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IMPROVING CONCEPTUAL UNDERSTANDING IN QUANTUM PHYSICS THROUGH THE IMPLEMENTATION OF A DIGITAL VISUALIZATION-BASED ARCS-V

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Abstract
Quantum Physics is a compulsory course for Physics students that requires both mathematical and conceptual understanding. A survey of 41 Physics Education students at Sriwijaya University revealed that 85.7% experienced difficulties in learning Quantum Physics. Specifically, 79.5% struggled with formula derivations, 63.6% with problem-solving, and 47.7% with the language used. The Schrödinger equation is one of the most difficult topics as it involves the relationship between wave functions, energy, and probability. This study aimed to develop digital teaching materials based on the ARCS-V (Attention, Relevance, Confidence, Satisfaction, and Volition) motivational approach to support students' understanding of Quantum Physics concepts. The Rowntree development model was applied, consisting of planning, development, and evaluation stages, along with Tessmer's formative evaluation, including self-evaluation, expert review, one-to-one evaluation, and small group evaluation. Expert validation results showed a 97.5% (very valid) feasibility level, while student responses in the trial stage reached 89.6% (very practical). The digital visualization of the wave function $\Psi(x,t)$, eigenstates in a one-dimensional potential well, and the $|\Psi|^2$ graph effectively helped students relate the Schrödinger equation to the concepts of energy quantization and probability.

Keywords: *Quantum Physics, Schrodinger's Equations, ARCS-V, Digital Visualization*

Abstrak
Fisika Kuantum merupakan mata kuliah wajib bagi mahasiswa Fisika yang menuntut pemahaman matematis dan konseptual secara bersamaan. Berdasarkan hasil survei terhadap 41 mahasiswa Pendidikan Fisika Universitas Sriwijaya, sebanyak 85,7% mahasiswa mengalami kesulitan dalam memahami materi Fisika Kuantum. Secara spesifik, 79,5% mengalami kesulitan dalam memahami penurunan rumus, 63,6% dalam menyelesaikan latihan soal, dan 47,7% dalam memahami bahasa yang digunakan. Salah satu topik yang paling sulit dipahami adalah Persamaan Schrödinger karena melibatkan hubungan antara fungsi gelombang, energi, dan probabilitas. Penelitian ini bertujuan mengembangkan bahan ajar digital berbasis pendekatan ARCS-V (Attention, Relevance, Confidence, Satisfaction, dan Volition) untuk membantu mahasiswa memahami konsep dasar Fisika Kuantum. Metode penelitian menggunakan model pengembangan Rowntree dengan tiga tahap: perencanaan, pengembangan, dan evaluasi, serta evaluasi formatif Tessmer (self-evaluation, expert review, one-to-one evaluation, dan small group evaluation). Hasil validasi ahli menunjukkan kelayakan media sebesar 97,5% (sangat valid), sedangkan tanggapan mahasiswa pada tahap uji coba mencapai 89,6% (sangat praktis). Visualisasi digital fungsi gelombang $\Psi(x,t)$, keadaan eigen pada potensial sumur satu dimensi, dan grafik $|\Psi|^2$ membantu mahasiswa memahami keterkaitan antara Persamaan Schrödinger dengan konsep energi kuantisasi dan probabilitas.

Kata Kunci: *Fisika Kuantum, Persamaan Schrodinger, ARCS-V, Visualisasi Digital*

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INTRODUCTION

Quantum physics is a fundamental theory in physics that provides an overview and understanding of the physical properties of a particle on a very small (microscopic) scale. The phenomenon of microscopic bodies described in quantum physics is difficult to explain in classical mechanics and difficult to imagine intuitively. So there are often misconceptions among students regarding the basic concepts of quantum physics. Some examples of basic concepts that are still often misconceptionized by students are the concepts of wave-particle duality, wave functions and probability, photoelectric effects, and Heisenberg's uncertainty principle. (AJ et al., 2025; Mulyati et al., 2018; Natal Waruwu & Harefa, 2025)

Therefore, the Quantum Physics course is an important subject to be taught clearly about the ontological interpretation of each topic to face and overcome students' classical ideas about the world of physics, and avoid misconceptions. Misconceptions can occur due to conceptual errors from students' initial knowledge. So, the right teaching strategies and teaching materials are needed for students. One of them is with a conceptual approach and interactive learning. The relationship between teaching strategies and the use of interactive teaching materials leads us to recognize that there are various elements that strengthen educators' andragogy practices by expanding the various strategies used in face-to-face classes, one of which is by integrating tools such as virtual education platforms into the student learning process. (Valencia et al., 2017).

Based on the results of a survey of 41 Physics Education students at the Physics Education Study Program, Sriwijaya University, the Quantum Physics materials taught so far only use teaching materials in the form of e-books and books. According to the survey results, almost all students (85.7%) who filled out the questionnaire admitted that the teaching materials used had not helped them in understanding the Introduction to Quantum Physics material. To increase student engagement and motivation, the ARCS-V (reference) approach is used, which focuses on five motivational components: attention, relevance, confidence, satisfaction, and willingness. (Keller, 1987, 2008, 2016).

The ARCS model is a design model used to motivate students in learning, which stands for attention, relevance, confidence, satisfaction, and volition. The ARCS model states that in motivating students, teachers must (1) capture and sustain students' attention; (2) provide a statement of why students must study the material; (3) make students confident that they are capable of succeeding if they put in the effort; (4) help students feel appreciated and proud. (Keller, 1987, 2016). The ARCS model uses a systematic process that can be defined into four steps: defining, designing, developing, and evaluating. (Li & Keller, 2018). The combination of this motivational approach with interactive digital visualization is expected to help students understand the physical meaning of Schrodinger's equations conceptually, not just mathematically.

METHODS

This research uses the development research method. The development model used is the Rowntree model, which consists of three stages, namely: (1) the planning stage; (2) the development stage, and (3) the evaluation stage. At the evaluation stage, the formative evaluation proposed by Tessmer will be used. The formative evaluation stage of Tessmer consists of self-evaluation, expert review, one-to-one evaluation, and small group evaluation (Tessmer, 1993). Digital teaching materials are created using Microsoft Sway applications that combine text, animations, videos, and interactive quizzes. The focus of the material developed is the Schrodinger Equation dependent on time,andterpretation of $|\Psi|^2$, and some problems with a more detailed discussion.

Planning Stage

Before the development process, a needs analysis was conducted to identify students' learning difficulties in Quantum Physics. A preliminary survey involving 41 Physics Education students from Universitas Sriwijaya was administered. The instrument was a structured questionnaire using a Likert scale and several closed-ended items addressing students' challenges in understanding mathematical derivations, solving practice problems, and interpreting the formal language used in the subject.

The results of this needs analysis became the basis for selecting the content focus of the digital teaching material, specifically the time-dependent Schrödinger Equation, the interpretation of $|\Psi|^2$, and several example problems with detailed explanations.

Development Stage

Digital teaching materials were developed using Microsoft Sway, integrating text, animations, videos, and interactive quizzes. The design emphasized the ARCS-V motivational approach (Attention, Relevance, Confidence, Satisfaction, and Volition) to enhance student engagement and conceptual understanding. At this stage, self-evaluation was conducted by the researchers to revise the initial prototype before expert validation.

Evaluation Stage (Formative Evaluation by Tessmer)

The evaluation phase followed Tessmer's formative evaluation model, consisting of:

a. Expert Review

Two subject-matter experts and one media expert were asked to evaluate the digital teaching material using a validation sheet with a five-point Likert scale. The aspects assessed included content accuracy, clarity of explanations, media quality, and alignment with learning objectives. Expert suggestions were used to revise the product before student testing.

b. One-to-One Evaluation

Three students participated in the one-to-one evaluation to obtain initial insights into the clarity, usability, and visual attractiveness of the material. Walkthrough interviews were used to gather qualitative feedback, while practical response questionnaires were collected quantitatively.

c. Small Group Evaluation

A small group of students tested the revised product to assess practicality and user experience. Students completed a practicality questionnaire consisting of Likert-scale items evaluating ease of use, clarity, and effectiveness of visualizations (e.g., wave function animations, $|\Psi|^2$Graphs and overall satisfaction.

Data Analysis Techniques

The data obtained from *the walkthrough* interview will be analyzed descriptively, which aims to be an input to revise the digital teaching materials developed. The validation sheets given to experts to assess the products are made on a Likert scale with five categories of answers. Then, the practicality of the tested product can be seen from the acquisition of questionnaire data at the one-to-one evaluation and small group evaluation stages. Walkthrough interview and questionnaire data will be assessed based on the following calculations (1);

$$\text{Validity/Practicality Value} = \frac{\text{Total score earned}}{\text{The highest total score}} \times 100\% \quad (1)$$

Table 1. Percentage of Validity and Practicality Scores from Experts (Wiyono, 2015)

Percentage	Category
86 ≤ HVA/HEOS ≤ 100	Very Valid/Very Practical
70 ≤ HVA/ HEOS ≤ 86	Valid/Practice
56 ≤ HVA/ HEOS ≤ 70	Less Valid/Less Practical
0 ≤ HVA/ HEOS ≤ 56	Invalid/Impractical

RESULTS AND DISCUSSION

The digital teaching materials that have been created are tested for validity through the walkthrough interview method and product practicality using the one-to-one evaluation and small group evaluation methods.

Product Validity

The digital teaching materials that have been prepared are assessed for validity by two experts, namely material experts and media experts. The results show that the materials and media in the teaching materials are considered valid. The validity values given by the experts for the material and media, respectively, were 96.4 and 97.5. The aspects that received the highest rating were the suitability of the ARCS-V-based teaching material model and the suitability of visual representation with physical concepts. Expert commentary emphasizes the clarity of the equation reduction, the completeness of the sample problem, and the feasibility of animation to show the evolution of Ψ Over time. Digital teaching material products can be accessed online through *links* that can be accessed anytime and anywhere. The following is an illustration of the digital teaching material products developed (Figure 1 (a) and (b)) and an overview of the media content (Table 2).

Table 2. Media Content Outline

No	Assessment Criteria	Media
1	Schrodinger Equation	Text, Images, Animations, Videos, and PDFs
2	Statistical Interpretation	Text, Animation, Video, Google Forms
3	Probability	Text, Animation, Video, Google Forms, Images
4	Exercises	Text, PDF
5	Evaluasi	Text, Google Form

(a) (b)

Figure 1. (a) Illustration of the display of digital teaching materials. (b) Features in the Teaching Materials

In addition to the general structure displayed in Figure 1, further visualization of the developed digital module is presented in Figures 2 and 3. Figure 2 shows the main landing page of the Microsoft Sway-based material, which includes the topic introduction, learning objectives, and primary navigation components evaluated by media experts. Meanwhile, Figure 3 provides a detailed view of the navigation flow and the introductory section on the wave-function concept used in the time-dependent Schrödinger Equation. These visualizations represent the prototype interface reviewed during expert validation to ensure conceptual accuracy, clarity of explanation, and consistency of visual design with ARCS-V motivational components. The results of expert judgment confirm that the structure, content organization, and visual presentation of the digital materials are appropriate and valid for use in the next evaluation phase.

Figure 4 shows the interactive visualization section included in the digital teaching material. This section provides a dynamic representation related to the evolution of the wave function $\Psi(t)$ over time, designed to enhance learners' conceptual understanding through visual and temporal cues. Experts noted that this form of visualization supports the ARCS-V components, particularly *Attention* and *Visualization*, and strengthens the material's effectiveness in illustrating abstract quantum mechanical concepts.

The results of the validation of digital teaching material products by two experts show a very high level of feasibility. The material expert's assessment of the aspects of content suitability, depth of concept, clarity of presentation, and relationship with practice questions obtained an average score of 96.4%, included in the very valid category. The aspect that received special attention was the use of language and redaction, which were then refined based on the input of validators.

Figure 2. The interface of the digital teaching material was developed using Microsoft Sway.

(a) (b)

Figure 3. Digital visualizations integrated in the teaching material; (a) Visualization of the quantum wave function, (b) Example of an interactive student-response activity embedded in Sway.

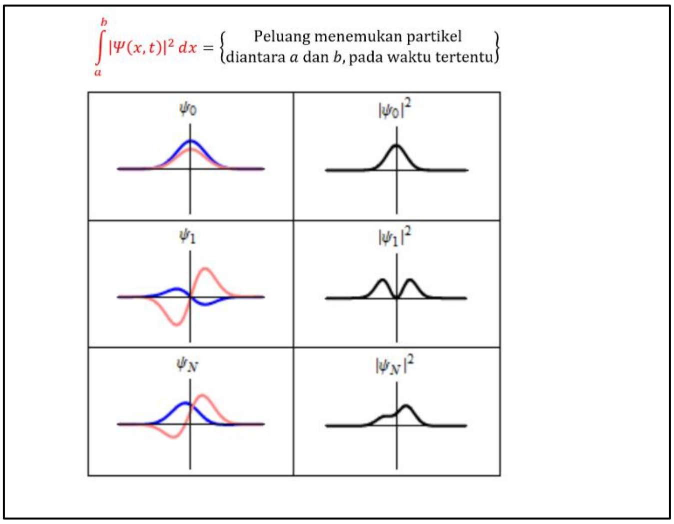

Figure 4. Digital visualization of the wave function and its probability density is integrated in the teaching material.

Meanwhile, the results of validation by media experts showed an average score of 97.5% with a very valid category. The most prominent aspects include visual appeal, precision of color selection and animation, and compatibility with the ARCS-V motivational model. These results show that the digital teaching materials developed are not only feasible in terms of content but also effective in attracting attention and increasing student learning motivation in the Schrödinger Equation Time-Dependent material.

Table 3. Results of expert validation of the Teaching Materials

Aspects Assessed	Assessment Indicators	Validator	Average Score (%)	Criteria
Suitability of learning content and outcomes	Suitability of the submaterial and clarity of presentation of the Schrödinger Equation	Material Expert	96,4	Highly Valid
Depth and relevance of material	Description of concepts and relationships with practice questions	Material Expert	96,4	Highly Valid
Language and editorial	Language clarity and writing accuracy	Material Expert	96,4	Highly Valid
Visualization and media	Attractiveness of displays, colors, and animations	Material Expert	97,5	Highly Valid
Layout and text	Clarity of font size, layout, and readability	Material Expert	97,5	Highly Valid
Compatibility with the ARCS-V model	Fulfillment of elements: Attention, Relevance, Confidence, Satisfaction, dan Volition	Material & Media Expert	97,0	Highly Valid
Total Average			96,9	Highly Valid

Practicality: One-to-one and Small Group Evaluation

The practicality of the product can be seen from the acquisition of questionnaires at the *one-to-one evaluation* stage and the *small group evaluation*. The assessment instrument is adapted to the ARCS-V aspect, which refers to the guide to developing motivational strategies in the teaching materials that Keller has written. (Keller, 2016) In his journal. The results of the practicality questionnaire showed an average of 88.6% student responses in one-to-one evaluation and 89.6% in small group evaluation, in the 'very practical' category. This evaluation assesses the ease of use, language clarity, interactivity, and motivational aspects of ARCS-V. Specifically, the ARCS-V indicator scores showed an increase in the Attention and Satisfaction components (88–89% average), while Confidence and Volition were slightly lower but remained in the good category (82–84%).

The results obtained from this study are relevant to the research conducted by Fitrianingrum (2015), which states that by including the ARCS-V motivational element in the teaching materials, students seem to be present in it so that they are interested in learning it. Similar research results were also obtained by (Karakis et al., 2016) who conducted a study on the impact of the use of computer-based teaching materials that use the ARCS-V motivation model in its design and the results showed that there was a positive change in behavior/attitude in students and an increase in learning outcomes. Research conducted by (Dhonny Prasetya Kusumajati, 2021) also shows that the application of the ARCS-V model in the learning media that he developed has a significant influence on the learning outcomes of educators. The results of this study are relevant to the results of research by (Ucar & Kumtepe, 2020) which states that the ARCS-V model is a valid and reliable framework to be applied in the online learning environment. According to (Knowles & Kerkman, 2007), online learning supports interaction between students and learning materials, students with teachers, and students with students. Research conducted by (Fitrianingrum, 2015; Huett et al., 2006; Karakis et al., 2016) also supports the claim about the effectiveness of the ARCS model as a viable strategy to improve students' motivation and performance in online learning.

The application used in developing this digital teaching material is the Sway Application. Sway is an internet-based application with various features so that when a presentation is run, it can combine text, images, videos, and sound (Widiastuti & Wiyarno, 2019). Referring to the products that the researchers produced, the Sway application can not only include text, images, videos, and sounds, but can also include powerpoint, PDF, word, animations, google forms, and links. These various media can be embedded into Sway easily as long as the media to be attached is supported by the Sway application or has an iframe link for animation products and similar forms google form. Through the Sway application, students do not need to leave the digital teaching materials link page to open various files embedded in the teaching materials because all files will be immediately able to be run/opened on the page. The features in this application also provide its own advantages for its users, such as the export feature which functions to download the material in the teaching materials into word/PDF form so that students can still read this digital teaching material without an internet connection if it has been exported.

The use of Sway-based digital teaching materials can not only increase students' motivation and interest, but also increase the effectiveness of the learning process. Based on research (Istiqomah, 2016) which has conducted an effectiveness test on its product in the form of Sway-based digital teaching materials, it was found that there was a significant increase in the learning outcomes of learners after using the product. This can be seen from the percentage of students who achieved the minimum score, which was originally only 63% to 94%. Similar results were also obtained by (Harefa et al., 2019; Junaedah & Nafiah, 2020) which obtained data that students' learning outcomes increased after using Sway learning media.

CONCLUSION

The digital teaching material development product developed is stated to be very valid and practical, and meets the motivational elements of ARCS-V in it. This digital teaching material product is suitable for use as teaching materials because it can increase motivation and make it easier for students to learn and understand Schrodinger's equation material.

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