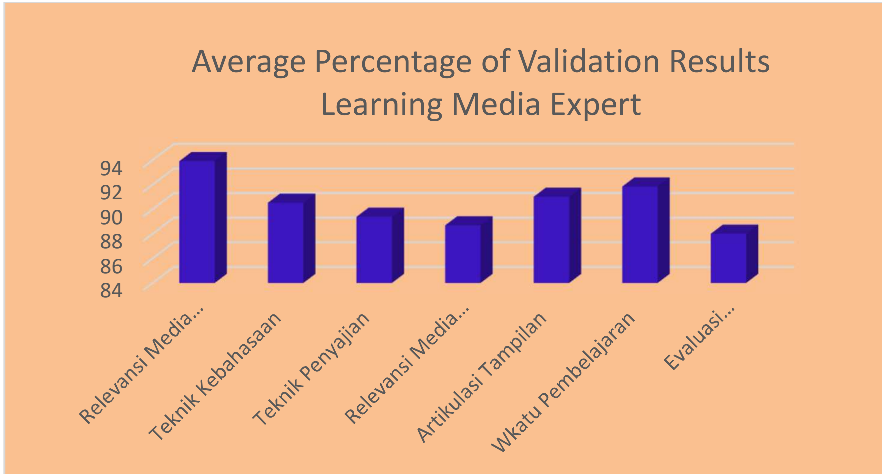

Figure 4. Learning Media Expert Validation Results

Results of Small Group

The results of small group trials on virtual laboratory media UV-Vis Spectrophotometer developed on 10 students gave an average percentage response of 90.66%. The results of the trial can be known through the following graph.

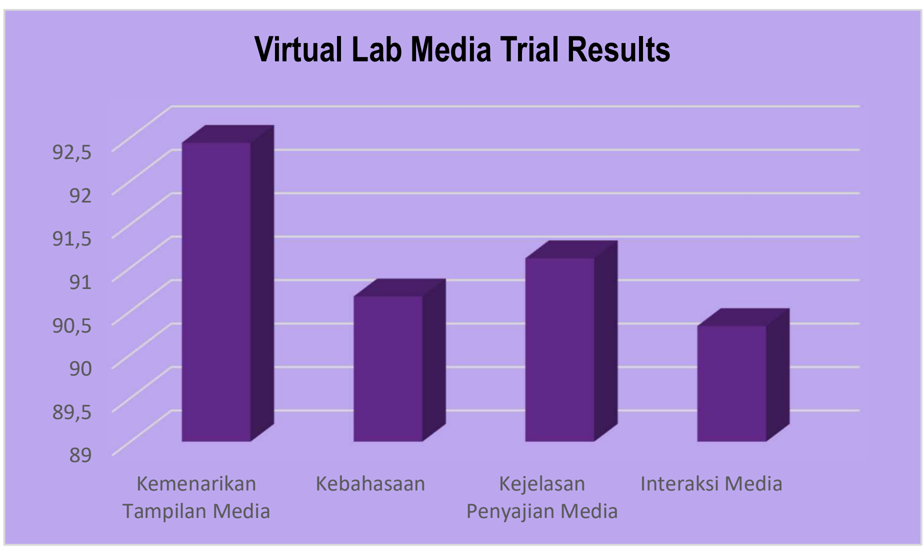

Figure 5. Results of Virtual Laboratory Media Trials of Developed UV-Vis Spectrophotometer

The results of trials on the UV-Vis Spectrophotometer Virtual Laboratory media developed showed that the media was excellent, shown by student responses with an average percentage of 90.66%. These results show that the UV-Vis Spectrophotometer Virtual Laboratory media developed is suitable for digital practicum in the Instrumental Analytical Chemistry Course. Furthermore, the effectiveness test showed that the virtual laboratory developed provided an effectiveness of 59.68%. These results are obtained through pretest and posttest results in the Trial field.

Discussion

The research is to provide digital instrumentation in virtual laboratory media, a UV-Vis Spectrophotometer resembling the original instrumentation, which can be used for digital practicum instead of actual practicum that cannot be held because of the high price of the instrumentation. At the same time, it can also be used in face-to-face learning in the classroom. However, of course, this digital practicum cannot replace an actual practicum in a real lab. However, digital practicum uses a virtual lab; its function is as an alternative solution to the limitations of analytical chemistry instrumentation and to support theoretical learning face-to-face in class.

In 2012, Rizman & Dinevski conducted an experimental study on using virtual laboratories, providing more effective chemistry learning results than without virtual laboratories. Furthermore, research on educational paradigms whose learning uses a student-centred approach using virtual laboratory learning media is very appropriate to be used in collaborative learning to support student creativity. This reason is one of the reinforcements for researchers to use virtual laboratory media. The use of chemistry virtual laboratories has a positive influence that has led to increased chemistry learning achievement in Turkish High Schools, carried out on the Chemical Separation material. The virtual laboratory was created using the macro flash application to process normal chemical reactions for SMA (Tuyzuz, 2010).

Another study used Java-based software for organic analysis. Things that need to be considered in developing the UV-Vis Spectrophotometer Virtual Lab are the technical variations of field samples as an example of analysis, which is then inputted into macro flash software. Standard solution data must be synchronized with the analyte on dialysis.

CONCLUSION

Based on the development research that has been carried out, it can be concluded as follows: 1) The concept of virtual laboratory media development UV-Vis Spectrophotometer for Instrumental Analytical Chemistry Course is an instrumental development for digital practicum based on the demands of 21st Century learning which is currently in the Industrial Revolution Era 4.0, namely, with 4C learning characters: Communication, Critical thinking, Collaboration, Creativity to innovation. 2) Physical product of virtual laboratory media development This UV-Vis Spectrophotometer is a Macromedia flash computer program application developed for digital practicum instrumental Analytical Chemistry courses. 3) Virtual Laboratory Media UV-Vis Spectrophotometer for the practicum of the Instrumental Analytical Chemistry course developed is declared feasible and effective for use in the digital practicum of the Instrumental Analytical Chemistry course. It is recommended to utilize and implement this Spectrophotometer virtual laboratory media in the Instrumental Analytical Chemistry digital practicum.

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