

# Systematic Quality Evaluation of Java Programming Mobile Learning Applications: A LORI-Based Assessment of Android Platforms

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## ABSTRACT

Despite the proliferation of Java programming learning applications on mobile platforms, no systematic quality-based framework has been applied to evaluate their instructional adequacy, leaving educators without reliable evidence for media selection. This study aims to systematically evaluate Java programming learning applications available on the Google Play Store to identify those most suitable for use as instructional media. A descriptive qualitative approach with structured assessment was employed, in which applications were systematically collected using predefined keywords and filtered through a six-stage elimination process prior to evaluation. The remaining 30 applications were assessed using the Learning Object Review Instrument (LORI), which evaluates seven aspects: content quality, learning objective alignment, feedback and adaptation, motivation, presentation design, interaction usability, and accessibility. Each aspect was scored on a scale of 1 to 4, and a final percentage score was calculated for each application. Of the 30 applications assessed, three achieved the highest scores: CodeGym (92), Java by Coding and Programming (90), and Java X (89), all of which demonstrated strong performance across content quality and usability dimensions. Notably, Google Play Store user ratings were found to be inversely proportional to LORI-based instructional quality scores, suggesting that popularity metrics do not reflect pedagogical value. These findings indicate that a structured, criteria-based evaluation framework is essential for educators selecting Java learning applications, and that Play Store ratings alone are insufficient as a proxy for instructional quality. Future studies are recommended to validate these findings through user testing with actual learners across multiple educational contexts.

**Keywords:** mobile learning; Java programming; application evaluation; LORI; programming education.

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## 1. INTRODUCTION

The rapid development of technological knowledge makes teaching staff such as teachers forced to keep up with the times. Especially in determining assistive devices for the learning process such as learning media. Media should be an integral part and should be in accordance with the learning process as a whole. The process of learner interaction with the selected media is the result of choosing the right learning media (Nurrita, 2018). Learning media can improve the quality of educated learning outcomes and can foster positive attitudes (Wahid, 2022). Learning media can foster positive motivation in students so that it can improve student learning outcomes (Abi Hamid et al., 2020). Learning media makes students love science more and can encourage

students to love to seek information from various sources independently and students' ability to learn from various sources will be able to increase initiative in finding their own sources of information they need in meeting information needs (Febrita & Maria, 2023). The existence of learning media helps educators to convey information to students, and with the help of the development of modern times, there are many sophisticated tools that facilitate this process (Moto et al., 2019). The use of mobile applications in learning is very effective in improving the quality of the results of the learning process in students, learning media makes it easier for teachers and students to achieve the results of the learning process (Rahmatullah et al., 2020). There is a significant difference in learning outcomes between those who use Mobile Learning and those who do not use it (Prasetyo, Y.D., Yektyastuti, R., 2015). A teacher is a facilitator for his students, of course not only inclusive of differences in students but more practically the teacher must facilitate the learning process to be more enjoyable by providing various learning media, designing and processing learning media properly (Zunidar, 2019).

Technology continues to develop as well as learning applications that are increasingly emerging, creating new challenges in keeping up with technological developments and how to use the technology. The utilization of mobile applications as learning media in the learning process shows very effective results, can be accessed anywhere and anytime making the learning process more fun and challenging (Sari, 2019). Learning applications come in various forms and features, such as mobile applications, web platforms, and computer software. In this research, there is a problem where there is no accurate and detailed reference that discusses a good Java programming language learning media application. Many applications are circulating on the Google Play Store with various features and qualities offered such as "learn java", "learn java", "java tutorial" etc. Java is a programming language that is quite popular among programmers and is widely used in making computer and smartphone programs (Efitra, 2021). Java is also well received in schools, students quite enjoy the process of learning Java programming language (Zakir, 2020). 90 percent of Fortune 500 companies use Java as a language for developing backend systems and desktop applications (Rezqiana & Sari, 2021). Not all learning applications have good quality and security, there are concerns about user security, quality of learning content and data confidentiality. The necessity of using learning apps is also an important factor in choosing learning media, some may choose for formal learning purposes at school, while others seek help in extracurricular lessons and understanding certain concepts. The proper use of android applications as learning media shows positive and significant results on student learning outcomes, from the questionnaire results obtained 80.05% positive responses during the learning process (Putra et al., 2017). Based on alpha beta research that GDP increased by 16% with the increase in digital talent in Indonesia, "for this reason, the introduction of programming in the world of education has a very important role in the development of the world of education" (Hendriyanto, 2024). The use of mobile applications as a learning medium shows good results. The application of mobile learning and informal learning methods is more effective than learning methods using laptop or book media and lecture learning (Sung et al., 2016). The use of mobile learning media shows a good percentage and the quality of learning media can affect learning outcomes and student motivation, so that the professionalism of teachers as teaching staff can make students more creative through learning media (Ardiansyah & Nana, 2020). Salem and rohaida conducted research in analyzing applications circulating in the application market to support the learning process with various programming techniques (Amro & Romli, 2019). Mobile applications for learning must fulfill several aspects, including being easy to operate, easy to understand, understandable, and interesting and must provide a pleasant experience for students. For this reason, this research will solve the problem of lack of reference in selecting Java learning applications by assessing each application circulating on the Google Play Store with the LORI assessment instrument developed by Vargo, Nesbit, Belfer, and Archambault which was further developed by Nesbit and Li in 2004 (Devi et al., 2022). This study aims to: (1) systematically evaluate Java programming learning applications on Google Play Store using the LORI framework; (2) identify applications meeting quality thresholds for instructional use; and (3) contribute an evidence-based recommendation framework for educators selecting Java learning media in formal and informal learning contexts.

## 2. RESEARCH METHOD

This study employs a descriptive qualitative approach with structured assessment, which is suited to research that aims to systematically describe and evaluate the characteristics of existing phenomena based on predetermined criteria, without the intent of constructing new theory (McCusker & Gunaydin, 2015). This approach is appropriate for the present study because the primary objective is to characterize and compare the instructional quality of Java programming learning applications available on the Google Play Store, rather than to explain causal relationships or generate grounded theoretical propositions. The structured assessment

component refers to the use of the Learning Object Review Instrument (LORI) as a standardized evaluation framework, which operationalizes quality dimensions into measurable criteria and ensures consistency across all evaluated applications (Nesbit et al., 2004). This methodological combination has been applied in comparable studies evaluating digital learning media, wherein qualitative judgment is anchored by quantified rubric scores to enhance the reproducibility and transparency of the evaluation process (Devi et al., 2022). In this study, the data studied are applications collected from the Google Play Store in the form of Java programming language learning applications. application collection is carried out using keywords that are relevant to the topic of discussion in this study without limiting the number of applications observed. The keywords used in this study are: “Learn Java”, ‘Java Tutorial’, ‘Learn Java’, ‘Java’.

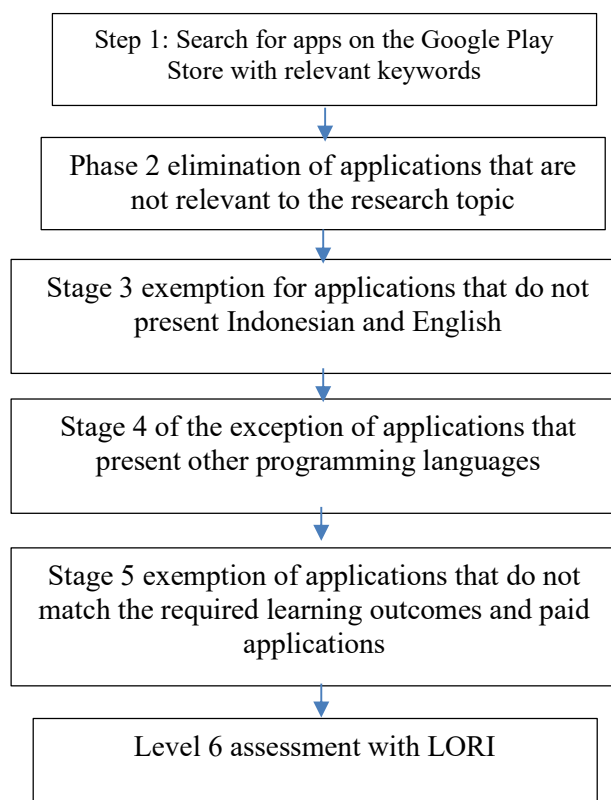


Figure 1. application analysis stages

Then the data obtained will be analyzed through 6 stages. The first stage is done by searching for applications that will be observed with keywords relevant to the research topic on the google play store, namely “Learning Java”, “Learn Java”, “Java Tutorial”. The second stage is to eliminate applications that are not relevant to the topic of discussion in this study. The third stage excludes applications that do not present English and Indonesian language options, the fourth stage eliminates applications that combine other programming language learning materials, with the aim that the application can be focused on learning Java alone. Stage five eliminated apps that did not meet the required learning outcomes and paid apps. The sixth stage is the assessment of applications that are categorized using LORI. This study exclusively utilized data from publicly available applications on the Google Play Store, including application names, features, interface displays, and user-accessible content. No personal data, user accounts, or private information were accessed or collected at any point during the research process. As all evaluated materials are publicly accessible to any registered Google Play Store user without special authorization, this study does not require formal ethical clearance from an institutional review board. Nevertheless, all applications were evaluated solely for academic and educational purposes, and the findings are intended to inform instructional media selection rather than to commercially assess or disparage any application developer.

The aspects of LORI are explained in detail to get accurate data on the value of each application in the following table:

*Table 1 The aspects of LORI*

Aspects	Description	Explanation
Quality of content or learning object	Truthfulness, diversity, accuracy, suitability of the presentation of ideas, completeness of learning aspects/elements and details of the material.	Good material content is content that is free from errors and free from bias or omissions that can mislead students. The statement submitted must be accompanied by evidence or opinions based on logic. In your presentation, highlight important ideas in sufficient detail. Ethnic and cultural differences are balanced. Learning objects vary depending on the needs and characteristics of learning outcomes.
Suitability with learning objectives	Alignment between learning objectives, activities, assessments, and student characteristics	Learning objectives are determined either in the content that students access or in the metadata provided. The learning objectives are adjusted to the target group. The learning activities, content and assessments provided by the facility are consistent with the stated objectives. The subject itself is enough to allow the student to achieve his or her learning goals
Feedback and adaptation	Adaptive content or feedback must be in accordance with the answers from students in accordance with the terms used.	The right learning object has the following characteristics: (a) targeting learning activities or messages to the needs and characteristics of students, or (b) encouraging or compiling the facts that are researched according to the response to student input.
Motivation	the ability to motivate or attract the intended learner.	Good learning objects have high motivation. Learning media has goals that are in accordance with the needs of learners and has visuals, drama, multimedia, interaction, humor, and games that are interesting for learners to fill their learning activities. The expectations and success criteria stated here are very realistic. Feedback consists of comparing student performance against predetermined standards, providing logical consequences for that performance, and explaining why student performance can be improved. After using a learning object, students usually become more interested in the topic discussed by the object.
Presentation design	Design visual and auditive information to strengthen and streamline the learning process	A good learning object has a presentation design that helps students learn effectively. The given presentation minimizes visual search. The accompanying text is easy to read. The accompanying graphics and diagrams are well-labeled and not visually distracting. The title shows that the content of the writing is clear, complete, and error-free. Colors, music, and decorative elements are for aesthetic purposes and not for educational purposes.
Usability of interaction	ease of navigation, predictability of the user interface, and quality of assistance features.	The design of the user interface implicitly conveys to learners how to use the learning media or provides explicit instructions for directing how to use it. Moving objects is easy and intuitive, and there are no undue delays.

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Accessibility	The design of controls and the format of the presentation accommodate Mobile Devices	The right learning objects can be accessed using portable devices. The application must be as easy to use and access as possible, not making it difficult for users to use the application.
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The collected applications will be assessed by the indicators contained in the LORI, each indicator will be given a score of 1 to 4. A score of 1 is for the lowest score and 4 is for the highest score of each indicator point. The final score obtained will later be used as a reference in determining the feasibility of the application as a learning medium. The final score is obtained by using the following scale to get the final score in accordance with the above instruments.

$$\frac{a}{b} \times 100 = P$$

a = Earned Score

b = maximum score

p = value result

### 3. RESULT AND ANALYSIS

#### 3.1. RESULT

This study examined Java programming learning applications collected from the Google Play Store as its primary data source. The data collection period was deliberately bound to ensure consistency in the application pool, given that the Google Play Store is a dynamic platform on which applications may be added, removed, updated, or repriced at any time. Any changes occurring to an application after the specified data collection window were not considered in this study. Application collection was carried out using keywords relevant to the research topic without imposing a minimum or maximum limit on the number of applications retrieved. The keywords used were: "Learn Java," "Java Tutorial," and "Java." Based on these keywords, 274 applications were identified and subsequently analyzed through six elimination stages. The first stage involved searching for applications using keywords. The second stage eliminated applications irrelevant to Java programming. The third stage excluded applications not available in English or Indonesian. The fourth stage removed applications combining multiple programming languages, ensuring focus on Java learning exclusively. The fifth stage eliminated applications that did not meet the required learning outcomes or required payment to download. The sixth stage subjected the remaining applications to full assessment using the Learning Object Review Instrument (LORI). The following is an explanation of the results of elimination and observation:

- a. The first stage is to search for the application on the Google Play Store with relevant keywords namely "Learn Java", "Learn Java", "Java tutorial". At this stage, 274 applications appear in the search, the applications that appear are application recommendations from the Google Play Store that are still random between Java programming applications and other programming languages, social media applications, learning applications, game applications, etc. then to get applications that are in accordance with the research topic, the application will be eliminated in the second stage.
- b. The second stage is the process of elimination of applications that are not relevant to the topic discussed in this study. This stage is carried out the elimination of applications that are not related to Java programming. At this stage, out of 274 applications, there are 187 applications that are not related to Java topics, so that there are 87 applications that are related to Java topics. The remaining applications in the second stage are a combination of program code processing applications, Java learning applications, combined programming learning applications, and sample applications of program code collections.
- c. The third stage is the process of eliminating applications that use languages other than English and Indonesian, at this stage 2 applications are obtained from 87 applications that use languages other than English and Indonesian. So that 85 applications will enter stage four.

- d. The fourth stage eliminates applications that combine other programming language learning materials, with the aim that the application can be focused on learning Java only. Of the 85 applications, 14 applications were obtained that presented other programming learning materials and the remaining 71 applications were obtained.
- e. The fifth stage is to eliminate applications that are not in accordance with the required learning outcomes and applications that are paid or must be purchased to be downloaded. At this stage, applications that do not present Java programming materials or tutorials from the introduction stage of the Java profile to the implementation of Java program code will be eliminated, including applications that only display Java program code examples. Of the 71 applications, 41 applications were obtained that did not present Java learning materials, these applications included program code sample applications, paid applications, program code processing applications. At this stage, 30 applications were obtained that will be assessed through the sixth stage with LORI (Learning Object Review Instrument).

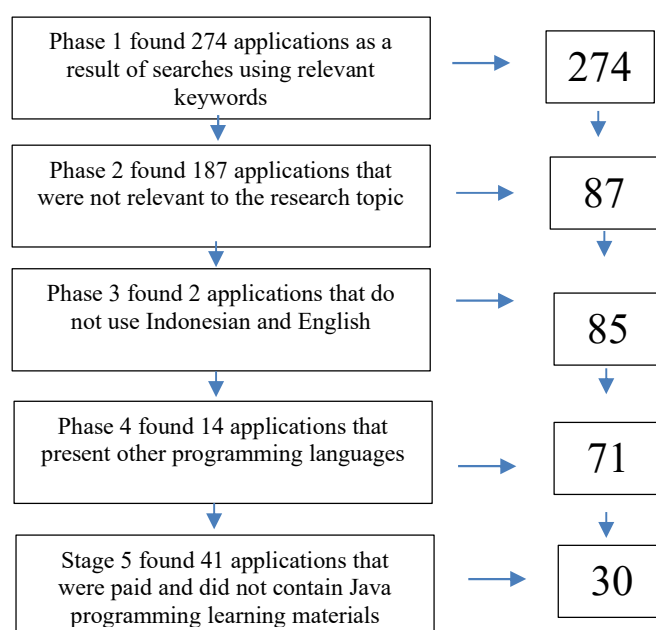


Figure 2. Details of Research Results and Elimination

Based on the assessment that has been carried out using the LORI instrument, the results of the score and final score are obtained which will later be used as a reference in determining applications that are declared suitable for use as a learning medium for the Java programming language. Here are the names and score data along with the final score obtained by each application.

Table 2. LORI assessment results

NO	APP NAME	Assessment Aspects							Sum Shoes	Value
		1	2	3	4	5	6	7		
1.	CodeGym	23	4	8	8	8	23	6	80	92
2.	Java	22	4	8	8	8	22	6	78	90
3.	Java X	22	4	8	8	7	22	6	77	89
4.	Java champ	22	1	5	8	8	21	6	71	81

5.	Learn java	20	1	5	7	7	23	6	<b>69</b>	<b>78</b>
6.	Easy coder	21	1	8	8	6	19	6	<b>69</b>	<b>78</b>
7.	Learn java	22	1	4	7	7	21	5	<b>67</b>	<b>76</b>
8.	Learn advance java	22	1	4	6	7	22	5	<b>66</b>	<b>75</b>
9.	JAVA	23	1	4	6	4	20	7	<b>65</b>	<b>74</b>
10.	Coding Dojo	21	1	7	5	7	19	5	<b>65</b>	<b>74</b>
11.	Learn java	21	1	4	6	7	20	5	<b>64</b>	<b>73</b>
12.	Java tutorial	20	1	4	6	7	20	5	<b>63</b>	<b>71,5</b>
13.	Java programming App	23	1	5	7	7	21	5	<b>63</b>	<b>71,5</b>
14.	Learn java-c programming	22	1	4	6	7	17	6	<b>63</b>	<b>71,5</b>
15.	Java Concept	22	1	4	6	5	19	6	<b>63</b>	<b>71,5</b>
16.	Learn java	21	1	4	6	5	20	5	<b>62</b>	<b>70</b>
17.	Learn java	21	1	2	6	6	19	6	<b>61</b>	<b>69</b>
18.	Core Java	21	1	2	6	7	18	5	<b>60</b>	<b>68</b>
19.	Java tutorial	19	1	2	7	7	18	5	<b>59</b>	<b>67</b>
20.	Codee	17	1	5	5	7	19	5	<b>59</b>	<b>67</b>
21.	Learn java	22	1	2	4	5	19	5	<b>58</b>	<b>66</b>
22.	Java tutorial	20	1	2	4	5	19	5	<b>57</b>	<b>65</b>
23.	Java Programming	19	1	2	4	6	17	6	<b>55</b>	<b>62,5</b>
24.	Learn Java Programming	19	1	2	4	6	18	5	<b>55</b>	<b>62,5</b>
25.	Java Book (DVK)	19	1	2	4	7	16	5	<b>54</b>	<b>61</b>
26.	Learn java in 25 hours	17	1	2	5	6	18	5	<b>54</b>	<b>61</b>
27.	Learn java language	18	1	3	4	4	17	5	<b>52</b>	<b>59</b>
28.	Java Cheat sheet	15	1	2	4	5	19	5	<b>51</b>	<b>58</b>
29.	Java for beginner	15	1	2	4	6	16	5	<b>49</b>	<b>56</b>
30.	Learn java	7	1	2	2	2	15	4	<b>37</b>	<b>42</b>

The assessment is carried out as objectively as possible by looking at various aspects of the application. The final assessment on the application is given a scale of 1-100. Based on the results of the application scores above, 5 applications with the highest scores were obtained, namely Codegym, Java, Java X, Java Champ, Learn Java. The following is an example of an assessment of one of the applications that ranks first, there is Codegym from HiTech Rush Inc which has a score of 92. The details of the assessment of each aspect of the Codegym application are explained below.

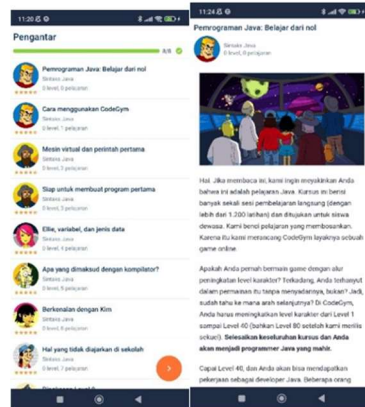


Figure 3. Capture images from the material display on the Codegym app

The application presents only material about Java programming without mixing other programming languages. The material is presented in detail by explaining each part of a code such as *packages*, *classes*, *methods*, *variables* and other code writing structures and requirements. Examples of several software that use Java in their development are given. There are 6 main materials in which there are sub-materials. The material is presented regularly from the introduction to how to write the program, each material is given an explanation and introduction. The material is presented with the help of pictures and illustrations. The material is presented with a story like a comic. Material applications are given sample program code that can be tried with *the compiler* to see the output of the program code. There is a summary on each level. The app presents content with communicative language and several parables to assist users in understanding the material.

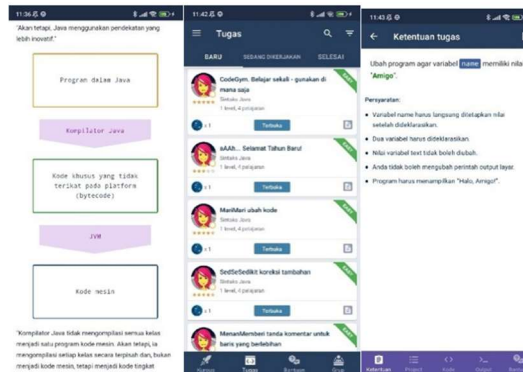


Figure 4. Learning objects in the application

The learning objects in the application are in accordance with the material presented and help improve learners' understanding. As in the image to explain the compiler is explained in a simple and easy to understand manner with the help of a diagram of the sequence of how the compiler works, each explanation is given a code example. Examples of programs are only found in the material and there are exercises in the form of code writing tasks at each level.

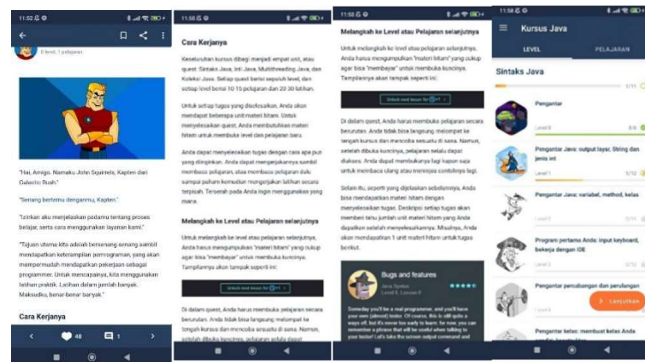


Figure 5. Learning objectives conveyed by the application

The learning objectives that the application wants to achieve are in line with the presentation of various activities and complete materials with easy-to-understand explanations and exercises to improve learners' understanding. The system leveling in the application, learners are required to study the material in order and there are practice questions that must be completed to ensure learners understand the material presented. And the material cannot be continued if the number of tasks completed is not qualified.

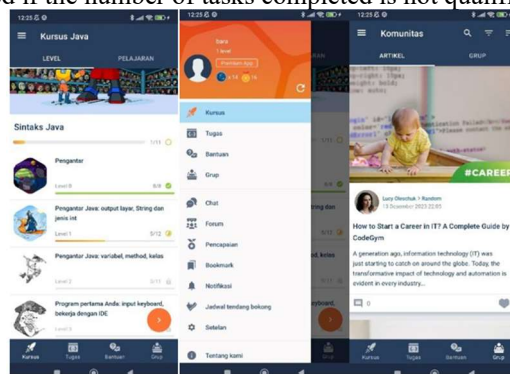


Figure 6. Attractive content and visual display

The app comes with commentary building the spirit of learning. The material is presented with a story like a comic. The material uses language that is easy to understand and presented in a complete manner. There are many choices of activities that can build the enthusiasm of users to learn the material more deeply. Features are clearly labeled according to the content of the material/content. All the main features are placed on the main page so that it is easy to choose activities. Text and images can be seen and read clearly without any visual disturbances. The interface design is made like a game with animated images as a fun decorative asset. Illustration images, text, and videos can be seen and read clearly and make it easier for users to understand the material.

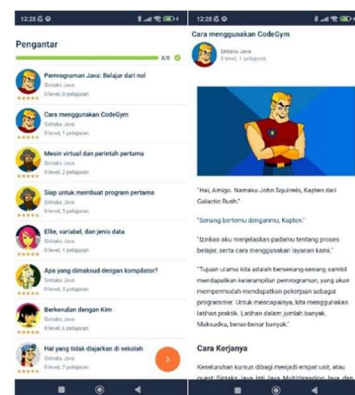


Figure 7. The design of the app informs how it operates

The app provides a guide on the first level page and a guide caption when you first install the app, as well as an interface design that informs how to interact with the app.

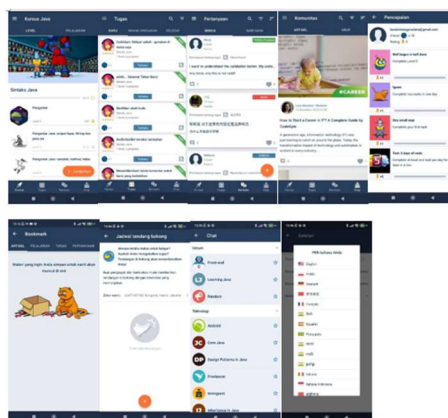


Figure 8. Usability features featured by the application

This application has many features that are featured to help users in the process of learning Java programming such as theoretical content that is leveled, tasks containing commands to compile a code with certain conditions, a discussion feature containing Q&A that contains answers to problems that users often encounter, a "from me" input feature if there are questions or problems that are not available in the Q&A feature, GRUB contains a collection of articles related to JAVA. Conversation grub is a discussion forum that connects with fellow users, Achievements that contain user learning achievement rankings, Bookmark feature to save articles, material content, assignments, questions, posts, and comments, Kick butt which is useful as a reminder or alarm for users to learn according to the specified time, chat feature to connect fellow users in discussing topics about Java, and there are several language options including Indonesian.

### 3.2. ANALYSIS

In the previous study, the results of programming suitability were obtained *Python mobile learning* on the overall indicator with a percentage of 91%. The results of the evaluation have 5 recommended applications, namely: "*Learn Python: Programmiz*", "*Learn Python Programming - Offline Tutorial*", "*Learn Python - Quiz & Top Interview Questions*", "*Python Foundation Learning : Tutorial Python*", and "*Learn Python: Tutorial Python*". (Devi et al., 2022). The assessment process is carried out by trying all applications and looking at various angles according to the assessment aspects of the instrument. Each aspect of the application is described and used as a reference in giving scores, the results of the score obtained by the application. The completeness and diversity of features provided will determine the number of scores obtained by each application. Then from the score, the applications are sorted based on the score obtained from large to small. Applications with high scores will be at the top and can be classified as the best recommended applications to use in programming language learning media *Java*. After analyzing the mobile application for Java programming language learning media, the following results were obtained:

1. Overall, the applications analyzed from 30 applications showed suitability for learning support because they had good quality in terms of material and usability.
2. All of the applications analyzed have their own advantages and disadvantages, both in terms of content quality and usability. For example, in Codegym with the highest score, there are still shortcomings in the usability aspect where the code editor feature only works according to the tasks given in the quiz questions so that users cannot write code according to their own wishes. In the second application, namely Java, only has 22 material content presented, 3 materials with video features, and errors in the audio feature that help explain the material.
3. Of the 30 applications, only 1 application was found that could not show the material, namely Learn Java from DigiBook Technologies. There was an error in the account creation verification process that caused the material to not be opened but it had several usability features that worked properly so it still got a score of 42.
4. The suitability of applications to the content quality criteria shows that most applications have good content quality, there are no errors in the delivery of information. The application with the lowest content quality score of 15 only has a limitation on the amount of material presented and there are no errors in the material presented.

5. In terms of usability, most applications meet the criteria. Most applications present theoretical and practical learning features in one application so that it can make it easier for users to learn without the need to add other applications to support the learning process. The application with the lowest score in the usability aspect only displays the material on the application without offering other features to make it easier for users to learn.
6. The evaluation of applications on the Google Play Store does not affect the results of the analysis conducted in this study and the results of the analysis show inversely proportional facts. High ratings on the Google Play Store assessment do not always show the application well based on the assessment aspect in this study, such as in the 3 applications with the highest scores, namely in the analysis results showing the order from highest to lowest, namely Codegym, Java, Java X. However, based on the Google Play Store assessment, Codegym shows that Codegym with a score of 4.8 out of 3,000 reviews but in the analysis results get a score of 92, Java with a score of 4.9 out of 30,000 reviews on the analysis got a score of 90, and Java X with a score of 5.0 out of 1,000 reviews got a score of 89 on the analysis.
7. There are 5 recommended applications that can be used as a medium for learning the Java programming language, including:

Table 3. *Recommended Applications*

No.	App Name	Value	Commentary
1.	Codegym	92	The application has a variety of materials with interesting themes, has many features to help users in learning the material, and presents a clear guide to using the application. However, the application has a drawback where the code writing feature cannot be customized according to the user's wishes.
2.	Java	90	It has a variety of material with additional basic code examples. It has an attractive interface and code writing features that can be customized according to the user's wishes. However, there is an error in the audio feature to explain the material, there are only 3 video features of the material.
3.	Java X	89	It has a variety of materials with illustration images and videos, tests in the form of quizzes and code writing. An attractive interface with clear labels. However, the code writing feature in the application is only found in the quiz at the end of the material, so it cannot be opened at any time
4.	Java champ	81	The app presents a lot of material with clear code examples and illustration images. The app's appearance is attractive and has clear labels. There are code writing features, tests in the form of quizzes or compiling code on the application to improve user understanding. However, the application has a lack of poor material structure where there is no introduction and summary of the material.

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5.	Learn Java	78	The application only presents 12 materials. However, it has an example code with a detailed explanation of how to write it. The structure of the material in the application is clear, all materials are given introductions, explanations, every detail of punctuation marks in the program code is explained its function. It has an attractive and easy-to-understand app appearance because it has clear labels. Various features ranging from materials along with code examples, quizzes, code editors, rankings based on learning outcomes.
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#### 4. CONCLUSION

This study employed a descriptive qualitative approach with structured assessment to systematically evaluate Java programming learning applications available on the Google Play Store. Through a six-stage elimination process applied to an initial pool of 274 applications, 30 applications met the predefined inclusion criteria and were subsequently assessed using the LORI framework. Overall, the application presents good quality material content without any misleading errors. The high and low ratings given by the Google Play Store do not affect the results of application analysis in this study. Because the ratings given are in the form of satisfaction with the experience of using the application based on the user's psychological and emotional conditions, not based on assessments with aspects that contain LORI. The results of the study showed that there were 5 applications that had the highest scores, namely Codegym from HiTech Rush Inc with a score of 92, Java from Coding and Programming with a score of 90, Java X from the Online institute of Java Programming with a score of 89, Java Champ from Yoan Enchev with a score of 81, and Learn Java from Programizz with a score of 78. The application has completeness in every aspect of content quality and usability determined by LORI. In other applications, there are still many shortcomings in the material that is limited or not detailed in its delivery, there are no features that help improve learners' understanding, the interface design is the same and unattractive, and there are many defects in the application.

This study acknowledges several limitations that should be considered when interpreting the findings. First, the sample was restricted to two classes at a single school. This limitation limits the generalizability of the findings to broader student populations across different schools, regions, or socioeconomic contexts in Indonesia. Second, the quasi-experimental design precludes definitive causal inference due to the absence of full randomization in assigning students to conditions; while the Non-Equivalent Control Group Design controls for some pre-existing differences through pretest measurements, unobserved between-group differences cannot be entirely ruled out. Third, several potential confounding variables were not systematically controlled in this study, including teacher enthusiasm and instructional style, students' prior experience with digital games, and students' baseline digital literacy levels — all of which may have independently influenced learning outcomes in ways that cannot be attributed solely to the Wordwall-mediated game-based learning intervention.

Considering the limitations identified above, several directions for future research are recommended. Future research should: (1) replicate this study across multiple schools and regions with diverse socioeconomic and demographic profiles to strengthen the generalizability of the findings; (2) employ true experimental designs with full random assignment of students to conditions, which would allow for more definitive causal inference regarding the effect of Wordwall-mediated game-based learning on informatics achievement; (3) investigate the long-term retention effects of GBL-Wordwall interventions through the administration of delayed post-tests conducted several weeks after the conclusion of instruction, thereby assessing whether learning gains are durable rather than transient; and (4) examine the moderating role of students' baseline digital literacy levels on GBL effectiveness, given that differential familiarity with digital game interfaces may amplify or attenuate the instructional benefits observed in the present study.

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