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# Development of problem-based learning virtual laboratory on human digestive system material to improve digital literacy and critical thinking students

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**Abstract**

This research was conducted to know the characteristics of the media and produce a feasible, practical, and effective problem-based learning virtual laboratory application to improve digital literacy and critical thinking skills of grade XI students of SMA Negeri 1 Depok Yogyakarta. This research is a research and development using the ADDIE model, which involves analysis, design, development, implementation, and evaluation. Field trials were conducted by the quasi-experimental method using a pretest-posttest control group design. A total of 72 students from two classes XI of SMA Negeri 1 Depok Yogyakarta became the subjects of field trials, divided into control classes (36 students) and experimental classes (36 students), with the application of cluster sampling techniques. Data was collected through digital literacy observation sheets and critical thinking skills test questions and then analyzed using the Manova test. The results showed that; (1) Virtual laboratories based on problem-based learning developed have the characteristics of interactive, collaborative, and emphasize independent/group research, which can motivate students by providing new learning experiences. (2) this media is suitable to be used from the aspect of media and material to improve digital literacy and critical thinking skills of students with very good categories, (3) and practical in improving digital literacy and critical thinking skills of students with very good categories, (4) and effective in improving these two aspects, by the results of the MANOVA test which indicate a significant difference In the application of these media to digital literacy and critical thinking skills of students.

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## Introduction

The 21st century is known as the century of knowledge, where space and time factors have been the main determinants of the speed and success of science (Falode & Gambari, 2017; Wardani et al., 2017). In this context, learners are expected to have skills in knowledge, technology, media, and information, as well as abilities in learning, innovation, life skills, and careers. In addition, digital literacy and critical thinking skills are also very important (Jagodziński & Wolski, 2015).

Digital literacy includes the ability to recognize and utilize digital information sources, solve problems, understand internet ethics, assess the validity of online information, build new knowledge, and play a role in improving academic quality and efficiency of academic tasks using software and computer programs (Akbar & Anggraeni, 2017; Alexander et al., 2016; Anthonysamy et al., 2020; Sukarno & Widdah, 2020). The results of interviews and

observations at SMAN 1 Depok, Yogyakarta, revealed that educators there had never measured the level of digital literacy of students. More than 95% of learners tend to use smartphones to play games and socialize on social media. These results are in line with research by Safitri (2019) which shows that the majority of students prefer to use smartphones to access social media and play online games, and rarely review subject matter outside of school (APJJI, 2021). Research conducted at SMAN 6 Banjarmasin and SMAN 1 Kuala also showed that the digital literacy of students in the two schools tended to be in the low category, with percentages of 43.93% and 35.5% (Oktavia & Hardinata, 2020; Pratama et al., 2019).

To be able to assess the correctness of the information sought or received, one needs strong digital literacy skills, supported by quality critical thinking skills (Tang & Chaw, 2016). Kartimi and Liliasari (2012) explain that critical thinking is an attitude that tends to consider and reflect on problems that arise from experience. This critical thinking ability is necessary for making wise judgments, thinking fairly about things that will be believed in the future, as well as for reflection, competence, and problem-solving both in the short and long term (Brookhart, 2010; Fong et al., 2017; Khasanah et al., 2017).

The results of observations of students' critical thinking tests showed a low level, as much as 41.8%. With a breakdown of indicators interpreting 30.29%, analyzing 38.89%, evaluating 38.22%, explaining 39.85%, and concluding 52.5%. The results of interviews with educators revealed that the average critical thinking ability of students still requires improvement. This can be seen from the few students who actively ask questions during learning, some who have not reached the KKM score, and the average cognitive ability that has not met the target. The Programme for International Student Assessment (PISA) noted that the science achievement score of students in Indonesia only reached 396 out of a maximum score of 489 (Penilaian Pendidikan Badan Penelitian, 2018), thus showing that the critical thinking ability of students in Indonesia is still relatively low.

A learning model that can be used as an alternative to improve critical thinking is the Problem-Based Learning (PBL) model. The results of interviews with educators show that the use of PBL models rarely occurs in the learning process, so the potential use of PBL has not been fully maximized. The application of the PBL model has the potential to train various thinking skills of learners, including critical thinking, solving complex problems, analysis, and the ability to collaborate and communicate, both oral and written (Rosa Novrita Mulya & Pujiati Anik, 2016). This finding is also in line with several other studies that have significantly shown that the use of PBL models can improve learners' critical thinking skills (Marnita et al., 2020; Pratiwi et al., 2021; Rezkillah & Haryanto, 2020; Saputra et al., 2019).

The results showed that in the material of the human digestive system, especially the sub-material of food substance testing, virtual practicum has never been carried out. Conventional practicum also cannot be carried out sustainably due to limited space and time. This is due to laboratory conditions that have not met good standards; The laboratory room used is still an ordinary classroom, not a special laboratory room. To overcome this weakness and overcome the obstacles that arise in practicum in physical laboratories, the use of virtual practicum can be considered an effective solution. The virtual practicum allows the simulation of practicum tools and activities so that users feel as if they are doing a practicum in a physical laboratory. This is one of the learning alternatives based on Information and Communication Technology

(ICT) (Gambari et al., 2018; Handayani Iryan et al., 2021; Hidayati & Masril, 2019; Stahre Wästberg et al., 2019).

One of the Biology materials for high school level grade XI Science is about the human digestive system. The results of interviews with Biology educators at SMA Negeri 1 Depok show that this material contains many concepts about internal mechanisms in the body that cannot be observed directly or are invisible. In addition, many objects of study are imaginative, but each student has limitations in terms of imagination, especially in understanding concepts that are difficult to observe directly, such as the process of breaking down food by enzymes in the stomach. In this process, food is mixed with stomach acid and enzymes produced by the stomach, which then breaks down the food into smaller molecules, making it easier for the body to digest.

Material about the human digestive system, in addition to being invisible, also has a high level of complexity. Several scientific terms need to be memorized, including the location and structure of organs, as well as the function of each organ in the human digestive system. Because of its complexity, learners often have difficulty understanding this material without the help of learning media. The results of initial observations at SMA Negeri 1 Depok show problems in learning, such as the low achievement of KKM scores in students' cognitive learning outcomes, the use of learning methods that do not stimulate students' critical thinking, and dependence on textbook-based learning media. This highlights the need for variety in the use of learning media in explaining the material of the human digestive system.

The advantages of virtual laboratories include the safe use of tools and materials, and time efficiency with accurate results (Falode & Gambari, 2017). Practicum can be carried out in a physical laboratory without the worry of errors, allowing the repetition of incorrect or incomprehensible steps to improve learners' understanding (Evangelou & Kotsis, 2019; Faour & Ayoubi, 2018). The use of virtual practicum media on mobile phones also attracts learners as it is more effective than conventional learning and helps in the development of natural skills as well as competencies (Dwiningsih et al., 2018; Elfeky & Yakoub Masadeh, 2016).

Based on the presentation of existing problems and facts, researchers developed a PBL-based virtual practicum as an alternative learning media that is relevant to the demands of the 21st century. Thus, this study aims to determine the characteristics of virtual laboratory application media based on problem-based learning of human digestive system material and produce virtual laboratory application media based on problem-based learning of human digestive system material that is feasible, practical, and effective to improve digital literacy and critical thinking of grade XI students of SMA Negeri 1 Depok Yogyakarta.

## Method

### 1. Development Model

This type of research is research and development (R&D). R&D research is a type of research used to develop a particular product. The development model used in this study is the ADDIE development model, which consists of 5 stages; analysis, design, development, implementation, and evaluation (Lee & Owens, 2004). The chart of the core model research development procedure conducted by the researcher is presented in Figure 1 of the ADDIE model development procedure schema.

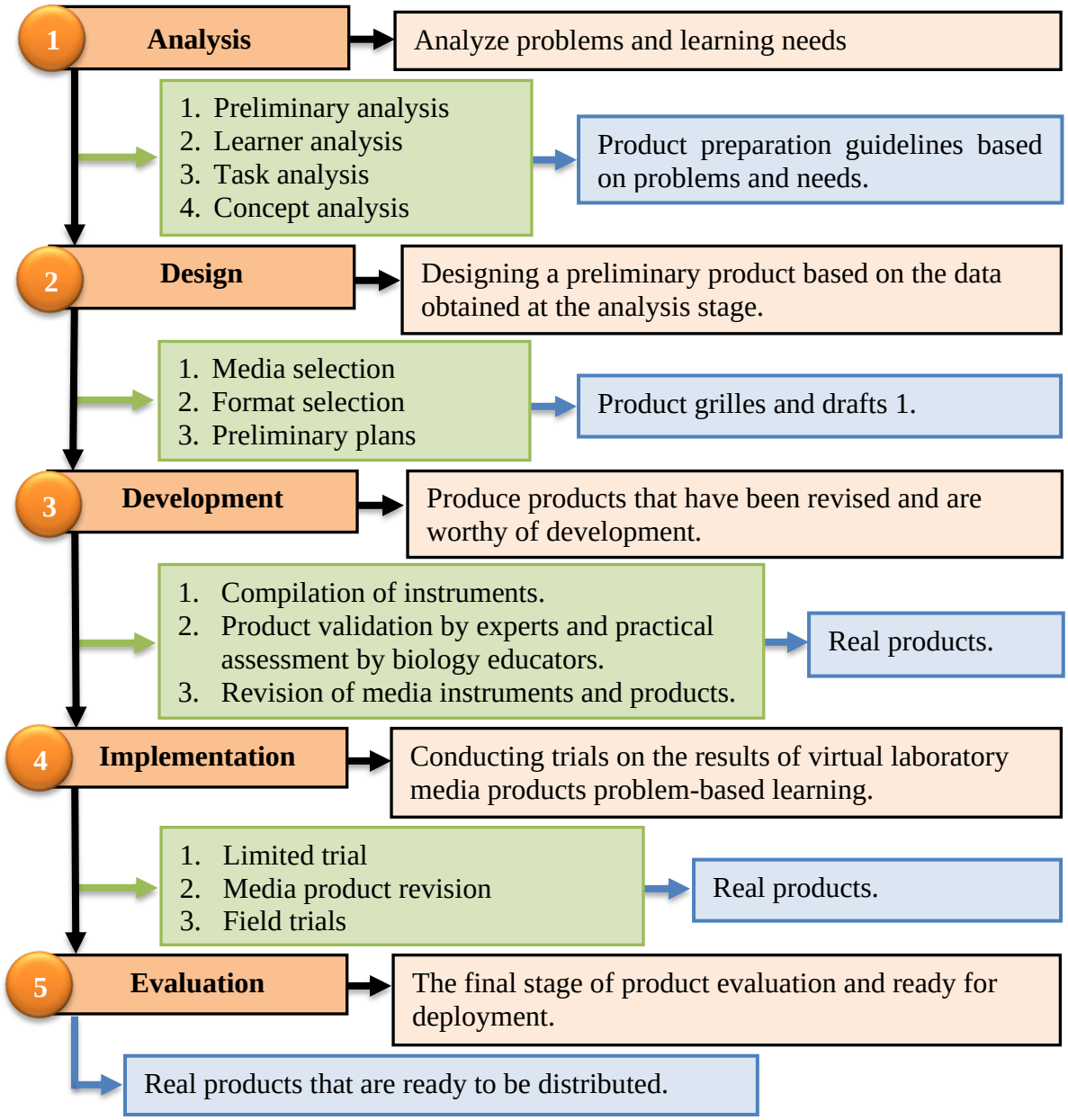


**Figure 1.** ADDIE Model Development Procedure Schematic

## 2. Subject, Place, and Research Design

The test subjects were divided into two: limited trials and field trials. The limited trial involved one class of grade XI students of SMA Negeri 1 Depok Yogyakarta with various levels of ability. The field trial involved 72 students from class XI of SMA Negeri 1 Depok Yogyakarta in the even semester of the 2022/2023 academic year, divided into control classes and experimental classes, each with 36 students. The experimental class uses a virtual laboratory problem-based learning application, while the control class uses demonstration

videos in Google Classroom. The sampling technique used is cluster random sampling, and the research design adopted is a pre-test and post-test control group design.

### 3. Techniques, Data Collection Instrument and Data Analysis

This study used two data collection techniques, namely test and non-test. The test is used to measure the ability of virtual problem-based learning practicum to improve student's critical thinking, using description questions as a measurement tool. Meanwhile, non-test techniques are used to evaluate the feasibility, practicality, and readability of the practicum media. To measure students' digital literacy and learning implementation, researchers use observation sheets, while interview guidelines are used to understand conditions and problems related to practicum implementation in schools. Virtual laboratory media assessment and validation instruments consist of feasibility assessment sheets by media experts and material experts, practicality assessment sheets by biology educators, readability assessment sheets by students, digital literacy observation sheets, and critical thinking assessment sheets for students.

Data analysis techniques used in this study include: First, the data used is descriptive data derived from comments and suggestions of material experts, media experts, educators, and learners during the product development and trial process. Second, validation and assessment of media quality are carried out based on the results of assessments from media experts and material experts, as well as practical assessments by biology teachers and student readability responses. Widoyoko (2011) believes that converting the average score into a qualitative score is part of knowing a media quality as can be seen in Table 1. Finally, test the hypothesis using the Manova test with the SPSS 26 program. This test aims to determine the difference in scores between sample groups in digital literacy and critical thinking skills of learners. The hypothesis proposed is that there are differences in the use of virtual laboratories on digital literacy and critical thinking skills of students, which will be accepted if the Sig value < 0.05.

**Table 1.** Media Eligibility and Practicality Criteria

| No. | Score Range | Value | Category |
|---|---|---|---|
| 1. | $X > (\bar{X}_i + 1{,}8Sb_i)$ | A | Excellent |
| 2. | $(\bar{X}_i + 0{,}6Sb_i) < X \leq (\bar{X}_i + 1{,}8Sb_i)$ | B | Good |
| 3. | $(\bar{X}_i - 0{,}6Sb_i) < X \leq (\bar{X}_i + 0{,}6Sb_i)$ | C | Enough |
| 4. | $(\bar{X}_i - 1{,}8Sb_i) < X \leq (\bar{X}_i - 0{,}6Sb_i)$ | D | Less |
| 5. | $X \leq (\bar{X}_i - 1{,}8Sb_i)$ | E | Very Lacking |

**Information:**

X = Score empires

$\bar{X}_i$ = Average ideal (1/2 (score maximum + score minimum))

$Sb_i$ = Ideal standard deviation (1/6 (maximum score - minimum score))

Virtual laboratory media products' problem-based learning is said to be feasible if they meet the minimum category of "Good".

## Results and Discussion

### 1. Product Characteristics Description

The development of virtual laboratory media products based on Problem-Based Learning (PBL) has important significance in introducing characteristics that distinguish it from conventional learning media. This media is designed to provide learning experiences

that are interactive, and collaborative, and encourage problem-solving independently and in groups. Its main characteristics include well-structured content, diverse multimedia interactions, and an emphasis on developing critical and analytical thinking skills. Adopting a PBL approach challenges learners to confront real-world problems, encourages them to actively seek solutions, and deepens their understanding through self-directed exploration. Visual representations of the various characteristics of this virtual laboratory media are shown in Figure 2 display of the results of media development.


**Figure 2.** Display of Media Development Results

Based on Figure 2 learning media in the form of problem-based learning virtual laboratories was developed with the hope of being able to be a solution to limitations in real practicum, due to incomplete practicum tools and materials, as well as inadequate laboratory conditions. In this media, practicum activities along with the tools and materials used can be simulated to look real.

Interactive content: this problem-based learning-based virtual laboratory presents interactive and engaging content to increase student participation and engagement. This can include the use of multimedia elements such as images, videos, animations, and interactive simulations. Interactive content helps learners to be more actively engaged in learning and

gain a deeper understanding of the material of the human digestive system. In this problem-based learning-based virtual laboratory, students use each test with a smartphone and the animation that appears can be moved or can be observed changes that occur when the test is carried out. In line with research conducted by Ridwan &; Kembuan, (2021) the use of problem-based learning (PBL) using virtual laboratories in internship practice has proven to have a significant impact on interactive learning.

Authentic cases or problems: this problem-based learning virtual laboratory provides cases or problems that are authentic and relevant to the real lives of students. Such cases can trigger critical thinking and prompt learners to apply their knowledge of the human digestive system in the context of real situations. This helps learners to develop real-world relevant problem-solving skills and strengthen their digital literacy. In line with research conducted by Suarni et al., (2022) which shows that virtual practicum based on problem-based learning (PBL) provides cases or problems that are authentic and relevant to the real lives of students.

Online collaboration and discussion: virtual labs based on problem-based learning can invite students to collaborate and share ideas. It allows them to work together in finding solutions to given problems, discuss concepts related to the human digestive system, and expand their understanding through the exchange of information. Collaboration can be done online, improve students' digital literacy skills, and build communication and cooperation skills. In line with research conducted by Vosinakis and; Koutsabasis, (2012) virtual practicum based on problem-based learning (PBL) can invite students to collaborate and share ideas. In PBL, students learn by overcoming problems that are not clearly defined and openly, collaboratively so that the process of discussion and exchange of information can be carried out.

Emphasis on independent/group research: virtual laboratories based on problem-based learning can encourage students to conduct research independently or in groups using digital resources. They may be asked to seek additional information on a particular topic, explore reliable sources, and analyze and evaluate the information they find. Emphasis on independent or group research is expected to develop students' digital literacy and involve them in thinking critically about the resources they encounter. In line with research conducted by Ma'rufin et al., (2020) that virtual practicum based on problem-based learning (PBL) can encourage students to conduct research independently or in groups using digital resources Rizki et al., (2021) Also revealed in research conducted by universities, the development of information technology-based independent learning resources, such as virtual laboratories, can increase self-efficacy and facilitate students in completing tasks independently.

In addition, with this media, students can also take advantage of technology appropriately because it is equipped with interesting human digestive system material, offline LKPD, and exercises on critical thinking skills. So it is expected to be able to develop and improve the digital literacy and critical thinking skills of students. Problem-based learning virtual laboratory media is a special attraction for students because it provides new experiences for students in carrying out practicum activities, based on the results of interviews with biology educators at SMA Negeri 1 Depok Yogyakarta, biology learning

has never used problem-based learning virtual laboratory media on human digestive system material.

Virtual laboratory biology learning based on problem-based learning is an interesting and innovative variety of teaching media. Suryaningsih et al., (2020) also revealed that learning biology using virtual laboratories has become an interesting and innovative variety of teaching media. Activities in virtual laboratories based on problem-based learning are interesting because they can combine virtual objects and are designed in such a way as if the user is in a real practicum. Learners perform 4 tests consisting of carbohydrate test, glucose test, protein test, and fat test. When virtual practicum activities are based on problem-based learning, students use each test using a smartphone and the animation that appears can be moved or can be observed changes that occur when the test is carried out.

The purpose of developing problem-based learning media is to provide a different learning experience by utilizing existing technology so that learning will be more interesting and realistic for students (Marti et al., 2020). With the virtual laboratory, students can carry out practicum activities like in a real laboratory without fear of making mistakes (Faour & Ayoubi, 2018). The development of problem-based learning virtual laboratory media can be a potential and effective media that has a positive influence on the learning process. It is proven that when the learning activities of experimental class students who use problem-based learning virtual laboratory media are more enthusiastic than control class students. They feel bored and less interested in practicum activities because they only use video demonstrations.

The virtual laboratory media developed in this study has advantages because it integrates one of the learning models recommended by the 2013 curriculum, namely the problem-based learning model. Learning is designed by following the syntax of the problem-based learning model so that it can be used as an effort to improve the digital literacy and critical thinking skills of students. This is because students are faced with problems that are commonly found in everyday life, with this problem, students are required to be able to find solutions to the problems faced, one of which is by having digital literacy and critical thinking skills. In line with the results of Serungke et al.'s research, (2020) which states that the use of virtual labs by implementing PBL syntax effectively increases critical thinking and learning potential. Research results of Nuryanti et al., (2019) also show that virtual laboratory media can significantly improve learners' critical thinking for higher and secondary vocational schools. On the other hand, the PBL-based virtual laboratory media developed in this study has weaknesses, including the lack of direct interaction between students and materials and practicum tools and materials. In virtual practicum, students only interact with materials, tools, and materials, and operate all practicum learning activities through virtual media such as virtual laboratory applications on smartphones. This may reduce the actual practicum experience where learners can directly interact with practicum materials and tools.

Problem-based learning activities start by creating small groups, then students analyze problems, identify relevant facts, and apply existing knowledge and experience to solve problems (Zhou, 2018). Problem-based learning models can be useful and effective for improving cognitive and affective skills in learning (Dolmans et al., 2016; Hmelo-Silver &

Eberbach, 2012). Problem-based learning also changes the learning process from a teacher center to a student center, educators play a role in accompanying students when conducting investigations in pairs or groups (Salari et al., 2018).

## 2. Product Eligibility

The results of virtual laboratory media validation based on Problem-Based Learning (PBL) were obtained through research involving material experts and media experts. The validation process is carried out to ensure that the media developed is by standards and has good quality in supporting learning. Material experts assess the content of the material from the virtual laboratory, ensuring that the information presented is accurate and corresponds to the concepts taught. Meanwhile, media experts evaluate the technical aspects of media, including continuity of interactivity, easy navigation, and conformity to instructional design principles. The results of validation by these two groups of experts are represented in Table 2, which presents the results of expert assessments.

**Table 2.** Expert Validation Results

| No. | Expert | Number of Validation Scores | Maximum Number of Scores | Category |
|---|---|---|---|---|
| 1. | Material | 43 | 52 | Excellent |
| 2. | Media | 58 | 60 | Excellent |

Based on the results in Table 2. show that the feasibility of virtual laboratory media based on problem-based learning material of the human digestive system is validated first by 2 expert lecturers based on the substance of the media and material before being used for trials. Some inputs from experts as media improvements include: "transition animation should be reduced, to be more efficient (for example: after animation the use of practicum PPE (preparation part) to animation tools & materials), discussion questions should ideally be based on data (may) be obtained from experimental activities, not limited to verification of concepts/theories and the writing system of standard and effective sentence writing needs to be improved". Two aspects are assessed related to media, namely visual and audio, and software engineering. The score of the validator is 58 out of a maximum score of 60, with the category very good, so the media is declared suitable for use. The aspects assessed are related to the material, consisting of learning and material/content. The score of the validator amounted to 43 out of a maximum score of 52 with the very good category, so the material was declared suitable for use. In the development of learning media applications, the media developed must be able to provide an increase in the enthusiasm of students. In addition, the virtual laboratory media animation based on problem-based learning displayed is designed to resemble the original model.

**Table 3.** RPP Validation Results

| Expert | Number of Validation Scores | Maximum Number of Scores | Category |
|---|---|---|---|
| Validator 1 | 55 | 60 | Excellent |
| Validator 2 | 54 | 60 | Excellent |

Based on the results in Table 3, show that lesson plans (RPP) are designed to support the use of virtual laboratories in learning. The eligibility of RPP values is based on the completeness of RPP components consisting of RPP identity, formulation of indicators and learning objectives, learning activities, and language. The results of the assessment of RPP show that all aspects assessed by validator 1 and validator 2 are on very good criteria with an average score of 54.5 out of a maximum score of 60 so RPP is suitable for use in learning. The input from validators is "the formulation of indicators that are not appropriate, correct typos, and formulations that are not by good and correct Indonesian systems".

**Table 4.** Results of Expert Validation on Instruments

| Instruments | Validation Score | Max Score | Category |
|---|---|---|---|
| Digital Literacy Observation Sheet | 43 | 48 | Excellent |
| Critical Thinking Skills | 44,1 | 45 | Excellent |

Based on the results of instrument validation in Table 4, it can be seen that observation sheets and critical thinking skills questions are valid and suitable for use in research. The input from the validator is "related to writing the use of language so that it is improved so that it does not cause multiple interpretations in students". Three aspects of digital literacy assessment instruments become assessment materials, namely content, construction, and language. The score from the validator is 43 out of a maximum score of 48 with a very good category so the instrument is declared feasible to be used to measure students' digital literacy. The critical thinking ability assessment instrument is assessed by experts to determine the validity of its contents using Aiken's V. The validation results of the critical thinking ability assessment instrument in the form of description questions show that Aiken's V value for each question item is in the range of >0.8. This value indicates that the critical thinking ability assessment instrument is valid.

**Table 5.** Empirical Validation Results on Critical Thinking Skills

| Instruments | Valid | Number of Question Items | | Unreliable |
|---|---|---|---|---|
| | | Invalid | Reliable | |
| Critical Thinking Skills | 15 Questions | - | 15 Questions | - |

Based on the results in Table 5 which shows that the results of the analysis with the correlation between r product moment and Cronbach's Alpha are known all questions are declared valid because the value of r product moment is greater than 0.344. Likewise, in the reliability test, all questions are declared reliable with a Cronbach's Alpha value of 0.902. This shows that all questions can be continued in the trial, but the researcher only took 10 questions, namely 5 questions for the pretest and 5 questions for the posttest. So it can be concluded that based on empirical tests conducted on 35 students and analyzed using the SPSS 26 program show that 15 reliable and valid questions can be used to measure students' critical thinking skills.

### 3. Product Practicality and Legibility

This assessment aims to determine the practicality of problem-based learning in virtual laboratory media. Data is obtained based on assessments by biology educators in the form of questionnaires. In the media practicality questionnaire, four aspects were assessed, namely visual and audio, software engineering, learning, and material/content. Table 6 shows the results of media practicality assessments by biology educators.

**Table 6.** Results of Media Practicality Assessment by Biology Educators

| Aspects | Number of Validation Scores | Maximum Number of Scores | Category |
|---|---|---|---|
| Visuals and Audio | 34 | 36 | Excellent |
| Software Engineering | 22 | 24 | Excellent |
| Learning | 28 | 28 | Excellent |
| Material/Content | 21 | 24 | Excellent |

Table 6 shows that the practicality of the product developed is based on the results of an assessment by biology educators using media practicality questionnaires. Educators say, this media is by the development of science and technology and has features that are easy to understand, and interesting because it provides new experiences for educators in carrying out virtual practicum activities based on problem-based learning on digestive system material in biology learning. The learning activities and LKPD developed are also by the syntax of the problem-based learning model. Data is obtained based on assessments by biology educators in the form of questionnaires. In the media practicality questionnaire, four aspects were assessed, namely visual and audio, software engineering, learning, and material/content. The assessment results show that the developed product has an excellent category, so it is practical to use.

**Table 7.** Media Readability Questionnaire Results

| Aspects | Average Score | Category |
|---|---|---|
| Learning and Materials | 9,9 | Excellent |
| Media Display and Operations | 26,3 | Excellent |

Table 7. It is the result of obtaining product readability based on assessment by 35 students in a limited trial using questionnaires. The results show that the products developed have excellent categories and can be used in field trials. Comments from students related to problem-based learning virtual laboratory media include: "interesting media display, virtual practicum activities based on cool problem-based learning, easy to understand the material, on some Android smartphones old versions of the application cannot be installed, and when the application is used to carry out practicum activities virtually for a long time it makes the smartphone hot".

## 4. Product Effectiveness

Effectiveness is a measure of the success of virtual laboratories based on problem-based learning of human digestive system material in improving digital literacy and critical thinking skills of students through field trials. Field trials consist of two different sample groups. The first sample group is an experimental class that uses virtual laboratory media based on problem-based learning, while the second sample group is a control class that uses practicum video demonstrations.

### a. Digital Literacy Differences between Experimental and Control Classes

Learning using virtual laboratory media problem-based learning material on the human digestive system can facilitate the digital literacy of students, which is shown through the analysis of observation sheets. The results of digital literacy observations showed that the experimental class had an average score of each aspect higher than the control class. In line with the results of the study Yanitama et al., (2021) stated that training activities using virtual laboratories can improve the digital literacy of teachers and students. The comparison of the average scores of each aspect of digital literacy of the experimental class and the control class is shown in Figure 3 of the graph comparing the average scores of each aspect of digital literacy.

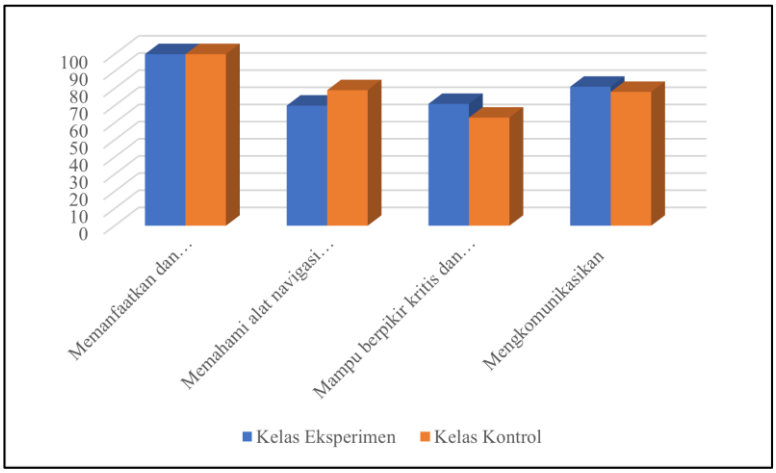


**Figure 3.** Graph comparing the average score of each aspect of digital literacy

The average comparison of each aspect of digital literacy scores between the experimental class and the control class was influenced by the use of virtual laboratories based on problem-based learning developed. Students who use problem-based learning virtual laboratory media are more enthusiastic about participating in learning because they get new experiences by carrying out virtual practicum activities that have never been done before. Research by Vrana Radovan (2014) shows the results that digital literacy has a positive influence on academic performance. Digital literacy can contribute to more efficient task completion through the help of software and computer programs (Akbar & Anggraeni, 2017). While the control class students get bored quickly because they only watch demonstration videos of practicum activities.

**b. Differences in Critical Thinking Abilities of the Experimental Class and the Control Class**

Critical thinking skills after field tests in both classes improved. The increase in the average value of critical thinking ability is shown in Figure 4 graph of comparison of average critical thinking ability value.

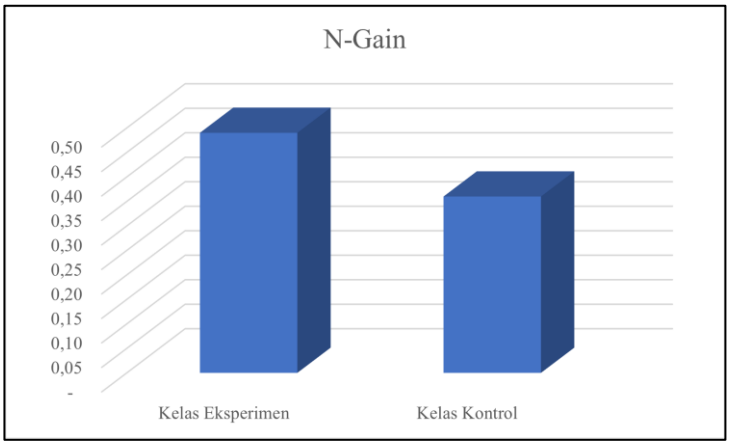


**Figure 4.** Comparison Graph of Average Critical Thinking Ability Scores

Increasing students' critical thinking ability can be seen from the calculation of N-Gain. The results showed that the average N-Gain of critical thinking ability of the experimental class was higher than that of the control class so that the increase in critical thinking ability of students in the experimental class was better than the control class. The use of virtual laboratory media is effective in improving students' critical thinking skills. This is based on the results of the effect size test showing the result of Coben's value of 0.28. In line with the results of the study Serungke et al., (2020) state that the use of virtual labs by implementing PBL syntax effectively increases critical thinking and learning potential. Research results from Nuryanti et al., (2019) also show that virtual laboratory media can significantly improve learners' critical thinking for higher and secondary vocational schools.

**c. The Effect of Virtual Laboratories Based on Problem-Based Learning Human Digestive System Material on Digital Literacy and Critical Thinking Abilities of Students**

The hypothesis test is performed after the prerequisite tests are met. The results of field trials showed that the digital literacy and critical thinking skills of the experimental class were better than those of the control class. There are differences in the use of virtual laboratories based on problem-based learning of human digestive system material on digital literacy and critical thinking of students in experimental classes and control classes. Supported by the results of statistical analysis of the Manova test in Table 8, Sig. value 0.012. This means that the value of Sig. (2-tailed) < 0.05 so that $H_0$ is rejected and $H_1$ is accepted. This proves that virtual laboratory media based on problem-based learning material of the human digestive system is effectively used in biology learning to improve the digital literacy and critical thinking skills of students.

**Table 8.** Multivariate Test Results

| Multivariate Tests | | | | |
|---|---|---|---|---|
| **Effect** | | **Value** | **F** | **Sig** |
| Class | Pillai's Trace | 0,121 | 4,744[b] | 0,012 |
| | Wilks' Lamda | 0,879 | 4,744[b] | 0,012 |
| | Hotteling's Trace | 0,138 | 4,744[b] | 0,012 |
| | Roy's Largest Root | 0,138 | 4,744[b] | 0,012 |

| Tests of Between-Subjects Effects | | | | |
|---|---|---|---|---|
| **Source** | **Dependent Variable** | **Mean Square** | **F** | **Sig** |
| Class | Digital Literacy | 8,000 | 0,047 | 0,830 |
| | Critical Thinking Skills | 684,500 | 9,601 | 0,003 |

Virtual laboratories based on problem-based learning (PBL) have a significant influence on the digital literacy and critical thinking skills of students. In PBL-based virtual labs, learners interact with digital technology and online resources to solve problems relevant to the learning material. This involves searching for information, evaluating the reliability of digital resources, and applying other digital literacy skills. Learners learn to utilize digital technology as a tool to access, understand, and effectively communicate information. In line with research conducted by Yanti et al., (2023) which shows that the results of training activities on the use of virtual laboratories show that overall each indicator of teachers' digital literacy ability has increased. Based on the results of the activity, it can be concluded that training on the use of virtual laboratories to improve digital literacy is considered successful in achieving the 70% target that has been set.

In addition, PBL-based virtual laboratories also encourage students' critical thinking skills. In the context of this practicum, learners are given challenges in solving complex problems and finding innovative solutions. They are invited to analyze relevant information, identify underlying assumptions, evaluate arguments, and develop logical and rational thinking. This process develops learners' ability to think critically, argue, and make decisions based on deep consideration. In line with the results of the study, Ma'rufin et al., (2020) and Serungke et al., (2020) and research Nuryanti et al., (2019) state that the use of virtual laboratories by implementing PBL syntax effectively increases critical thinking and learning potential and virtual laboratory media can significantly improve the critical thinking of learners for high and secondary vocational schools.

PBL-based virtual labs effectively integrate digital literacy and critical thinking skills in real, relevant learning contexts. Through a combination of digital technology and a problem-based approach, this practicum provides an immersive experience for learners to develop the skills needed in an increasingly connected and complex world. It is important to continue the use of PBL-based virtual laboratories in education to strengthen students' digital literacy and critical thinking skills so that they are ready to face the demands of the growing digital world.

## Conclusion

Based on findings from research and development of virtual laboratories based on problem-based learning (PBL) material of the human digestive system, it was found that the

characteristics of the virtual laboratory, including interactive content, collaboration, and emphasis on independent/group research, provide new and exciting learning experiences for learners. This virtual laboratory is suitable to be used to improve students' digital literacy and critical thinking skills, as well as being effective in biology learning. The results of the Manova test show significant differences in the use of virtual laboratories on digital literacy and critical thinking skills of students. This shows the positive impact of virtual laboratories as a variety of innovative teaching media on digital literacy and critical thinking skills of students. Therefore, it is recommended to develop virtual laboratories on other topics in biology and other science subjects, as well as add features that facilitate students learning.

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**Wanda Agus Prasetya:** Conceptualization, Supervision, review. **Anggi Tias Pratama:** Conceptualization, Supervision, review & editing. **Wulan Safitri:** Writing-review & editing.

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