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Development of an Android-Based Educational Game for Early Childhood Mathematics Learning Using Fisher–Yates Shuffle

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Abstract: *This study aims to develop an Android-based educational game to support early childhood mathematics learning through an interactive approach. The game implements the Fisher–Yates Shuffle algorithm to randomize question sequences and object positions, with the goal of reducing repetition and increasing gameplay variation. The development process follows the Software Development Life Cycle (SDLC), including requirements analysis, planning, design, development, and testing. System evaluation is conducted using Black Box and White Box Testing to assess functionality and algorithm implementation. The results show that all system features operate as expected, achieving a 100% success rate with no identified errors. In addition, the Fisher–Yates Shuffle algorithm produces unique random sequences across all trials, indicating consistent randomization performance. These findings demonstrate that the developed application functions reliably and has potential as a supporting tool for early childhood mathematics learning.*

Keywords: *Android-based Educational Game, Early Childhood Education, Mathematics Learning, Fisher–Yates Shuffle Algorithm, Game-Based Learning.*

1. Introduction

Mathematics is a foundational subject that plays a vital role in education systems worldwide, including in Indonesia. It not only fosters logical reasoning and problem-solving abilities but also provides a basis for understanding a wide range of other disciplines. For this reason, introducing mathematics at an early stage is essential to equip students with the skills needed for everyday life as well as future careers. A solid grasp of fundamental concepts enables students to perform tasks more efficiently, develop confidence, and handle real-world situations that require mathematical thinking.

For early childhood, mathematics is often perceived as a challenging subject to understand [1], [2], [3]. This perception creates a challenge for teachers to develop more diverse and accessible instructional strategies. However, classroom practices indicate that some teachers still emphasize solving problems alone, rely on less effective methods, and predominantly use direct instruction without sufficiently addressing students' affective, cognitive, and psychomotor development [4], [5].

A low level of interest in learning mathematics is another significant barrier in the educational process [6]. Many students are not yet familiar with numbers, which makes it difficult for them to distinguish between them and contributes to relatively low average achievement [7]. In addition, limited instructional media further aggravates this issue. The repeated use of textbooks can lead to boredom, and students often struggle to grasp the material because they find it difficult to visualize the concepts explained by the teacher. As education continues to evolve, a range of alternative teaching approaches has emerged, offering opportunities to enhance students' understanding and learning outcomes [8].

The use of information and communication technology in education continues to expand as an alternative approach to teaching and learning, one of which is through the integration of educational games. Numerous studies indicate that educational games can enhance students' learning interest, thereby contributing to a more engaging and interactive learning environment [9], [10], [11]. As a learning medium, educational games enable students to participate actively by combining learning activities with gameplay. However, their development must be carefully structured by considering pedagogical, cognitive, and technical aspects to ensure they function not merely as entertainment but also as effective tools for improving students' knowledge and skills.

In the development process, accessibility is a critical factor to ensure that the application can be used anytime and anywhere. This can be achieved by utilizing Android-based smartphones, which are widely adopted due to their user-friendly interface and relatively affordable cost compared to other platforms.

In this study, one of the key features implemented in the educational game is the randomization of learning content, particularly mathematics questions, so that each gameplay session presents a different sequence of questions. To achieve this, the Fisher–Yates algorithm is employed as the randomization method. This algorithm is known for its efficiency in generating uniformly distributed random permutations, ensuring that the sequence of questions is unpredictable. The application of this algorithm is expected to increase the level of challenge in learning and reduce students' boredom caused by repetitive question patterns.

A previous study by Ijlal and Chotijah developed an Android-based educational game for introducing colors to early childhood learners by applying the Fisher–Yates Shuffle algorithm [12], which was shown to effectively randomize questions, colors, and object positions, thereby reducing gameplay monotony. However, the study primarily emphasized the development process using the Multimedia Development Life Cycle (MDLC) and relied solely on Black Box Testing, without conducting a more comprehensive functional evaluation or an in-depth analysis of the algorithm's implementation. In addition, there is a fundamental difference in the type and complexity of tasks, as the previous study focused on color recognition through object selection, whereas this study implements more complex activities involving counting objects and selecting the correct numerical answers, thereby engaging more advanced basic numeracy skills. Therefore, the contribution of this research lies not only in the application of the Fisher–Yates Shuffle algorithm, but also in the adoption of a more structured development approach using SDLC, a more comprehensive evaluation through both Black Box and White Box Testing, and the design of learning interactions with a higher level of cognitive complexity compared to previous work.

2.Methods

A. Algorithm Method

In this study, the Fisher-Yates shuffle method is used. The Fisher–Yates Shuffle is an algorithm used to generate a random arrangement of a finite set, originally introduced by Ronald Fisher and Frank Yates . In simple terms, it is designed to shuffle the order of elements within a dataset. This method is widely adopted due to its high efficiency and speed, making it particularly suitable for numerical data, as it can produce random permutations in a relatively short time.
In the development of educational games, the Fisher–Yates algorithm is applied to randomize the sequence of questions as well as visual elements, such as colors displayed on the screen, ensuring that each gameplay session presents a unique and non-repetitive pattern. In general, the algorithm exists in two forms: the original version and the modern version. As noted by Maulana et al. (2020) the Fisher–Yates algorithm is one of the techniques used to generate random permutations from a finite dataset [13].

The algorithm was later refined by Richard Durstenfeld in 1964 for implementation in computer systems. In this modern version, the randomization process is performed by swapping the current element with another randomly selected element from the remaining unshuffled portion, rather than removing elements from the original sequence [12]. According to Vinay Singh (2017), this approach reduces the algorithm's time complexity to O(n), making it significantly more efficient than other randomization methods, such as sorting-based techniques that involve nested loops and require greater computational time . The flowchart of the Fisher–Yates Shuffle algorithm is presented in Figure 1.

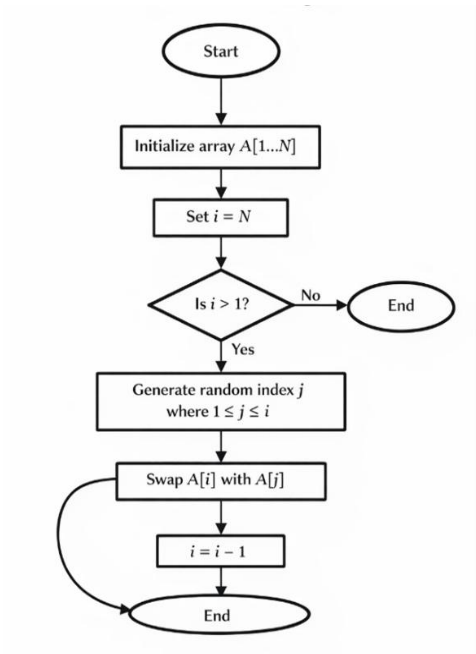

Figure 1. Flowchart of Fisher–Yates Shuffle Algorithm

The flowchart structure of the Fisher–Yates Shuffle algorithm illustrates an efficient in-place method for randomizing the elements of an array. The process begins by initializing an array containing elements from 1 to N, followed by setting an index variable i to N, which represents the boundary of the unshuffled portion. The algorithm then checks whether i is greater than 1; if not, the process terminates since all elements have been randomized. If the condition is satisfied, a random index j is selected within the range of 1 to i, and the elements at positions i and j are swapped. After the swap, the value of i is decremented to reduce the range of elements that still need to be shuffled, and this process continues iteratively until all elements have been processed. This structure is considered optimal because it operates without additional memory allocation and avoids redundant steps, resulting in a time complexity of O(n) and a space complexity of O(1), making it a standard and efficient approach for generating random permutations.

B. Research Stages

To develop a high-quality system, a structured, systematic, and practical approach is essential. Accordingly, this study adopts the Software Development Life Cycle (SDLC) as its development methodology. SDLC is chosen because it offers clearly defined, well-organized, and logically sequenced phases, ranging from requirements analysis to system maintenance. Furthermore, it is relatively easy to understand and implement, making it suitable for both small development teams and large-scale projects, while ensuring a well-controlled development process that produces software aligned with user requirements. The main objective of SDLC is to maintain software quality, control costs, manage risks, and ensure that the final system meets the specified requirements [14]. SDLC consists of six stages, as shown in Figure 2.

Figure 2. SDLC Stages

1. Requirements Analysis
   This stage focuses on systematically identifying and defining user requirements in detail, including both functional and non-functional aspects. Data collection is carried out through techniques such as interviews and observations. The results of this analysis serve as the basis for determining the design and type of educational game to be developed.
2. Planning
   During the planning phase, decisions are made regarding the development platform to be used, supporting software, and relevant development tools. In addition, this stage defines the methods or approaches to be applied in developing the educational game, along with the formulation of an implementation strategy to ensure that the application aligns with learning objectives and effectively enhances user engagement.
3. Design
   The design phase is carried out in a structured manner, encompassing key components, particularly the workflow and user interaction within the game. The system design is primarily represented through flowcharts.
4. Development
   At this stage, the previously developed design is translated into a functional application using the selected development platform.
5. Testing
   Testing is conducted to ensure that the application operates in accordance with the specified requirements. The methods employed include Black Box Testing and White Box Testing.
6. Maintenance
   The maintenance phase takes place after the application is released and aims to ensure that the system continues to operate effectively. This stage includes fixing bugs, improving performance, adding new features, and maintaining compatibility with evolving devices and operating systems.

3. Results and Discussion

A. Requirements Analysis

Requirements analysis is a critical initial stage in software development, including the design of educational games for mathematics learning. In this phase, all system requirements are systematically identified and clearly defined based on data from various sources, such as previous studies and input from stakeholders, including students, teachers, and parents. This process involves determining the necessary features, such as the learning content to be presented and the types of games that are engaging for users. In addition, non-functional aspects are also considered, including accessibility on Android devices and a child-friendly user interface design. Through a comprehensive analysis, developers can ensure that the resulting game meets user needs while providing an effective and enjoyable learning experience. This stage serves as a foundation for all subsequent development processes. The game is also designed with appealing graphics and cheerful background music to enhance user motivation. The concept of the developed educational game is presented in Table 1.

Table 1. Educational Game Concept

Description	Details
Title	Hitung Lebah (Cepat Tepat)
Genre	Educational Application
Graphics	Two-dimensional (2D) visual design
Operating System	Android
Target Audience	Early Childhood Students
Interactivity	Students are required to count the number of bees displayed and select the correct answer
Animations	Includes background elements, bee objects, and interactive answer buttons

The educational game developed in this study, titled Hitung Lebah (Cepat Tepat), is designed as a learning medium for early childhood students. The application features a two-dimensional (2D) visual design and is built on the Android platform, enabling easy access via mobile devices, in line with the widespread use of Android-based smartphones [15]. In terms of interactivity, users are required to count the number of bees displayed on the screen and select the correct answer, thereby supporting the development of basic numeracy skills. Additionally, the application incorporates animated elements such as backgrounds, bee objects, and interactive answer buttons to enhance user engagement and make the learning experience more appealing.

B. Planning

After completing the requirements analysis stage, the development process continues to the planning phase. In this phase, GameMaker is chosen as the primary platform for developing the educational game due to its widespread use, user-friendly interface, and efficiency in creating 2D games. The platform also provides GameMaker Language (GML), a scripting language that allows developers to implement more advanced game logic. Additionally, its drag-and-drop functionality facilitates the creation of game elements such as characters, objects, and environments, reducing the need for extensive coding.

During this stage, the modern Fisher–Yates Shuffle algorithm is incorporated into the educational game Hitung Lebah (Cepat Tepat) to address repetitive question patterns and monotonous gameplay. The algorithm is applied to randomize both the sequence of questions and the number of bee objects displayed at each level. For example, before the game starts, the system initializes an array containing variations in the number of bees, such as [1, 2, 3, 4, 5, 6, 7], which is then shuffled using the Fisher–Yates algorithm to generate a different arrangement each time the game is played, such as [3, 2, 6, 7, 5, 1, 4], as illustrated in Table 2.

Table 2. Example of Fisher–Yates Shuffle Algorithm Simulation

Range	Roll	Scratch	Result
		1234567	
1 - 7	4	123567	4
1 - 6	1	23567	14
1 - 5	5	2367	514
1 - 4	7	236	7514
1 - 3	6	23	67514
1 - 2	2	3	267514
	Results obtained:		**3267514**

In the gameplay design, the randomized sequence determines the order of questions at each level, preventing players from predicting the next outcome. Additionally, the same randomization approach can be applied to the positioning of the bees on the screen to create a more dynamic and visually engaging experience. Therefore, at the planning stage, the Fisher–Yates algorithm is established as a core component of the game logic to enhance variability, ensure fairness, and provide a more engaging and less repetitive learning experience for early childhood learners.

C. Design

After completing the planning stage, the next step is to conduct a comprehensive system design. In developing the educational game Hitung Lebah (Cepat Tepat), the design phase is carried out in a structured manner, covering key components, particularly the design of workflow and user interaction within the game. This system design is primarily represented using a flowchart.

The flowchart illustrates the sequence of processes in the game, from user input to the resulting output, and shows how each stage of the gameplay is organized in a logical and systematic manner. By using a flowchart, developers can better understand and visualize the overall system operation [16], [17], [18]. The system flowchart for the educational game Hitung Lebah (Cepat Tepat) is presented in Figure 3, depicting the gameplay flow from start to finish, thereby facilitating the implementation and further development process.

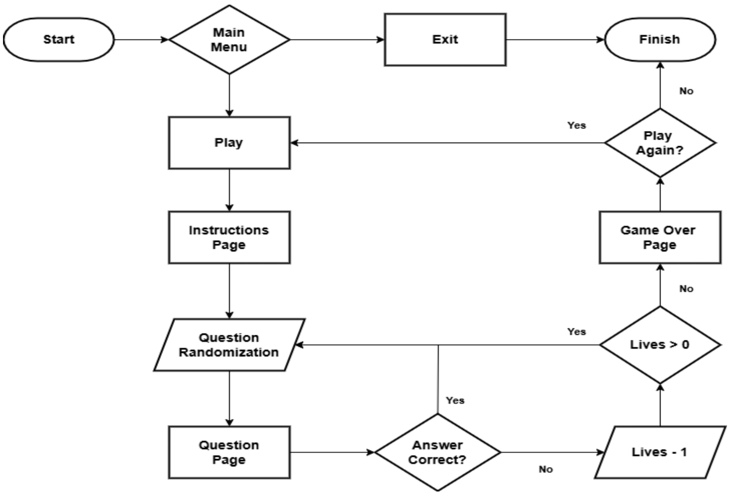

Figure 3. Flowchart of the Educational Game Hitung Lebah

The flowchart illustrates the gameplay sequence of the educational game Hitung Lebah (Cepat Tepat), starting from the Main Menu, where the player can choose to start the game or exit. If the player selects the play option, they proceed to the Instruction Page, after which the system randomizes the questions using the Fisher–Yates algorithm and displays the Question Page. The player then answers the question, and the system evaluates whether the response is correct or incorrect. If the answer is incorrect, one life is deducted; as long as the player still has remaining lives, the game continues. However, if all lives are depleted, the game transitions to the Game Over Page. At this stage, the player can choose to restart the game or exit, allowing the gameplay loop to either repeat or terminate based on the player's selection.

D. Development

This stage involves transforming the system design into a functional Android-based educational game using the GameMaker platform. The development process focuses not only on implementing visual elements but also on integrating interaction design, game mechanics, and algorithmic logic to support the learning characteristics of early childhood users.

The main interface, as shown in Figure 4, is designed to be simple and visually engaging, considering users with limited reading ability. The use of colorful visuals, familiar objects, and minimal text helps improve usability and reduce cognitive load. This approach enables intuitive navigation, allowing users to easily start or exit the game without complex interactions. Such a design aligns with Human–Computer Interaction (HCI) principles, which emphasize simplicity, clarity, and ease of use, especially for children and novice users.

Figure 4. Main Page View

The instruction page shown in Figure 5 serves as a crucial transition before gameplay by clearly presenting the game rules and objectives. The use of simple language and visual cues helps users understand the task of counting objects and selecting the correct answers. This stage ensures that users are cognitively prepared, minimizing confusion during gameplay and supporting effective learning interactions. This approach is consistent with cognitive learning principles, where clear instructions and guided interactions help reduce extraneous cognitive load and enhance task comprehension.

Figure 5. Instructions Page View

The gameplay interface, shown in Figure 6, represents the core functionality of the system, where interaction, learning, and algorithmic processes are integrated. The Fisher–Yates Shuffle algorithm is applied to dynamically randomize both the sequence of questions and the arrangement of objects in each session, preventing repetitive patterns and reducing answer memorization while encouraging active participation in counting tasks.

In addition, game mechanics such as scoring, time limits, and limited lives are incorporated to sustain user motivation and provide immediate feedback. The scoring system rewards correct answers, while penalties for incorrect responses introduce an appropriate level of challenge. These elements contribute to a more interactive and engaging learning experience. Furthermore, the integration of interaction, feedback, and challenge reflects key principles of game-based learning, where active participation and immediate feedback support effective learning. The use of randomization also aligns with engagement theory by maintaining user interest and preventing monotony.

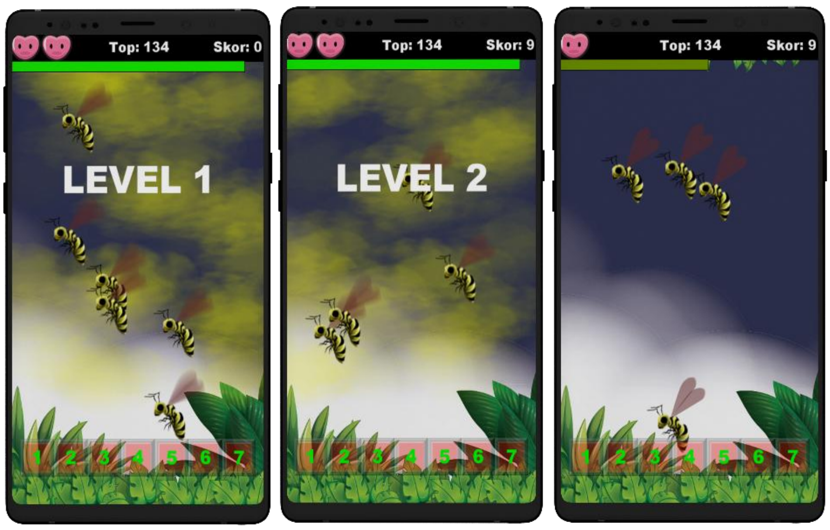

Figure 6. Question Page View

The Game Over interface shown in Figure 7 provides feedback on user performance through the display of scores and replay options. This feedback mechanism plays an important role in reinforcing learning outcomes and encouraging continued interaction. The option to restart the game enables users to encounter new randomized scenarios, further promoting engagement and repeated practice. This approach aligns with reinforcement theory, where feedback and repetition help strengthen learning behavior through continuous interaction.

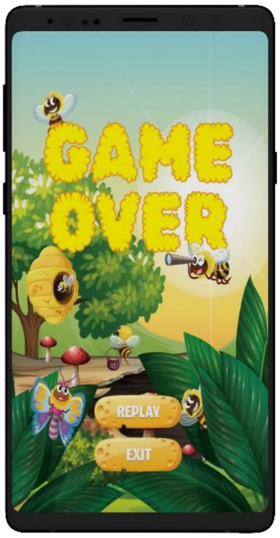

Figure 7. Game Over View

Overall, the development stage emphasizes the integration of user interface design, interaction mechanisms, and algorithmic implementation to create a functional and engaging educational application. Rather than focusing solely on visual aspects, this approach highlights how design decisions influence usability, user engagement, and learning effectiveness. The resulting system reflects a combination of educational principles, user-centered design, and algorithmic techniques, supporting both usability and engagement within the learning environment.

E. Testing

The testing phase in the development of this educational game is conducted to ensure that all features and system functions operate as intended. Two testing approaches are applied, namely Black Box Testing and White Box Testing. Black Box Testing focuses on evaluating system functionality without examining the program's internal code, emphasizing the alignment between given inputs and the resulting outputs [19], [20]. In contrast, White Box Testing examines the internal logic of the program, particularly the implementation of the Fisher–Yates algorithm, to verify that the randomization process functions correctly [21], [22], [23]. The testing results are presented in the System Testing and Evaluation Results section, as shown in Table 3.

Table 3. System Testing and Evaluation Results

No	Test Aspect	Test Scenario	Expected Result	Result	Error Rate	Notes
1	Application Stability	Run application (30 trials)	No crash or force close	Success	0%	Stable in all trials
2	Navigation Function	Move between pages	Correct page transition	Success	0%	No navigation errors
3	Answer Validation	Select correct / incorrect answers	Score/life updated correctly	Success	0%	Works as designed
4	Timer Function	Countdown during gameplay	Timer decreases consistently	Success	0%	No delay or malfunction
5	Scoring System	Accumulate points	Score increases correctly	Success	0%	Accurate calculation
6	Replay Function	Restart game	Game resets properly	Success	0%	Fully functional

7	Exit Function	Exit application	Application closes normally	Success	0%	No hanging process
8	Response Time	User interaction	<1 second response	Success	0%	Fast response
9	Fisher–Yates Shuffle	Randomize questions (30 trials)	Unique sequence each run	Success	0%	30/30 unique sequences
10	Data Consistency	Question and object display	No duplication or missing elements	Success	0%	Data integrity maintained

Based on all testing aspects, the system achieved a 100% success rate with no critical errors identified. Stability testing conducted over 30 trials showed that the application experienced neither crashes nor force closures, indicating a high level of robustness. In addition, the system's response time, which remained under one second, demonstrates that the application meets performance efficiency requirements. From an algorithmic perspective, the implementation of the Fisher–Yates Shuffle generated 30 distinct question sequences across 30 trials, indicating that the algorithm effectively produces random permutations without duplication. These findings demonstrate that the system operates correctly and exhibits strong algorithmic performance.

To further validate the quality of the randomization, a distribution analysis was conducted based on 30 trials. The distribution was measured by examining the frequency of each object appearing in the first position after the shuffling process. The Distribution of Fisher–Yates Shuffle graph is presented in Figure 8.

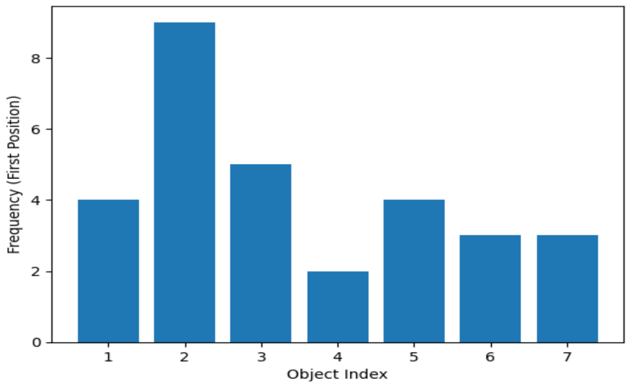

Figure 8. Distribution Of Fisher-Yates Shuffle (30 Trials)

The distribution analysis was conducted through 30 trials to evaluate the quality of randomization produced by the Fisher–Yates Shuffle algorithm. The results indicate that each element has a chance to appear in the first position with a relatively even distribution and no fixed pattern. Although minor variations in frequency are observed, these remain within acceptable limits given the limited sample size. Overall, the algorithm produces permutations that approximate a uniform distribution, thereby ensuring effective randomization, reducing repetitive patterns, and enhancing variation in the game.

F. Maintenance

The maintenance phase occurs after the application is released to ensure its continued proper operation, including bug fixes, performance enhancements, and compatibility with evolving devices and operating systems. It also involves incorporating user feedback to maintain the application's relevance. However, this study is limited to the testing phase and does not cover post-release maintenance.

4. Conclusions

This study successfully developed an Android-based educational game titled Hitung Lebah (Cepat Tepat) aimed at improving early childhood numeracy skills through an interactive and engaging learning approach. The implementation of the Fisher–Yates Shuffle algorithm proved effective in randomizing question sequences and object arrangements, thereby reducing repetitive patterns and enhancing gameplay variability. The development process, which followed the Software Development Life Cycle (SDLC), ensured a structured and systematic approach from requirements analysis to testing. Based on the results of both Black Box and White Box Testing, the system demonstrated optimal performance, with all features functioning correctly and achieving a 100% success rate without critical errors. In addition, the randomization testing showed that the algorithm generated unique sequences across all trials, indicating a near-uniform distribution and confirming its reliability for educational game applications.

However, this study is limited to the development and testing stages and does not include post-deployment evaluation or long-term learning impact analysis. Therefore, future research is recommended to assess the effectiveness of the application in real classroom settings and to explore further enhancements in adaptive learning features.

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