The Development of Virtual Food Simulation (VIFO) Media as a Realization of 21st Century Learning Demands

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***Abstract*—Information and communication technology is increasingly penetrating almost all areas of human life, including education. One form of technology in education is the emergence of virtual laboratories, which are technology-based learning facilities for acquiring practical skills. This research aims to develop Virtual Food Simulation (VIFO), a virtual laboratory learning media, as a proper biology learning medium. This study uses the Research and Development (RND) method with stages according to the Hannafin and Peck model. This research was conducted from April to July 2023. The research test subjects included expert validators (media experts, material experts, and language experts), biology teachers, and 29 students of class XII MIPA. The average result of the due diligence by media experts, material experts, and linguists was 88.6% in the very feasible category, the results of the use test by biology teachers were 100% in the very good category, and the results of the field test by students were 91.3% in the very good category. The conclusion of this study shows that VIFO learning media is very feasible to be used as a learning medium to support biology practicum and enrich learning media in schools, and in its implementation, students give a positive impression of the media.**

***Keywords*—development research, 21st century learning, virtual laboratory, learning media, Virtual Food Simulation (VIFO)**

I. Introduction

Biology is a branch of science that studies natural phenomena through observation. The subject of biology is one of the fields that has experienced significant development in 21st-century learning. In the 21st century, critical thinking, creativity, communication, and collaboration are key competencies to face the challenges of a rapidly changing world [1]. Students in 21st-century learning must be more active so that the learning process is student-centered. Laboratories have a very important role in biology learning. Learning activities in the laboratory aim to develop students' skills, such as using tools and training accuracy in recording and reporting the results of observations made [2].

The laboratory can be interpreted as a room or place used to carry out scientific activities. The understanding of laboratories also develops with the need for the meaning of a place of learning for certain scientific concentrations. The laboratory is often interpreted as a place with learning tools and materials. Besides that, the laboratory can also be shaped like a classroom or the surrounding nature.

Along with the development of science and technology, the laboratory concept has also developed. Laboratories are no longer interpreted as limited by time and space but develop into virtual laboratories. A virtual laboratory is a learning medium that can be an alternative to help with practicum activities [3].

Virtual laboratory is one of the Information and Communication Technologies (ICT) based learning facilities that can be used as an alternative practicum in schools, especially for schools with limited laboratory facilities. The virtual laboratory is computer software that is used to observe or carry out experimental activities as is done in real laboratories [4].

Researchers or teachers can develop virtual laboratories. In the development of virtual laboratory learning media, a device is needed. One software that can be used to develop virtual laboratory learning media is PowerPoint. Learning with PowerPoint software media is significantly more effective compared to conventional learning [5]. Some researchers who previously developed PowerPoint-based learning media stated that this media is feasible to develop because it supports an efficient learning process [6, 7].

The updates in VIFO media development use PowerPoint software, whereas virtual laboratory development uses Adobe animate [8, 9]. The choice of using PowerPoint software is because it has advantages in making it relatively easy, there is no need to code in design, the animation is available to support the creation of virtual laboratories, and this media can increase student learning interest [10]. In contrast, in terms of users, it is easier for students to access this virtual laboratory learning media.

Using a virtual laboratory, students can flexibly conduct practicum simulations to support biology learning. This virtual laboratory is named VIFO, which stands for Virtual Food Simulation and contains practicum simulations, maker information, practicum procedures, and student worksheets. This VIFO media can provide additional references in developing PowerPoint-based virtual laboratory learning media. The resulting products can also enrich learning media so that improved quality of learning processes and outcomes can be achieved, especially food test practicum in high school biology learning.

II. Theoretical Framework

A. Development Research Concept

Development research, also called Research and Development (RND), is research aimed at developing a product to be used by the wider community. In development research, several stages are conducted, namely: (1) Analysis; (2) Design; (3) Implementation. The stages in development research need to be considered. Before development is carried out, it is necessary to conduct a needs analysis. This stage is the initial stage of development research design [8]. Research and development are closely related to the field of technology. One product in the field of education that can be developed with development research is learning media. Learning media is an inseparable part of the learning process. Besides being determined by teaching skills and mastery of the material, learning is also influenced by the media [11]. Learning media can be developed through development research. Media development certainly needs to pay attention to learning outcomes.

The development of media by implementing technological innovations is possible. Technological innovation can enrich the learning process, especially when explaining abstract biological objects [12]. In development research design, there are several examples of development models such as Dick and Carey, Borg and Gall, 4D, ADDIE, PLOMP, and Hannafin and Peck [13]. The development model used in this study is the Hannafin and Peck model. The Hannafin and Peck model is a product-oriented development model, especially multimedia products [14]. The reason behind the selection of this model is because the model is flexible and systematic, steps in development are simpler, and the revision at each stage allows for minimizing errors because, at each step, revision has been done [15]. This development model consists of 3 stages, namely: (1) the needs analysis stage (need assessment), (2) the product design stage (design), and (3) the development and implementation stage (development and implementation), where between the two stages an evaluation and revision are carried out before proceeding to the next stage.

B. *Virtual Laboratory*

A virtual laboratory is a simulation environment that can simulate a real laboratory in a virtual world using computer programs and 3D graphics [16]. In a virtual laboratory, students can conduct practicum experiments interactively using virtual laboratory equipment and instruments provided and designed to resemble a real laboratory. Virtual laboratories can be used in various fields, such as physics, chemistry, biology, engineering, and medicine. The development of virtual laboratories for learning requires an understanding of three domains [17], namely technology, pedagogy, and content knowledge. The "learning by doing" approach derived from constructivist pedagogy is usually applied during learning with virtual labs [18].

Virtual laboratories have advantages, which are: (1) practicum can be done anywhere and anytime and do not require laboratory tools and materials but only need computer devices and internet access [10, 19]; (2) This media can visualize something abstract into concrete so that the learning process can be more meaningful; (3) Learning using virtual laboratories can make students more active in learning activities [20]; (4) Guided inquiry learning with virtual labs has a significant effect on science process skills [21]; (5) The use of virtual laboratories can make students acquire work skills without the risk of accidents that can occur in real laboratories; (6) Learners can repeat the experiment as many times as necessary to acquire a scientific concept [22]. The disadvantages of virtual labs are (1) Learners do not acquire practical laboratory skills and do not have access to tactile information that encourages the acquisition of conceptual knowledge based on cognitive theory [23]; (2) Virtual labs rely heavily on visual images so that they require the virtual lab creators to make it as real as possible in order to make the students understand; (3) Students are lacking socialize skills or collaboration during virtual experiments [24].

C. *Virtual Learning and Its Mechanisms*

Biology is a branch of science that studies natural phenomena through observation and experimentation, resulting in facts and concepts [25]. To support the scientific process, biology learning requires supporting facilities in the form of laboratories to carry out experiments to get scientific evidence. However, in its implementation, some schools need more laboratory facilities and infrastructure. For this reason, media is needed that can be an alternative to facilitate student practicum activities.

Currently, there are many learning media that teachers can choose in delivering the practicum, one of which is computer-based. Using computers to help simulate practicum activities is known as a virtual laboratory. A virtual laboratory is a practicum with the help of applications on computers in the form of experimental simulations [26–28]. Virtual laboratories are used as support, not a substitute for real practicum. In its implementation, virtual laboratories require devices to run virtual laboratory programs. In the learning process, students must be obedient and committed so that when the teacher allows students to open devices, students can focus on only opening a virtual laboratory that will be simulated.

Virtual laboratories provide optimal conditions for practice procedures through appropriate provisions. Sensors include dripping reagents into foodstuffs, such as in the test lab of carbohydrates, proteins, and fats. This makes it possible to slow down the performance of a procedure or train an unlimited number of users. The use of virtual labs to acquire procedural knowledge has specifically been used with procedures that are difficult or dangerous to train in real life, such as fire safety behavior [29, 30].

III. METHODOLOGY

The method used in this study is the development research method. Development research is research aimed at developing and validating products that will be used in the learning process [13]. This study adapts Hannafin and Peck's model. This development model consists of 3 stages, namely: (1) the needs analysis stage (need assessment), (2) the product design stage (design), and (3) the development and implementation stage (development and implementation), where between the two stages an evaluation and revision are carried out before proceeding to the next stage.

Here is a picture of Hannafin and Peck's model, as shown in Fig. 1.

The first stage in this model is the needs analysis stage. Needs analysis is divided into two, namely, the analysis of teachers' needs and students' needs. This stage aims to identify needs in product development. The needs in question are problems in learning, the learning process, the availability of supporting equipment, and the product targets. Needs analysis is carried out through interviews, observations, and questionnaires [31] through Google Forms so that it is easy to be distributed and filled directly by students and biology teachers.

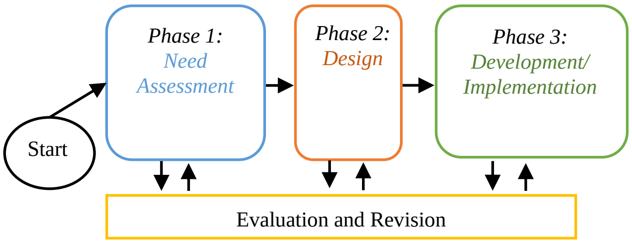

Fig. 1. Research flow of Hannafin and Peck.

Furthermore, evaluation and revision are carried out if there are shortcomings. The grid of instruments used to analyze the needs of biology teachers and learners in Table 1 and 2.

Table 1. Analytical instruments for biology teacher needs [32]

No	Indicators	Questions	Items	Total Items
1	Learning support facilities	Completeness of facilities and infrastructure that support learning	1, 2, 3, 4	4
2	Food test practicum learning	Use of biology learning media in schools	5, 6	2
		Learning media for food test materials	7	1
3	Knowledge of virtual laboratory learning media	Knowledge of virtual laboratory learning media	8, 9, 10	3
		Use of virtual laboratory learning media	11, 12	2
	Total			12

Table 2. Instruments analyzing the needs of learners [32]

No	Indicators	Questions	Items	Total Items
1	Learning support facilities	Completeness of facilities and infrastructure that support learning	1, 2	2
2	Food test learning	Difficulty of students mastering the concept of biological material	3, 4, 5	3
		Use of biology learning media in schools	6, 7, 8, 9	4
		Virtual laboratory learning media food test	11, 12, 13, 14	4
3	Indicators	Knowledge of virtual laboratory learning media	10	1
	Total			14

The next stage is the design stage. The design stage is known as the blueprint. The results of the needs analysis are used in this stage with various considerations in order to make the product created properly. At this stage, product design is created with an attractive color selection and interprets the real laboratory so that the students get practical practicum experience in visuals. The resulting output is in the form of a framework or storyboard of the product. The storyboard arranges graphics, such as illustrations or images, displayed sequentially to visualize moving graphics or interactive media sequences. Usually, storyboards can be made like picture stories or simple comics. The storyboard is a visualization of the idea of the application to be built to provide an overview of the application to be produced. The storyboard can also be a visual script that will be used as an outline of a project, displayed shot by shot, commonly known as scenes. Storyboards are now more widely used to create interactive media creation frameworks such as advertisements, short films, games, and interactive learning media. There are two main parts of a storyboard: the first is the sequence of different scenes to tell a story, and the second is the information provided for each scene. Storyboards can allow users to experience changes in the storyline to trigger a deeper reaction or interest [33]. When the design stage has been completed, an evaluation is conducted to achieve maximum results, which are then revised.

The third stage is development and implementation. At this stage, learning media development activities are carried out by basic competencies and indicators of competency achievement are shown in Table 3.

Table 3. Basic competencies and indicators of achievement of digestive system competence [34]

Basic Competency	Competency Achievement Indicators
Analyze the relationship between the structure of the tissues that make up organs in the digestive system about nutrition, bioprocesses, and functional disorders that can occur in the human digestive system	Describe the types and functions of food substances that the body needs Analyze the carbohydrate, protein, and fat content of food based on food substance test results
Present reports of food substance test results that contained in different types of materials food attributed with energy requirements each individual as well as Processing technology Food and Safety food	Conducting food tests on various foods Presenting the results of the Food Test Practicum

After the media has been developed, the next stage is conducting a feasibility test by media experts, material experts, and linguists. This is conducted because experts have a deep understanding of the content of the material and concepts, ensuring the written text meets the language standards. By considering suggestions and input from the experts, evaluation and revision are done to get maximum product development results. The following is an instrument of media feasibility test instruments, material feasibility tests, and language feasibility tests. The media feasibility tests instruments are shown in Table 4, material feasibility tests are shown in Table 5, and language feasibility tests are shown in Table 6.

Table 4. Media feasibility test instrument framework [32]

No	Component	Assessment Indicators	Items	Total Items
1.	Presentation of features in VIFO virtual laboratory (virtual food simulation) User-friendliness aspect	Text color composition and background	1	1
		Layout	2, 3	2
		Design attractiveness	4	1
2.	Consistency	Systematics of presentation	5	1
		Ease of use	6, 7, 8	3
3.	Component	Consistency in the use of words, terms, and sentences	9	1
		Consistency in the use of font types and sizes	10	1
		Layout consistency	11	1
4.	Presentation of features in VIFO virtual laboratory (virtual food simulation)	Use of color	12	1
		Font usage	13, 14	2
		Use of illustrations	15	1

Table 5. Material feasibility test instrument framework [32]

No	Aspects	Assessment Indicators	Items
1	Content feasibility aspect	Material conformity with CP and KD	1, 2
		Accuracy of the material	3, 4, 5, 6
		Material up-to-date	7, 8, 9, 10
		Encourage curiosity	11, 12
2	Presentation aspect	Presentation technique	13, 14
		Presentation support	15, 16
		Presentation of Learning	17, 18
		Coherence	19

Table 6. Language feasibility test instrument framework [32]

No	Assessment Indicators	Items	Total Items
1.	Businesslike	1, 2, 3	3
2.	Communicative	4	1
3.	Interactive	5	1
4.	Conformity with language rules	6, 7	2
5.	Use of terms, symbols, or icons	8, 9	2

After evaluation and revision based on the input from experts, the next stage is product implementation. The implementation of the product is carried out in two stages, namely, testing the use of media by biology teachers and field tests by students. After these two stages, suggestions and input were obtained from teachers and students. These suggestions and inputs become the material for evaluation and revision of the development of learning media.

After conducting media feasibility tests, media use tests and field tests, the next stage is to conduct quantitative data analysis based on Badan Standar Nasional Pendidikan (BSNP) scale assessments, as shown in Table 7.

Table 7. VIFO media feasibility test rating scale [32]

No.	Criteria	Score
1.	Very good	5
2.	Good	4
3.	Enough	3
4.	Less	2
5.	Very less	1

The feasibility quality score of Virtual Food Simulation (VIFO) virtual laboratory learning media is obtained based on the following formula:

$$\text{score} = \frac{\textit{value obtained}}{\textit{maximum value}} \times 100\% \qquad [32]$$

After the percentage value is obtained, the feasibility of VIFO virtual laboratory learning media (virtual food simulation) can be known based on the interpretation of the feasibility test score [32], described in Table 8.

Table 8. Interpretation of feasibility test scores [32]

No.	Score Range	Interpretation
1.	81%–100%	Very decent
2.	61%–80%	Proper
3.	41%–60%	Pretty decent
4.	21%–40%	Not worth it
5.	0%–20%	Very unworthy

IV. Results and Discussion

Research and development of VIFO virtual laboratory learning media are carried out through several stages by the steps of Hannafin and Peck model development, namely (1) need assessment, (2) design, (3) development and implementation, where at each stage an evaluation and revision are carried out [35]. Here are the results at each stage of development.

A. Need Assessment

The analysis stage was carried out to determine problems related to the development of biology learning media at SMA Negeri 16 Jakarta aimed at class XII MIPA students and biology teachers. The importance of conducting a needs analysis is to discover the problems that arise so that the designer gets a clear goal for the development product [36]. Needs analysis consists of two forms, namely, teacher needs analysis and student needs analysis.

1) Analysis of biology teacher needs

The following is a graph of the results of the needs analysis of biology teachers.

Based on the results of the analysis of teacher needs in Fig. 2, it is known that the school provides projectors and Wi-Fi, teachers allow students to use devices to support biology learning, teachers have never used virtual laboratory learning media, and teachers agree with the development of virtual laboratory learning media.

After analyzing the needs of teachers, it was found that the school has various facilities to support the learning process, including the availability of projectors and Wi-Fi connections. Nowadays, information and communication technology are increasingly penetrating almost all domains of human life, including education. In addition, with the current global trend to achieve 21st-century learning skills, digital literacy is one of the main goals, and there is a need to integrate technology into education [37–39].

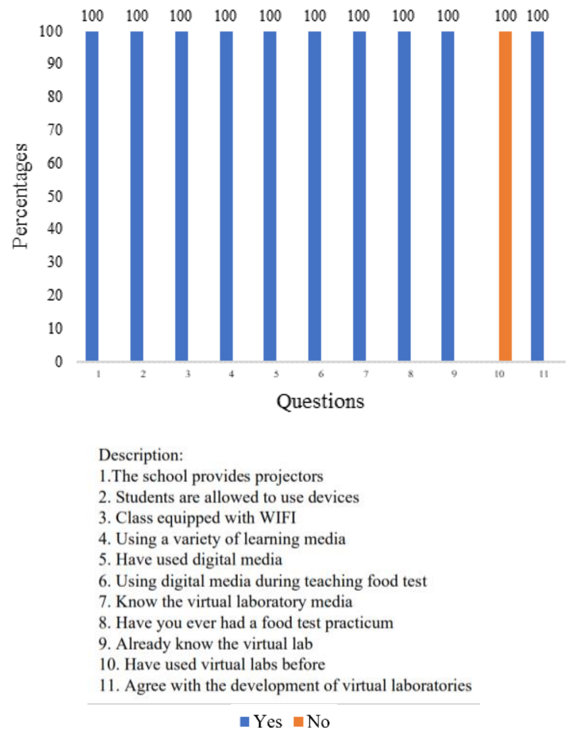

Fig. 2. Results of biology teacher's need analysis.

2) Analysis of student needs

Questionnaires were distributed to XII MIPA students, including 54 students. Graphic of the analysis of student needs shown in Fig. 3.

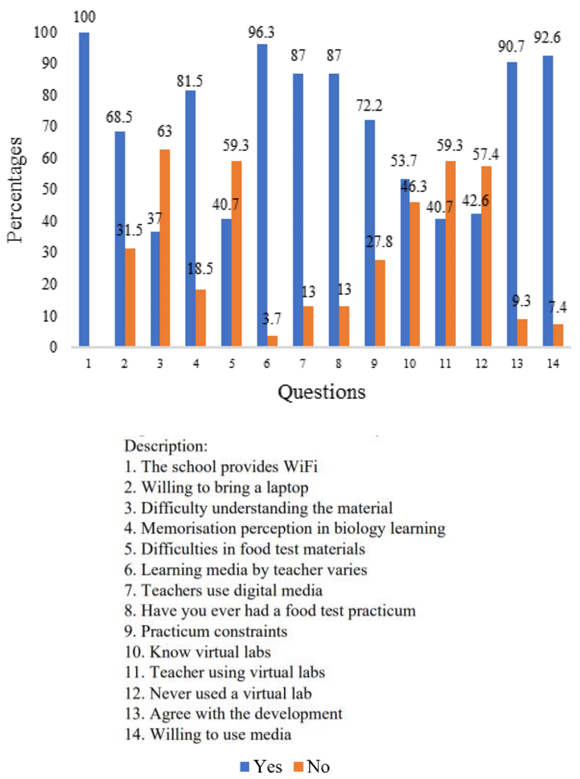

Fig. 3. Results of student's need analysis.

Based on the results of the needs analysis, it is known that schools provide Wi-Fi facilities, as many as 68.5% of students are willing to bring laptops in biology learning, 96.3% of students say that the learning media used by teachers varies, as many as 72.2% of students experience problems when carrying out food test practicum. As many as 90.7% of students agree with developing virtual laboratory learning media.

Based on interviews conducted at the needs analysis stage, students revealed several obstacles they experienced when carrying out food test practicum, namely the need to explain how to use laboratory equipment and difficulty in measuring droplets of materials used (Lugol, Benedict). The results of the needs analysis show that there is potential for the development of virtual laboratory learning media. Using virtual labs makes it easier for teachers to explain complex theoretical concepts through visual and immersive experiences that can make it easier for learners to understand the material [38]. The use of virtual labs allows learners to experiment with immediate feedback and interactivity [40], [41]. Virtual labs can help science concepts in general and specifically become more concrete [42] and meaningful to learners without the need for complicated and expensive equipment [43–45]. Biology is one of the science subjects that requires lab work in the laboratory as part of the process of acquiring practical skills [46]. Most biology learning topics rely heavily on practicum activities, especially in laboratories [47–49]. In connection with that, software was developed, namely VIFO (Virtual Food Simulation).

B. *Design*

The next stage is media design. This stage is the stage after analyzing the needs of teachers and students by accommodating suggestions and input from these respondents. Then, a basic design or storyboard is produced from VIFO media. In media development, storyboards have a very important role in describing the content of the media [50]. The storyboard is a visualization of the idea of the application to be built to provide an overview of the application to be produced. The storyboard can also be a visual script that will be used as an outline of a project, displayed shot by shot, commonly referred to as scenes. Storyboards are now more widely used to create interactive media creation frameworks such as advertisements, short films, games, and interactive learning media. Storyboards can make users experience a deeper interest in media [31].

C. *Development and Implementation*

The development phase involves various processes to produce the actual media, continuing the results of the storyboard design. The media design shown in Fig. 4. The process carried out at this stage includes application development and validation by experts, which includes media feasibility tests, material feasibility tests, and language feasibility tests to obtain more effective and efficient media results [51]. Then media use tests by biology teachers and field tests by students.

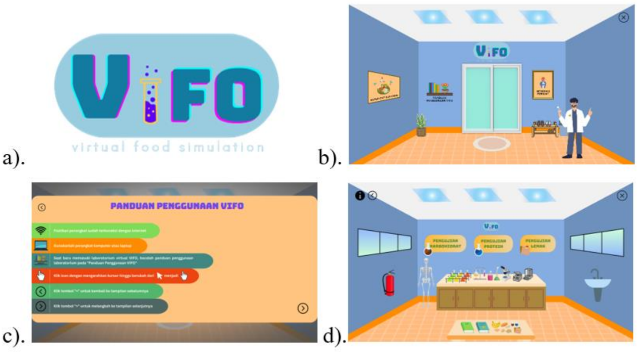

Fig. 4. The draft of storyboard design; a). VIFO logo, b). VIFO main menu display, c). VIFO usage guide, and d). Menu display before entering the practicum simulation.

1) VIFO media development

The following is a display of the results of VIFO's media development.

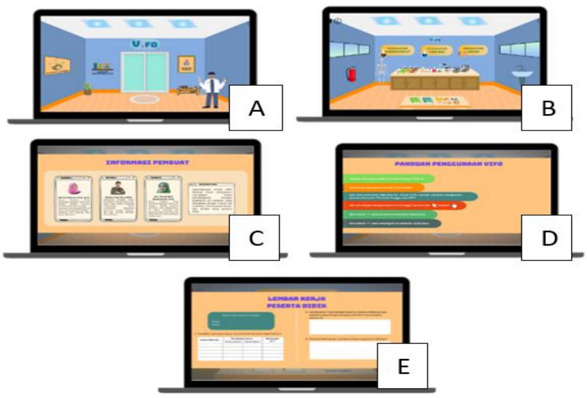

Fig. 5. Display of VIFO result; A). Main menu, B). Simulation preparation room, C). Maker information, D). Guide to use VIFO, and E). Student worksheets.

Shown in Fig. 5, the final product of VIFO virtual laboratory media development is software.

After the development is conducted, the next stage is a feasibility test to assess the feasibility of the media. Based on the results of the feasibility test by media experts, the feature presentation aspect gets a score of 95%, the ease of use aspect gets a score of 100%, the consistency aspect gets a score of 93.3%, and the graphic aspect gets a score of 85% as shown in Fig. 6.

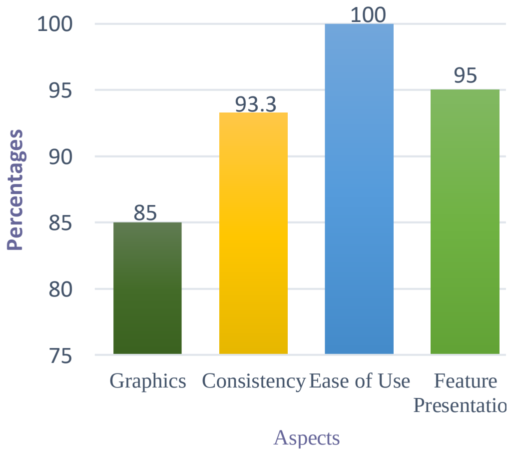

Fig. 6. The results of the VIFO media feasibility test by media experts.

Comments from media experts are that the learning media developed is suitable to be used as a learning media. The assessment results of media experts are very feasible. This is because the learning media developed meets four criteria factors, namely relevance, ease, attractiveness, and expediency [52]. The more relevant a media is, the more interesting and useful the use of learning media is. Appropriate media is expected to be used in the learning process so that it can be a tool to overcome limitations in material delivery [53].

Based on the results of the VIFO media feasibility test by material expert validators, the content aspect scored 83.3%. In comparison, the presentation aspect scored 77.1%, as shown in Fig. 7

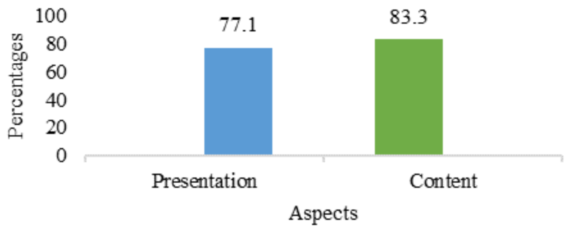

Fig. 7. The results of the VIFO media feasibility test by material experts.

The comment from material experts is that it is necessary to modify the type of test material, for example, with food ingredients that are trending in the school environment, to identify the nutritional content of these foods. Based on these suggestions and comments, media improvements can be made. The following Fig. 8 is an overview of the results of VIFO media improvements.

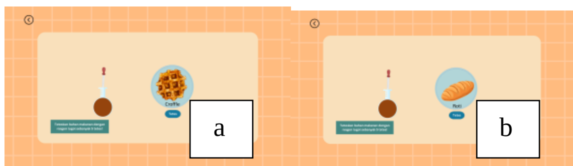

Fig. 8. Display of revised result; (a). Before revision, and (b). After revision.

The results of the Assessment from material experts were declared feasible. This is because VIFO media presents material that is in accordance with the competencies and indicators of competency achievement of regulation of the minister of education and culture Number 37 of 2008. The up-to-date aspect of the material is very important in developing learning media to be relevant to learning outcomes. Using virtual laboratories, students are introduced to technology-based learning media as a manifestation of 21st-century learning, namely 4C (Critical thinking, creativity, communication, and collaboration) [54].

Based on the feasibility test of VIFO media by linguist validators with businesslike aspects getting a score of 93.3%, communicative aspects getting a score of 100%, interactive aspects getting a score of 80%, aspects of conformity with language rules getting a score of 80%, aspects of using terms, symbols, and icons getting a score of 100% as shown below in Fig. 9.

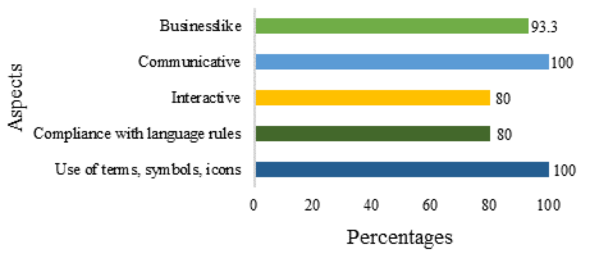

Fig. 9. The results of VIFO media feasibility test by linguists.

The results of the Assessment from linguists are declared very feasible. This is because the learning media developed needs to focus on good and correct linguistic aspects by paying attention to the preparation of clear sentences so that they are easy to understand [55].

Fig. 10 shows due diligence results from media, material, and language experts.

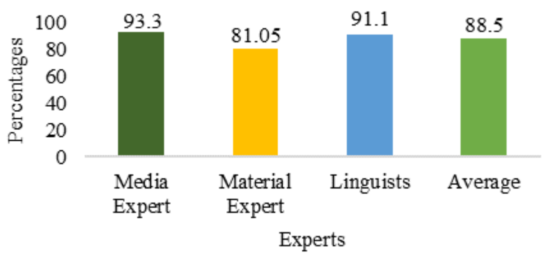

Fig. 10. The results of the VIFO media feasibility test by experts.

After the product is validated and declared feasible, the next stage is implementation. Implementation is a stage of implementing or applying learning media created and declared feasible by experts in learning activities.

2) VIFO media implementation

After evaluating and revising expert comments, the next stage is implementing media use tests by biology teachers and field tests by students. Here are the results of product implementation.

Based on Fig. 11, the average score for the test of media use by biology teachers is 100% with very good criteria. Comments from biology teachers are interesting developed media for online practice media, perhaps can be developed for other material.

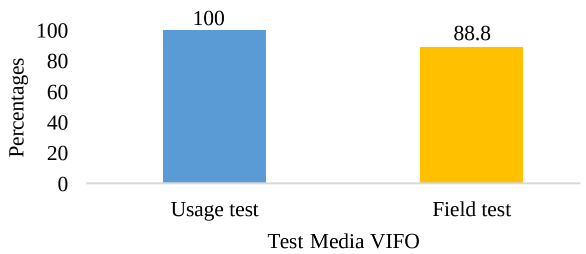

Fig. 11. The results of media VIFO implementation.

After testing media use on teachers, the next stage is student field tests. Based on the results of the use test on students, the product received an average score of 88.8% with very good criteria. The comments of some students for the virtual features of the laboratory are interesting to make students enthusiastic about learning, and the use of software is easy to use. The results of the media use test are very good. The media use test aims to get input through assessments and comments from biology teachers [56].

After calculating the average of the media feasibility test, material feasibility test, and language feasibility test, we obtained the results of 88.5%, which is in the very good category. The media use test by biology teachers obtained 100%, which is in the very good category, and the field test by students obtained 88.8%, which is in the very good category.

Using the Hannafin and Peck model, the development of VIFO media is more optimal because, in all three stages, it has gone through the evaluation and revision stages [57]. The uniqueness of VIFO learning media is the ease of accessing it, so anyone can easily use it [58]. VIFO media can be accessed via Google Drive, which has been provided and can be downloaded and operated immediately without installing other drivers and Adobe Flash Player. In VIFO media there are student worksheets so that learning will be more structured to foster learning motivation. The learning materials will have a clearer meaning so that the student can have a better understanding and allow students to master learning objectives well. For the shortcomings of VIFO learning media, some mobile users cannot open it, so it is recommended to use VIFO media on a computer or laptop device. The obstacle faced when developing VIFO media is during the development stage, namely creating hyperlinks and combining animations so that a virtual laboratory can be created that suits the needs of students.

V. Conclusion

VIFO virtual laboratory learning media has been developed into a viable learning media through research and development. The stages carried out in this study include needs analysis, feasibility tests by media, material, and language experts, media use tests by biology teachers, and field tests by students. Based on the results of feasibility tests by experts, the product is declared very feasible. Biology teachers and students involved in media use tests and field tests give a positive impression of VIFO media. This media can be used to support biology learning on food test materials. The next development implication for virtual laboratory media is using flexible media so that it cannot only be run through computer or laptop devices.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Eka Putri Azrai and Ratna Dewi Wulaningsih designed and directed research, reviewed product designs and compiled and reviewed articles. Muhammad Bayu Rifqi analyzed data, created VIFO virtual laboratory learning media, and compiled articles. All authors have approved the final version.

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REFERENCES

[1] F. B. Florez, G. Danies, S. Restrepo, and C. Hernandez, "Fostering 21st century competences through computational thinking and active learning: A mixed method study," *International Journal of Instruction*, vol. 14, no. 3, pp. 737–754, 2021.

[2] V. S. Varod, Y. E. Alkalai, and N. Geri, "Tracing research trends of 21st-century learning skills," *British Journal of Educational Technology*, 2019. https://doi.org/10.1111/bjet.12753

[3] Z. Tatli and A. Ayas, "Effect of a virtual chemistry laboratory on students achievement technologies for the seamless integration of formal and informal learning," *Journal of Educational Technology & Society*, vol. 16, no. 1, pp. 159–170, 2013.

[4] D. T. P. Yanto *et al*., "Validity test analysis of virtual laboratory-based job sheet for power electronics course," *International Journal of Information and Education Technology*, 2023. https://doi.org/10.18178/ijiet.2023.13.9.1951

[5] M. Jusuf and S. Negeri, "Efektifitas Media Komputer Dengan Perangkat Lunak Powerpoint Dalam Meningkatkan Hasil Belajar Bahasa Inggris Materi Pronoun Pada Peserta Didik Kelas X Teknik Surveying di SMK Negeri 3 Gorontalo," *In Klasikal: Journal of Education, Language Teaching and Science*, vol. 1, 2019. https://doi.org/10.52208/klasikal.v2i1.80

[6] P. D. Pramesti, I. K. Dibia, and P. R. Ujianti, "Media Pembelajaran Daring Interaktif Berbasis Power Point Dengan Fungsi Hyperlink," *Jurnal Pedagogi Dan Pembelajaran*, vol. 4, no. 2, pp. 258–267, 2021. Available: https://ejournal.undiksha.ac.id/index.php/JP2/index

[7] F. A. B. Putri and S. Rezkita, "Pengembangan Media Pembelajaran IPA Berbasis Powerpoint Interaktif Untuk Siswa Kelas V Sekolah Dasar Negeri Gondolayu," *Jurnal Pendidikan Ke-SD-An*, vol. 5, no. 3, pp. 684–693, 2019. http://dx.doi.org/10.30738/trihayu.v5i3.6122

[8] F. A. Hidayat and F. Fathurrahman, "Pendampingan Pemanfaatan Laboratorium Dalam Pembelajaran IPA," *Jurnal ABDIMASA Pengabdian Masyarakat*, vol. 1, no. 1, pp. 6–14, 2018. https://unimuda.e-journal.id/jurnalabdimasa/article/view/154/134

[9] N. K. M. Puspayanti, D. Santoso, G. Hadiprayitno, and L. Ilhamdi, "Pengembangan Laboratorium Virtual Berbasis Android dengan Aplikasi Adobe Animate untuk Pemahaman Konsep Sains Peserta Didik Kelas XI MIPA SMAN 8 Mataram," *Jurnal Ilmiah Profesi Pendidikan*, vol. 8, no. 1, pp. 507–515, 2023. https://doi.org/10.29303/jipp.v8i1.1252

[10] M. J. Samonte *et al*., "A personality-based virtual tutors for adaptive online learning system," *International Journal of Information and Education Technology*, 2023. https://doi/org/10.18178/ijiet.2023.13.6.1885

[11] A. Suryanda, E. P. Azrai, and D. S. Rini, "Peningkatan Keterampilan Guru IPA dalam Mengembangkan Media Pembelajaran Inovatif Berbasis Potensi Lokal," *DINAMISIA: Jurnal Pengabdian Kepada Masyarakat*, vol. 5, pp. 836–842, 2021. https://doi.org/10.31849/dinamisia.v5i2.3849

[12] D. S. Rini *et al*., "Augmented reality (AR) technology on the android operating system in human respiratory system: From organ to cell," *Jurnal Biosfer*, vol. 15, no. 1, pp. 25–35, 2022. https://doi.org/10.21009/biosferjpb.23448

[13] M. M. Gall, J. Gall, and W. R. Borg, *Educational Research An Introduction*, Pearson, 2003.

[14] M. Rohman and S. Amri, *Strategi dan Desain Pengembangan Sistem Pembelajaran*, Prestasi Pustakaraya, 2013.

[15] N. Nordin, I. N. Mohd, E. Zakaria, and M. A. Embi, "Development and evaluation of web quest for the science subject," *International Journal of Learning*, vol. 18, no. 5, pp. 221–236, 2012. https://doi.org/10.18848/1447-9494/cgp/v18i05/47592

[16] N. Hikmah, N. Saridewi, and S. Agung, "Penerapan Laboratorium Virtual Untuk Meningkatkan Pemahaman Konsep Siswa," *Jurnal Kimia dan Pendidikan*, vol. 2, issue 2, 2017. http://dx.doi.org/10.30870/educhemia.v2i2.1608.g1758

[17] M. Koehler and P. Mishra, "What is technological pedagogical content knowledge (TPACK)?" *Contemporary Issues in Technology and Teacher Education*, vol. 9 issue 1, pp. 60–70, 2009. https://doi.org/10.1177/002205741319300303

[18] K. Dimitropoulos, A. Manitsaris, and I. Mavridis, "Building virtual reality environments for distance education on the web: A case study in medical education," *International Journal of Social Sciences*, vol. 2. issue 1, pp. 62–70, 2008. https://www.researchgate.net/publication/27383991

[19] R. Setiadi and D. A. A. Muflika, "Eksplorasi Pemberdayaan Courseware Simulasi PhET Untuk Membangun Keterampilan Proses Sains Siswa SMA," *Jurnal Pengajaran MIPA*, 2012. https://www.researchgate.net/publication/308225926

[20] P. Wen, A. Z. M. Ali, and F. Lu, "Examining the user experience of a digital camera virtual reality lab with attention guidance," *International Journal of Information and Education Technology*, 2022. https://doi.org/10.18178/ijiet.2022.12.8.1673

[21] S. Srisawat and P. Wannapiroon, "The development of virtual professional learning community platform with experiential design thinking process to enhance digital teacher competency," *International Journal of Information and Education Technology*, 2022. https://doi.org/10.18178/ijiet.2022.12.12.1753

[22] R. Heradio *et al*., "Virtual and remote labs in education: A bibliometric analysis," *Journal Computers & Education*, 2016, vol. 98, pp. 14–38. http://dx.doi.org/10.1016/j.compedu.2016.03.010

[23] M. Abdulwahed and Z. K. Nagy, "The TriLab, a novel ICT based triple access mode laboratory education model," *Journal Computers and Education*, vol. 56, no. 1, pp. 262–274, 2011. http://dx.doi.org/10.1016/j.compedu.2010.07.023

[24] K. M. Y. Law, S. Geng, and T. Li, "Student enrollment, motivation and learning performance in a blended learning environment: The mediating effects of social, teaching, and cognitive presence," *Journal Computers & Education*, vol. 136, pp. 1–12, 2019. https://doi.org/10.1016/j.compedu.2019.02.021

[25] F. Yuniarti *et al*., "Pengembangan virtual laboratory sebagai media pembelajaran berbasis komputer pada materi pembiakan virus," *Unnes Journal of Biology Education*, 2012, pp. 86–94. https://doi.org/10.15294/jbe.v1i1.371

[26] P. Salam *et al*., "Pembelajaran berbasis virtual laboratory untuk meningkatkan penguasaan konsep pada materi listrik dinamis," in *Proc. the 4th International Conference on Teacher Education; Join Conference UPI & UPSI Bandung*, Indonesia, 2010.

[27] F. B. Florez, G. Danies, S. Restrepo, and C. Hernandez, "Fostering 21st century competences through computational thinking and active learning: A mixed method study," *International Journal of Instruction*, vol. 14, issue 3, pp. 737–754, 2021. https://doi.org/10.29333/iji.2021.14343a

[28] N. Hikmah *et al*., "Penerapan laboratorium virtual untuk meningkatkan pemahaman konsep siswa," *Jurnal Kimia dan Pendidikan*, vol. 2, no. 2, 2017. http://dx.doi.org/10.30870/educhemia.v2i2.1608.g1758

[29] G. Makransky and G. B. Petersen, "The Cognitive Affective Model of Immersive Learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality," *Educational Psychology Review*, 2021. https://doi.org/10.1007/s10648-020-09586-2

[30] M. Mulders, M. Kerres, and J. Buchner, "A framework for the use of immersive virtual reality in learning environments," *International Journal of Emerging Technologies in Learning*, 2020. https://doi.org/10.3991/ijet.v15i24.16615

[31] R. K. Dewi, "Analisis Kebutuhan Media Pembelajaran Berbasis E-learning pada Mata Pelajaran Kimia di SMA Negeri 8 Semarang," *Jurnal Inovasi Pendidikan Kimia*, vol. 16, issue 2, pp. 118–122, 2022. https://doi.org/10.15294/jipk.v16i2.19138

[32] I. Ulumudin, M. Mahdiansyah, and B. S. Joko, *Buku Teks dan Pengayaan: Kelengkapan dan Kelayakan Buku Teks Kurikulum 2013 Serta Kebijakan Penumbuhan Minat Baca Siswa*, 2017.

[33] I. Kunto, D. Ariani, R. Widyaningrum, and R. Syahyani, "Ragam Storyboard Untuk Produksi Media Pembelajaran," *Jurnal Pembelajaran Inovatif*, vol. 4, issue 1, pp. 108–120, 2021. https://doi.org/10.21009/jpi.041.14

[34] Peraturan Menteri Pendidikan dan Kebudayaan Republik Indonesia Nomor 37/2018/Tentang Perubahan Atas Peraturan Menteri Pendidikan dan Kebudayaan Nomor 24 Tahun 2016 Tentang Kompetensi Inti dan Kompetensi Dasar Pelajaran Pada Kurikulum 2013 pada Pendidikan Dasar dan Pendidikan Menengah. [Online]. Available: https://jdih.kemdikbud.go.id/sjdih/siperpu/dokumen/salinan/Permendikbud%20Nomor%2037%20Tahun%202018.pdf

[35] B. L. Bradbury, I. H. Tahini, and A. K. Dadykin, "Fundamentals of new effective system to accelerate language acquisition using visual approach," *International Journal of Information and Education Technology*, vol. 8, issue 11, pp. 768–772, 2018. https://doi.org/10.18178/ijiet.2018.8.11.1137

[36] M. Rusdi, *Penelitian Desain dan Pengembangan Kependidikan* (1st ed), Depok: Rajawali Pers, 2018.

[37] O. Dakhi, J. Jama, D. Irfan, Ambiyar, and Ishak, "Blended learning: A 21st-century learning model at college," *International Journal of Multi-Science*, vol 1, issue 7, pp. 50–65, 2020.

[38] L. K. Smetana and R. L. Bell, "Computer simulations to support science instruction and learning: A critical review of the literature," *International Journal of Science Education*, vol. 34, issue 9, pp. 1337–1370. 2012. https://doi.org/10.1080/09500693.2011.60518
[39] T. Tarbutton, "Leveraging 21st century learning & technology to create caring diverse classroom cultures," *Journal Multicultural Education*, vol. 25, issue 2, pp. 4–6, 2018.
[40] N. R. Dyrberg, A. H. Treusch, and C. Wiegand, "Virtual laboratories in science education: Students' motivation and experiences in two tertiary biology courses," *Journal of Biological Education*, vol. 51, issue 4, pp. 358–374, 2017. https://doi.org/10.1080/00219266.2016.1257498
[41] S. Tan and R. Waugh, "Use of virtual-reality in teaching and learning molecular biology," in Y. Cai (Ed.), *3D Immersive and Interactive Learning*, 2013. https://doi.org/10.1007/978-981-4021-90-6_2
[42] G. Olympiou, Z. Zacharias, and T. DeJong, "Making the invisible visible: Enhancing students' conceptual understanding by introducing representations of abstract objects in a simulation," *Journal Instructional Science*, vol. 41, issue 3, pp. 575–596, 2013. https://doi.org/10.1007/s11251-012-9245-2
[43] T. Elangovan and Z. Ismail, "The effects of 3D computer simulation on biology students' achievement and memory retention," *Journal Asia-Pacific Forum on Science Learning and Teaching*, vol. 15, issue 2, pp. 1–25, 2014.
[44] G.Marbach-Ad, Y. Rotbain, and R. Stavy, "Using computer animation and illustration activities to improve high school students' achievement in molecular genetics," *Journal of Research in Science Teaching*, vol. 45, issue 3, pp. 273–292, 2008. https://doi.org/10.1002/tea.20222
[45] A. M. Marchevsky, A. Relan, and S. Baillie, "Self-instructional "virtual pathology" laboratories using web-based technology enhance medical school teaching of pathology," *Journal Human Pathology*, vol. 34 issue 5, pp. 423–429, 2003. https://doi.org/10.1016/S0046-8177(03)00089-3
[46] L. A. Borgerding, T. D. Sadler, and M. J. Koroly, "Teachers' concerns about biotechnology education," *Journal of Science Education and Technology*, pp. 133–147, 2013. http://dx.doi.org/10.1007/s10956-012-9382-z
[47] H. Cavanagh, J. Hood, and J. Wilkinson, "Riverina high school students' views of biotechnology," *Electronic Journal of Biotechnology*, vol. 8, issue 2, pp. 121–127, 2005. https://doi.org/10.2225/vol8-issue2-fulltext-1
[48] A. Çimer, "What makes biology learning difficult and effective: Students' views," *Academic Journals*, vol. 7 issue 3, pp. 61–71, 2012. https://doi.org/10.5897/ERR11.205
[49] J. Vijapurkar, A. Kawalkar, and P. Nambiar, "What do cells really look like? An inquiry into students' difficulties in visualising a 3-D biological cell and lessons 17 for pedagogy," *Journal Research in Science Education*, vol. 44, issue 2, pp. 307–333, 2014. https://doi.org/10.1007/s11165-013-9379-5
[50] S. Wang *et al*., "ReelFramer: Co-creating news reels on social media with generative AI," arXiv preprint arXiv:2304.09653, 2023.
[51] M. Tegeh, I. N. Jampel, and K. Pudjawan, *Model Penelitian Pengembangan* (1st ed), Yogyakarta: Graha Ilmu, 2014.
[52] Mulyanta, & Leong, *Tutorial Membangun Multimedia Interaktif Media Pembelajaran*, Yogyakarta: Universitas Atma Jaya Yogyakarta, 2009.
[53] R. Yektyastuti and J. Ikhsan, "Pengembangan Media Pembelajaran Berbasis Android Pada Materi Kelarutan Untuk Meningkatkan Performa Akademik Peserta Didik SMA," *Jurnal Inovasi Pendidikan IPA*, vol. 5, issue 1, pp. 88–99, 1800–1809, 2016. https://doi.org/10.31004/basicedu.v6i2.2207
[54] P. Partono *et al*., "Strategi Meningkatkan Kompetensi 4C (Critical Thinking, Creativity, Communication, & Collaborative)," *Jurnal Penelitian Ilmu Pendidikan*, vol. 14, issue 1, pp. 41–52, 2021. https://doi.org/10.21831/jpipfip.v14i1.35810
[55] A. M. A. Kandari and M. M. A. Qattan, "E-task-based learning approach to enhancing 21st-century learning outcomes," *International Journal of Instruction*, 2020. https://doi.org/10.29333/iji.2020.13136a
[56] M. Supriadi and L. V. Hignasari, "Pengembangan Media Pembelajaran Berbasis Virtual Reality untuk Meningkatkan Hasil Belajar Peserta Didik Sekolah Dasar," *Jurnal KOMIK (Konferensi Nasional Teknologi Informasi Dan Komputer)*, vol. 3, issue 1, 2019. https://doi.org/10.30865/komik.v3i1.1662
[57] R. Rabiman, M. Nurtanto, and N.Kholifah, "Design and development e-learning system by Learning Management System (LMS) in vocational education," *International Journal of Scientific & Technology Research*, 2020.
[58] U. H. Salsabil *et al*., "Pemanfaatan Aplikasi Quizizz Sebagai Media Pembelajaran Ditengah Pandemi Pada Siswa SMA," *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, vol. 4, issue 2, 2020. https://doi.org/10.22437/jiituj.v4i2.11605