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Developing introduction to quantum physics textbook in the syllabus of spin particles based on science, technology, engineering, and mathematics (STEM)

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Abstract. Integrating technology aspects in instruction development might provide a proper learning source for 21st-century learning. Furthermore, this study aims to produce a valid and practical Introduction to Quantum Physics textbook using science, technology, engineering, and mathematics (STEM)-based in the lesson of Spin Particles. Rowntree model is applied to produce this product—which consists of three stages: planning, developing, and evaluating stages. For evaluating phase, Tessmer formative evaluation is performed—involves self-evaluation, expert review, one-to-one, small group, and field test. Due to the research limitation—develop a valid and practical instructional, the field test is not conducted in this research. Moreover, for collecting data, the adopted techniques use walkthrough and questionnaire. Regarding the result of this research, the developed textbook is valid and practical categorized through assessment according to experts and users.

1. Introduction

Nowadays, innovation and technology play a key role as the crucial factor in determining city competitiveness [1, 2, 3]. Indonesia, for instance, decreases in terms of global competitiveness index ranking reported in World Economic Forum—declines from 37th in 2015-2016 to 41st in 2016-2017 (out of 138 countries), due to human basic needs quality (consists of health, basic education, and labor market) remains low[4]. According to [2], one of the important factors that affect the rank is soft connectivity—part of the taxonomy of cities competitiveness, which is an education-related aspect and practical use of technology.

There is a considerable amount of literature on the importance of integrating several disciplines in a learning activity. In [5,6]the authors highlight that by integrating technology and engineering component in science and mathematics both for school and academy might enhance the graduates skill to compete globally. This integrated Science, Technology, Engineering, and Mathematics (known as STEM) education provides a way to make learning become real-life oriented[7]. Furthermore, the quality of STEM education programs should reflect several features such as illustrate engineering design and problem-solving, promote inquiry, and be developed with grade-appropriate materials[8]. By this, the educators should highlight the potential merits of integrating technology in an educational activity to improve STEM learning outcome[9]. In addition, practices in undergraduate STEM Education should consider the learning content arrangement[10,11].

Several preliminary works were carried out by[12,13] which developed instructional materials in the science course for higher education and secondary school, respectively. According to [13], through facilitating learning using this developed STEM-based instructional might increase both of students

and also teachers in terms of their motivation to experience science course. Similarly, with [14], integrated STEM education in learning activity might increase student's creativity and motivation in studying Science. Moreover, learning activity using STEM-based might enhance a student's cognitive achievement [14].

Introduction to Quantum Physics is a part of the compulsory course in the Department of Physics Education in Universitas Sriwijaya. Spin particles—as a part of the area of study, furthermore, possess a potential to be developed in such teaching material using STEM-based due to its STEM component availability. These findings are determined by reviewing various journals related to this topic—the evidence shows that recent modern technologies deploy spin particles such as fermion and boson. Meanwhile, in order to develop a proper teaching material, it is crucial for deciding about the content compliant with the teaching and learning principles [4]. Regarding the related work by [12, 13, 14], in this paper, we aim to develop a valid and practical Introduction to Quantum Physics textbook in the lesson of spin particles using STEM-based.

The rest of this paper is organized as follows. Section 2 presents the research method. Section 3 outlines the developments results and reviews. Finally, section 4 offers the conclusion.

2. Research Method

This research is a Development Research which is a study for developing and validating education products such as learning tools, lessons, learning media, learning strategies, and assessments [16]. Furthermore, Rowntree Developmental model—a product-oriented developmental model [17] is used in this research. This model consists of three stages: planning, developing, and evaluating.

Prior to the actual developing of the textbook, it is first necessary for arranging the student needs. These requirements then act as a source for formulating the instructional goals. The second stage of the developing process, meanwhile, entails the topic development of Spin Particles materials. These evolved topics are then systematized into drafts. Once the drafts have been formatted, the developing process to produce the initial product (prototype 1) is ready to be conducted.

In the third and final phase, Tessmer formative evaluation is conducted for measuring the validity and practicality of the initial product. This evaluation which involves five stages (self-evaluating, expert review, one-to-one, small group, and field test) is a tool for measuring instructional materials regarding experts and users reviews [18]. Due to the research limitation—only to produce a valid and practical textbook, the field test is not performed. Figure 1 illustrates the procedure diagram of the research.

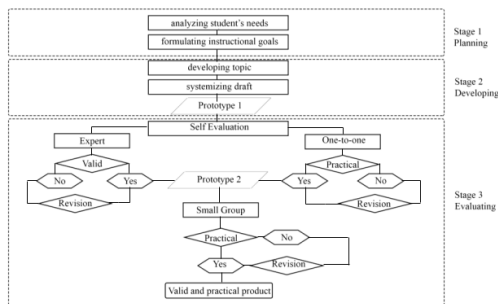


Figure 1. Diagram of Research Procedure.

This research adapts validation sheets and student questionnaires for data collection technique. Furthermore, the research divides the subject into two types: developed book during the developing stage and 8th term student of Department of Physics Education during the evaluating stage (only those who have passed the Introduction to Quantum Physics course). In order to identify product validity, therefore, experts assess the outlined aspects in validation sheets (a checklist questionnaire with five categories according to [19])—content and layout aspects. Each aspect consists of some indicators. The categories for those indicators are written in Table 1.

Table 1. Category of Validity Score

Category	Score
Excellent	5
Good	4
All Right	3
Not Good	2
Very Poor	1

Table 2. Validity Category

Average Score (\bar{X})	Criterion
$4,2 < \bar{X} \leq 5,0$	Very Valid
$3,4 < \bar{X} \leq 4,2$	Valid
$2,6 < \bar{X} \leq 3,4$	All Right
$1,8 < \bar{X} \leq 2,6$	Poor
$1,0 < \bar{X} \leq 1,8$	Very Poor

Equation (1), furthermore, shows the formula for processing the obtained data through experts review. By substituting the data to the formula, we obtain the average score. This average score determines the product category based on Table 2. While the outlined suggestions and comments in the validation sheets provide a recommendation for revising purpose.

1. Calculating the average score [19].

$$\bar{X} = \frac{\text{totalscoreofeachindicator}}{\text{totalnumberofvalidator}} \quad (1)$$

2. Determining the category of developed book's validity [20] according to Table 2.

Student's perceptions as the users, meanwhile, will decide the practical category regarding the initial product. The respondents mark the questionnaire form—adapts the Likert Scale, during the two stages: one-to-one and small group. The obtained results from these questionnaires provide data. Equation (2), moreover, reveals the conversion to achieve the average value. The resulting score stands for the developed products' practicality—based on the outlined category in Table 3. Student's comments regarding the developed textbook give the references for revision.

1. Calculating the average score from obtained data [19].

$$\bar{X} = \frac{\text{totalscoreofeachindicator}}{\text{totalnumberofrespondents}} \quad (2)$$

2. Categorizing the calculated score [20]

Table 3. Practicality Category

Average Score (\bar{X})	Criterion
$4,2 < \bar{X} \leq 5,0$	Very Practical
$3,4 < \bar{X} \leq 4,2$	Practical
$2,6 < \bar{X} \leq 3,4$	All Right
$1,8 < \bar{X} \leq 2,6$	Poor
$1,0 < \bar{X} \leq 1,8$	Very Poor

3. Result and Discussion

3.1. Planning Stage Result

This stage involves determining needs and designing learning goals phase. Regarding the result of analyzing needs, the spin lesson in Introductory to Quantum Physics course consists of STEM components and possesses the development potential into such book using STEM-based. By this, students might understand the fundamental meaning of spin by themselves due to the integrated materials with up-to-date technologies explanation.

Finally, the last phase in this stage is planning for instructional goals—designing the learning indicators and purposes. Both of components are developed from syllabus in order to produce a suitable book with existing curriculum.

3.2. Developing Stage Result

This stage consists of topic development, draft arrangement, and production of the prototype. In the topic, development phase starts with the evolving scope of material and substance of the textbook as the initial point of arranging book's draft. The related material for the content is sourced through Quantum Physics book, science-related journals, and related books. Materials' arrangement should consider the availability of science, engineering, technology, and mathematics components—Table 4 shows the existence of those elements.

Table 4. STEM Elements in the Lesson of Spin Particles.

Materials	STEM Availability			
	Science	Technology	Engineering	Mathematics
Atom and universe	✓			
Spin	✓			✓
Mathematical technique	✓			✓
Particle detector	✓	✓		
Fermion in universe	✓			
Stern-Gerlach Experiment	✓			
Pauli Exclusion Principle	✓			
Spin ½ system	✓			✓
Tomography	✓	✓	✓	
Neutrino in communication	✓	✓	✓	
Boson in universe	✓			

The books' substantial part consists of indicators, learning purposes, learning material, evaluation, and references. The textbook development in this research integrates STEM majors and compiles the content in accordance with the curriculum in the Department of Physics Education. Furthermore, this progress results in the initial product—labeled as prototype 1, which consists of three chapters: elementary particles, fermion, and boson.

3.3. Evaluating Stage Results

The developed prototype 1 is assessed by using Tessmer formative evaluation. First, in the self-evaluation phase, the researcher evaluates the product individually. During this stage, we discover several errors such as inconsistent numbering for the equation, meaningless cover (in terms of describing spin particles), and lack of materials regarding the technology application. These errors are revised before being evaluated by experts.

In the following phase, the expert review stage is required for measuring the validity—including content, design, and language. Table 5 outlines the results of this stage.

Table 5.Expert Review Results

Category	Score
STEM	4,0
Contents	4,3
Design	4,7
Language	4,7
Average	4,4
Category	Very Valid

One-to-one phase aims for analyzing the practicality regarding the initial product. In this research, this stage consists of three students with different latest cognitive achievement in the related course—high, medium, and low categorized. The obtained suggestions and comments in evaluating prototype 1 provide references for revising the product—labeled as prototype 2. After revising the product, we conduct the small group evaluation phase which involves nine students are involved and divided into three groups. This phase also intends to determine the product practicality. Table 6 written the results of both stages.

Table 6.Score Recapitulation of Determining Practicality

Indicator	Score Recapitulation	
	1	2
Content of materials	4,5	4,7
Integrated STEM components	4,3	4,6
Enhance student's motivation	4,3	4,5
Language	4,7	4,6
Total	4,5	4,6

(1 = one-to-one; 2 = small group)

The introduction to Quantum Physics textbook in the lesson of Spin Particles using STEM-based is evolved as an answer due to the urgency of 21st-century skills.

STEM proponents regard the implementation of technology and engineering aspects might increase the needs in mathematics and science courses for primary or secondary school and higher education. As a result, schools that adapt the STEM curriculum tend to produce high-skilled students in terms of global competitive skill. According to [6], the fundamental element that should be considered by educational institution either basic or higher level is the IT combination into the learning activity. The reason for this is due to technology remains the driving force aspect for the working place, community, and individual needs in the 21st century [21].

The development of educational tools might integrate STEM by using an abundance of methods such as book development, for instance. The academic institution might adjust the development for providing proper learning sources—as a preparation to enhance graduates quality [10]. American Chemical Society and McDermott, for instance, who integrated STEM into instructional materials for Chemistry and Physics subjects, respectively [10]. More recent evidence [22] produce a student's performance assessment for high school Physics lesson and [23] who develop materials for enabling student's in the robotic experiment. By this, it is apparent from the information supplied that integrating STEM discipline might be flexible for several educational tools regarding the availability of the components. Based on the mentioned research, it can be highlighted that STEM learning is possible to be implemented for any educational materials on many levels. By this, STEM is enabled for any degree.

Introduction to Quantum Physics is part of courses list in Department of Physics Education in Universitas Sriwijaya. This subject explains the natural phenomenon from fundamental particles to universal. There is a mountain of modern technology that might not be discovered without Quantum Physics scientists [24]. Quantum Physics, furthermore, has dominated technology aspect for more than

a half-century in 20th Physics development [25]. Similarly, with [26], proposes that Quantum Physics revolution has become the fundamental technology for modern society.

One of the material that included in Introduction to Quantum Physics course is Spin which is a lesson that illustrates the intrinsic angular momentum as a character of the particle. Regarding the results in content analyzing, it shows that the substance of Spin Lesson provides not only plentiful science and mathematics concepts but also involves technology as its real application. Analyzing pyramid through muon tomography, for instance, is a scanning technique using cosmic radiation of muon particle—an example of the spin $\frac{1}{2}$ particle, to produce 3D picture [25]. The technical use and comparison of the related technology represent the engineering aspect of spin particles lesson. By this, Spin lesson is potential to be developed in such instructional such as a STEM-based textbook.

Regarding the description and data analysis, the developed textbook in this research is valid and practical categorized—verified by expert (validity) and users (one-to-one and small group) for practicality. The obtained score through expert reviews shows by 4,4 with very valid categorized and the score regarding the users stands for 4,5 and 4,6 respectively with very practical categorized. This research is similar with [12] that also integrating STEM in book development for Statistical Physics lesson with valid and practical categorized by 87,31% and 85,92% respectively. In comparison with [12], although both of the developed textbooks are validly categorized in terms of the STEM component, the developed spin particles textbook provides a lower proportion compared to [12]. With regard to science and mathematics aspects illustrated in Figure 2, both of aspects proportion are similar—over than 80%. Followed by technology aspect proportion, the third largest composition—stand around to 90% and 80%, respectively, with a mere difference by 10%. On the other hand, engineering proportion for both products reveals the smallest proportion. This fact might exist due to the limitation of engineering topics that suitable for the related materials.

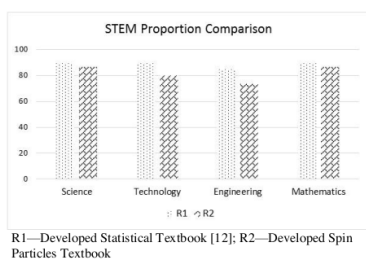


Figure 2. STEM proportion comparison with previous related research

In addition, [27] also develop a STEM-based course book for 3rd grade in secondary school specifically in the Kinematic topic—the developed book is valid, practical, and effective categorized. However, there is still a considerable issue in [27] regarding the difficulty in finding the real STEM-based problem. This issue might explain the proportion difference in Figure 2—the availability of STEM content might affect the STEM components' percentage. Although the developed spin particle textbook is lower in terms of STEM proportion compared to R1, this developed book remains valid categorized.

Regarding the users' review which is illustrated in Figure 3, it is apparent the fact that students could recognize the science, technology, engineering, and mathematics aspects in levers concept. All of the respondents in each research believe that the developed textbook using STEM-based could motivate their intention in learning related subjects.

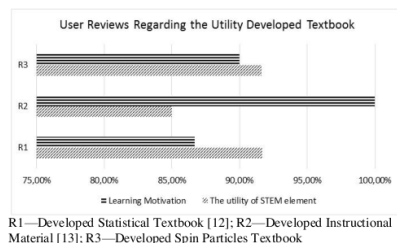


Figure 3. The comparison of user reviews regarding the developed STEM-based textbooks

Meanwhile, this introduction to Quantum Physics textbook using STEM-based in the lesson of Spin Particles also has several benefits and limitations. The benefits of this book are outlined as follows. First, this book accommodates both the technology and engineering aspects which provides additional learning sources. Second, this developed textbook is suitable for 21st-century learning which concentrates to the importance of understanding the technology. Third, this book might help students in terms of understanding the materials by themselves specifically in the lesson of spin. While the major defect in this textbook development is lack of engineering aspect—the inadequacy of engineering topics as the main obstacle in this research such as describing as a variable changing. Muon detector and Higgs Boson discovery, for instance, which is only oriented to the comparison of the technology uses—defining as technique.

4. Conclusion

The development of the textbook for Introduction to Quantum Physics in the lesson of Spin Particles using STEM-based is valid and practical categorized where the average score is measured by 4,42 and 4,5 for validity and practicality, respectively.

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PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9
