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The efficacy of teaching modules in enhancing students' sense of physics: Newton's laws

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Abstract: Sensemaking plays a crucial role as a bridge for students' understanding and intuition with explanations, thus addressing knowledge gaps. This bridging function helps students build new knowledge and comprehend related content materials. However, when facing physics problems, most students tend to engage in "answer-making" by presenting answers in the form of mathematical equations. This phenomenon of engaging in "answer-making" eventually causes students to perceive that physics does not "make sense." In response to this concern, a valid teaching module on improving students' sense of physics has been developed. This study is a quasi-experiment with a one-group pretest-posttest design. The posttest outcomes reveal an enhancement in the students' sense of physics among 60 students from two schools in Malang and Batu after they used the teaching module on Newton's Laws. However, when examining each indicator of students' sense of physics, further efforts are still needed to enhance the level of students' sense of physics.
Keywords: sense of physics; teaching module; newton's laws

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Introduction

It is important to recognize that sense is an essential component of learning content since it forms the basis for the construction of new knowledge and for understanding related content (Cannady et al., 2019; Katchanov & Markova, 2021). In this context, Physics sense refers to the notion of bridging students' understanding and intuition with explanations to resolve knowledge gaps or inconsistencies (Odden, 2020). Closing the gap in students' knowledge involves connecting various "pieces" of intuitive knowledge and linking explanations to everyday experiences (Sirnoorkar et al., 2023). Students' everyday experiences need to be balanced with theoretical pedagogical perspectives so that students can articulate and reinforce their knowledge explanations (Wood et al., 2018).

Studies indicate that teachers frequently neglect to modify learning materials to facilitate students' engagement in sensemaking activities (Yerdelen-Damar & Eryılmaz, 2021). Teachers' lack of attention to student sensemaking impacts the waning interest of secondary school students in physics, as they primarily encounter physics solely within the classroom setting (Kaya & Lundeen, 2010). While students are engaged in making sense of the world, teachers should meet their needs and interests, fostering their curiosity in science (Long et al., 2023). Research by Andriani and Handayani (2021) indicates that interest in physics tends to be low, as reflected in a significant decline in the number of enthusiasts for physics majors in universities. The study compared the number of enthusiasts with the capacity of physics education departments in universities in Eastern Indonesia using selection for university admission data from 2018 to 2020. The decline in interest in physics is regrettable,

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considering that physics, a fundamental discipline in the natural sciences, is a source of innovation in science and technology (Wu et al., 2022).

Students tend to lose interest in physics when confronted with challenging questions. In response to such situations, students tend to engage in "answer-making," expressing answers in the form of mathematical equations (Odden, 2020). This phenomenon indicates that students' understanding is still fragmented or inconsistent, leading them to perceive physics concepts as disconnected or nonsensical (Odden, 2021). To develop and sustain an interest in physics, active participation in the physics education system is essential (Steidtmann et al., 2023). Sustaining interest in physics can be achieved by enhancing students' sensemaking abilities, where the teacher's role involves assisting students in "grasping" the material, recognizing its relevance, and understanding its practical applications in everyday life beyond the classroom (Tomlinson & Imbeau, 2010). The objective is to provide students with the experience of addressing inconsistencies and fostering a more coherent understanding (Kuo et al., 2020).

However, most physics education has primarily focused on teaching sensemaking through demonstrations, lacking explicit sensemaking instructions in textbooks or lesson materials (Lenz et al., 2019). Meanwhile, science education researchers recommend teachers design learning activities that assist students in resolving inconsistencies, allowing them to make sense of scientific concepts and experiences more effectively (Yerdelen-Damar & Eryılmaz, 2021). For instance, the limited presentation of explicit sensemaking instructions on the topic of Newton's Second Law of motion has hindered students' understanding of the ideas embedded in the equation $\vec{F}_{nett} = m\vec{a}$ (Zhao & Schuchardt, 2021). Mechanics course requires students to confront their ideas and common sense with the taught theories (Serhane et al., 2020). This leads to a lack of sensemaking in students' mathematical and scientific knowledge.

An investigation concentrating on high school students' sense of physics involves the Modeling Instruction approach employing a whiteboard, pioneered by Megowan-Romanowicz (2016). This experimental study seeks to shift Urban Assembly Maker Academy in New York City students' behavior from merely answer-making to engaging in a sensemaking approach. Despite the demonstrated effectiveness of this instructional method, its practical application demands a considerable number of whiteboards, dry-erase markers, and a handful of shop towels. Research conducted by Sulaiman et al. (2023) found that the implementation of Project-Based Learning (PBL) led to improvements in students' sensemaking and engagement with physics learning, as measured by the Colorado Learning Attitude about Science Survey (CLASS) category, among high school students in Malaysia and South Korea. However, these studies have been limited in their coverage of diverse phenomena or problem variations to assess students' physics sensemaking comprehensively. Furthermore, phenomena might serve solely as a means to spark student interest without direct alignment with learning objectives (Long et al., 2023). Until recently, research on the sense of physics has predominantly utilized qualitative methodologies, focusing primarily on university students in the United States. There is a lack of quantitative studies offering specific guidelines on the sense of physics and strategies to enhance it, particularly among Indonesian high school students on Newton's Laws. Hence, this study seeks to examine the sensemaking abilities of high school students in physics by providing clear guidance on Newton's Laws through the teaching module.

The teaching module is structured to include general identity, Pancasila student profile, learning objectives, facilities, student characteristics, teaching materials, learning activities, assessment, teacher reflection, student reflection, worksheets, and references to Newton's Laws of motion. The learning activities adopt the Sensemaking Epistemic Game by Odden and Russ (2018), comprising: 1) assembling a knowledge framework, 2) identifying a gap or inconsistency, 3) generating an explanation, and 4) resolution. In this study, the assessment of students' physics sensemaking utilizes the Math-sci sensemaking framework by (Zhao & Schuchardt, 2021). This framework includes indicators such as description, pattern, and mechanism, which have been enhanced and integrated into a comprehensive characterization for each category by Kaldaras & Wieman (2023), encompassing three distinct levels. "Sci Description" involves the capacity to recognize specific attributes and pertinent variables for characterizing phenomena. Students engage in "Sci Pattern," identifying specific patterns among relevant variables. Students then develop a causal mechanistic explanation, "Sci Mechanism," of the phenomenon.

The research questions for this study are as follows:

1. How effective is the Teaching Module in enhancing students' physics sense?
2. How is the improvement in students' physics sense level?

Method

This research employs a quasi-experimental with a one-group pretest-posttest design to measure the level of physics sense before and after students use the teaching module on Newton's Laws as shown in Figure 1.

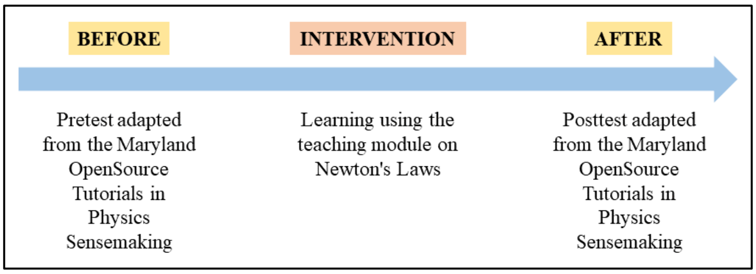


Figure 1. Research Flow Diagram

During the initial meeting, students did a pre-test adapted from the Maryland OpenSource Tutorials in Physics Sensemaking. The second to sixth meeting sessions focused on learning interventions using a teaching module on Newton's Laws. At the last meeting, a post-test was carried out to evaluate the increase in students' physics sense.

The validity of the teaching module has been verified through expert validation, with validity confirmed in both language and content suitability aspects. The language assessment by the validator yielded a score of 3.00, indicating a good level of validity. Meanwhile, the average content suitability score is 3.6, reaching a category of excellent validity.

The sampling technique employed is purposive sampling, with a sample size of 34 students from the 11th-grade Engineering program at one high school in Malang and 26 students from the 11th-grade Physics major at one high school in Batu.

The students' sense of physics was measured using pre-test and post-test questions adapted from the Maryland OpenSource Tutorials in Physics Sensemaking by Scherr and Elby (2020), specifically tailored to the subject of Newton's Laws that adjusted to match the Capaian Pembelajaran (CP) of high school students in phase F. Before employing these questions, their empirical validity, reliability, level of difficulty, and discriminatory power underwent initial testing. The pre-test and post-test data were assessed for normality using the Shapiro-Wilk test with a significance level of α=0.05, using the SPSS program. If the data met the assumption of normal distribution, parametric analysis would be conducted using the Paired Sample t-test. Yet, if the data did not adhere to a normal distribution, a non-parametric analysis would be conducted utilizing the Wilcoxon signed-rank test. The null and alternative hypotheses for this research are as follows.

Ho: There is no significant enhancement in students' sense of physics before and after learning using the teaching module.

Ha: There is a significant enhancement in students' sense of physics before and after learning using the teaching module.

Afterward, pre-test and post-test scores were examined by assessing the elevation in students' levels of physics sense as they transitioned from the pretest to the posttest, focusing on the indicators of description, pattern, and mechanism in each question.

Results and Discussion

Results of Item Analysis

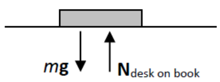
Six essays used to conduct an empirical validity test on students' physics sense. This test applied to 28 12th-grade science students in one high school in Malang who had studied Newton's Laws. Among the six questions, four are valid, while the remaining two are invalid. Based on the calculation results, question number 1 had a calculated r value of 0.917, number 2 was 0.774, number 3 was 0.909, number 4 was 0.917, number 5 was 0.000, and number 6 was 0.136.

The reliability was assessed through Cronbach's Alpha, yielding a value of 0.809. As this value exceeds 0.60, it is concluded that the six questions are considered reliable or consistent. The outcomes of the difficulty level test revealed that all six questions presented a moderate level of difficulty. On the other hand, from the differential power test results, four questions are good, one is less effective, and one needs revision. The researcher revised the question that was considered less effective and needed improvement. Figure 2 illustrates one of the questions deemed valid, reliable, moderate difficulty, and appropriate to use.

Reconciling intuition by looking at it another way: The case of normal force

Is the normal force really a "force"

A book is on the table. Physics class trains you to draw something like the free-body diagram shown here. However, two students found that the diagram does not make sense:



MARIA: On the one hand, they tell us a force is a push or pull exerted by one object on another. But the desk doesn't push on the book in the same way a person pushes on a book. The desktop just blocks the book from falling. So, although I know we're supposed to call the normal force a "force," I don't think it makes sense.

CARLOS: Along those same lines…If the book weighs 2 kg, the normal force is 2 kg. But if the book weighs 5 kg, the normal force is 5 kg. So, the normal force "adjusts." How does the desktop "know" how strong a force it needs to exert?

In terms of studying physics, how do you respond to Maria and Carlos' opinions? Explain.

Figure 2. Sense of Physics Question

Results of the Hypothesis Testing on Students' Physics Sense

Table 1 shows the results of the normality and homogeneity tests for the pretest and posttest scores of high school students in Malang and Batu.

Table 1. Results of Normality and Homogeneity Tests

School	Normality Test		Homogeneity Tests	
	Sig.	Normality	Sig.	Homogeneity
Pretest of Malang students	0.054	Normal	0.791	Homogenous
Posttest of Malang students	0.053	Normal		
Pretest of Batu students	0.133	Normal	0.765	Homogenous
Posttest of Batu students	0.151	Normal		

Based on Table 1, the Significance (Sig.) values for the pretest and posttest data in all four classes are greater than 0.05, indicating that the data distribution is normal. Moreover, the P values are greater than 0.05, so the measured data indicates homogeneity among the classes. The data is normally distributed and homogeneous, and the analysis employs parametric methods using the Paired Sample t-test. The outcomes of the Paired Sample t-test are presented in Table 2.

Table 2. Results of *Paired Sample t-Test*

School	Sig.	Interpretation
Malang high school	0.000	Ha accepted and Ho rejected
Batu high school	0.000	Ha accepted and Ho rejected

Table 2 indicates that the Significance value (2-tailed) for high schools in Malang and Batu is 0.000, which is smaller than 0.05. This result suggests that the alternative hypothesis is accepted, while the null hypothesis is rejected. Therefore, it can be concluded that there is a significant improvement in students' physics sense after participating in learning using the teaching module.

Cristina et al. (2012) illustrate sensemaking as depicted in Figure 3.

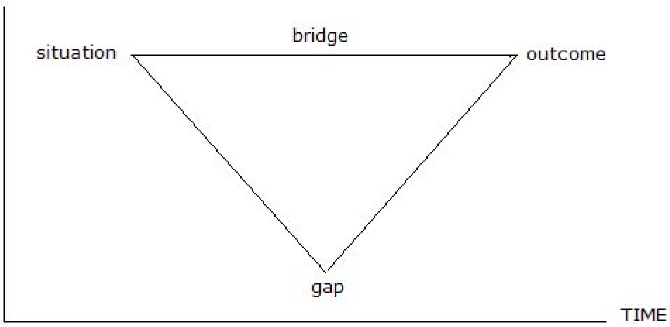


Figure 3. Triangulation of Sensemaking

Triangulation of this sensemaking focuses on three fundamental elements: situation, gap, and outcomes/utility, which are constantly moving in space and time. There are two sub-processes involved in sensemaking: construction and critique. The improvement in physics sensemaking after learning using the teaching module indicates that students have practiced constructing explanations by repeatedly coordinating (connecting) pieces of evidence to support claims. Claims are conclusions about the investigated scientific phenomena to make sense of the world, generally supported by scientific evidence or data (Aviyanti, 2020). The construction aspect essentially occurs during the connection process described in the cognitive process flow. In any case, students should carefully examine the explanation to ensure that all connected parts remain coherent with each other and that it remains coherent throughout.

Results of the Analysis of Students' Physics Sense Improvement

Figure 3 illustrates the improvement in physics sense of high school students in Malang for each indicator. Figure 3 shows the pattern of student response levels at high schools in Malang for each indicator in each case. In the pretest of case 1, all students provided answers to the description indicator question, with 88% at level 1, 12% at level 2, and no students reaching level 3. About 59% of students did not provide answers for the pattern indicator, while 41% were at level 1, and no students reached levels 2 and 3. Approximately 12% of students did not answer questions related to the mechanism indicator, while 88% of students were at level 1, and no students reached levels 2 and 3.

In the pretest of case 2, all students provided answers to the questions in the description indicator, with 88% of students at level 1, 12% at level 2, and no students reaching level 3. For questions in the pattern indicator, about 29% of students did not provide answers, 71% were at level 1, and no students reached levels 2 and 3. In the questions related to the mechanism indicator, all students provided answers and were at level 1, so no students reached levels 2 and 3.

Table 3. The Improvement in Physics Sense of High School Students in Malang

	Pre-test								Post-test					
	0	**%**	**Level 1**	**%**	**Level 2**	**%**	**Level 3**	**%**	**Level 1**	**%**	**Level 2**	**%**	**Level 3**	**%**
Case 1														
Description	0	0%	30	88%	4	12%	0	0%	0	0%	27	79%	7	21%
Pattern	20	59%	14	41%	0	0%	0	0%	33	97%	1	3%	0	0%
Mechanism	4	12%	30	88%	0	0%	0	0%	7	21%	27	79%	0	0%
Case 2														
Description	0	0%	30	88%	4	12%	0	0%	0	0%	32	94%	2	6%
Pattern	10	29%	24	71%	0	0%	0	0%	21	62%	13	38%	0	0%
Mechanism	0	0%	34	100%	0	0%	0	0%	10	29%	14	41%	10	29%

Table 4. The Improvement in Physics Sense of High School Students in Batu

	Pre-test								Post-test					
	0	**%**	**Level 1**	**%**	**Level 2**	**%**	**Level 3**	**%**	**Level 1**	**%**	**Level 2**	**%**	**Level 3**	**%**
Case 1														
Description	0	0%	24	92%	2	8%	0	0%	0	0%	25	96%	1	4%
Pattern	16	62%	10	38%	0	0%	0	0%	24	92%	2	8%	0	0%
Mechanism	3	12%	23	88%	0	0%	0	0%	4	15%	22	85%	0	0%
Case 2														
Description	0	0%	24	92%	2	8%	0	0%	0	0%	22	85%	4	15%
Pattern	9	35%	17	65%	0	0%	0	0%	14	54%	11	42%	1	4%
Mechanism	0	0%	26	100%	0	0%	0	0%	4	15%	17	65%	5	19%

In the posttest of case 1, students' responses to the description indicator increased, with 79% reaching level 2 and 21% reaching level 3. Students' answers for the pattern indicator showed that 97% were at level 1, 3% at level 2, and no students had reached level 3. For the mechanism indicator, 21% of students were at level 1, 79% were at level 2, and no students had reached level 3.

In the posttest of case 2, students' sense of physics levels for the description indicator increased, with 94% reaching level 2 and 6% reaching level 3. For questions related to the pattern indicator, 62% of students were at level 1, 38% were at level 2, and no students had reached level 3. Regarding the mechanism indicator, students' answers at level 1 were 29%, 41% were at level 2, and 29% were able to reach level 3.

The improvement in physics sense of high school students in Batu City for each indicator can be seen in Table 4. The pattern of responses from high school students in Batu City, as seen in Table 4, indicates that in pretest case 1, all students answered the questions for the description indicator, with 92% at level 1, 2% at level 2, and no students reaching level 3. About 62% of students did not answer the pattern indicator, while 38% were at level 1, and no students reached levels 2 and 3. For the mechanism indicator, 12% of students did not answer the question, while 88% were at level 1, and no students reached levels 2 and 3.

In pretest case 2, all students answered the questions for the description indicator, with 92% at level 1, 8% at level 2, and no students reaching level 3. For questions related to the pattern indicator, 35% of students did not answer, 65% were at level 1, and no students reached levels 2 and 3. On the mechanism indicator question, 26 students answered and were at level 1, so no students reached levels 2 and 3.

In posttest case 1, students' responses to the description indicator increased, with 96% reaching level 2 and 4% reaching level 3. Students' answers for the pattern indicator showed that 92% were at level 1, 8% at level 2, and no students had reached level 3. For the mechanism indicator, 15% of students were at level 1, 85% were at level 2, and no students had reached level 3.

In posttest case 2, students' understanding levels for the description indicator increased, with 85% reaching level 2 and 15% reaching level 3. For questions related to the pattern indicator, 54% of students were at level 1, 42% at level 2, and 4% of students reached level 3. Regarding the mechanism indicator, 15% of students answered at level 1, 65% were at level 2, and 19% were able to reach level 3.

Case 1 presents the phenomenon of a book on a table, where answering it requires introducing Newton's Laws I, II, and III as shown in Figure 1. Upon reviewing the pretest results, most students were at level 1, indicating that they couldn't recall Newton's Laws. Additionally, students couldn't illustrate, describe, and mention the forces at work for the book on the table. They were also unable to depict a free-body diagram for the book. However, in the posttest, students improved their answers to levels 2 and 3. This means that most students could illustrate the book on the table but were not yet able to describe the forces at work for the book on the table or draw a free-body diagram for the book. For students who reached level 3, they could describe, illustrate, and mention the forces acting on the book and table, as shown in Figure 4.

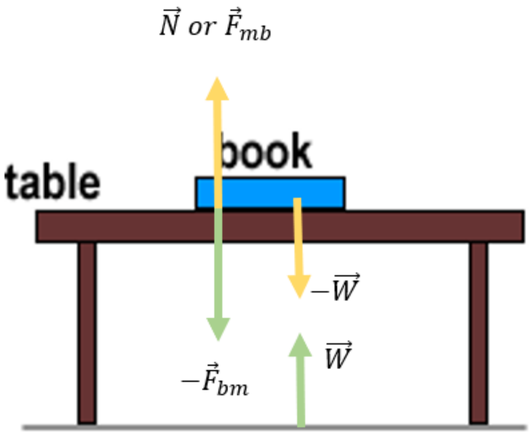


Figure 4. The Answers from Students Who Reached Level 3

Where, $\vec{N}$: normal force; $\vec{F}_{mb}$: force by the table on the book; $\vec{F}_{bm}$: force by the book on the table; and $\vec{W}$: gravitational force of the book.

Students can also draw a free-body diagram and mention that the table exerts an upward force on the book called the normal force, where the normal force is the force that prevents the book from falling off the table. This indicates that students are starting to apply strategies to make sense of their answers by making diagrams (Hahn et al., 2020).

The pattern indicator shows that most students, both in the pretest and posttest, are at level 1, and the rest are at level 2. This indicates that students cannot write the mathematical equations of Newton's Second Law and cannot explain these equations for the condition when the book is at rest. Meanwhile, a small number of students can write the mathematical equations of Newton's Second Law but cannot explain these equations for the condition when the book is at rest. A significant number of students who stay at level 1 suggest that they still lack the ability to utilize mathematical tools proficiently in depicting physical entities (Gifford & Finkelstein, 2020).

As with the pattern indicator, the mechanism indicator, most students show the same level in both the pretest and posttest. This means that most students cannot interpret the equations in a physical sense. Thus, students agree with MARIA's opinion that the normal force does not make sense. Students also cannot interpret the equations in a physical sense and cannot answer CARLOS's questions. This indicates that students concentrate solely on mathematical operations and overlook the physical significance of the mathematical symbols utilized in an equation (Hu & Rebello, 2014).

Case 2 presents the following phenomenon.

Pushing off: Does Newton's 3rd law hold?

Bob is a heavier roller skater than Alice. Bob and Alice stand facing each other. Bob places his hand on Alice's shoulder, Bob "pushes" so that the two skaters end up moving in opposite directions.

When looking at the results of the pretest for both schools on the description indicator, most students are at level 1, meaning that students cannot recall the material of Newton's Third Law. Additionally, students cannot describe and illustrate the forces at work in the condition where Bob is pushing Alice. However, when looking at the posttest results, most student responses are at level 2, indicating that students have started to recall Newton's Third Law, and they can illustrate Bob pushing Alice but have not yet been able to elaborate on the forces at work in the condition where Bob is pushing Alice. Some students can achieve level 3, so they can elaborate on and illustrate the forces at work when Bob pushes Alice. Students can also mention that right when Bob and Alice come into contact, Bob applies force to Alice, and Alice also applies force to Bob. So, when actively engaged in physics classes, students get the opportunity to share their ideas while collaboratively working together to make sense of the phenomena (Conlin, 2015).

On the pattern indicator, most students are at levels 1 and 2 for testing stages, both in the pretest and posttest. Students cannot write or can write the mathematical equations of Newton's Third Law but cannot elaborate on the equation for the condition of Bob pushing Alice. Typically, students use the "plug and chug" approach to manipulate mathematical equations without taking the fundamental principles of physics (Sand et al., 2018).

On the mechanism indicator, all students in both schools were at level 1 during the pretest. After the posttest, however, some students reached levels 2 and 3. Students who remained at level 1 could not interpret the equation physically. Thus, students assume that Bob exerts a greater force than Alice because Bob's mass is larger than Alice's mass. Students at level 2 can already interpret the equation physically, understanding that the force exerted by Bob is equal to the force exerted by Alice, but students may still be hesitant in answering questions. Students who progressed to level 3 demonstrated the ability to interpret the equation physically, understanding that the force exerted by Bob is equal to the force exerted by Alice, and they felt confident in their answers.

Students at level 1 align with the findings of Odden and Russ (2019), who discovered that one of the students in the study knew that when a car collides partially with a truck, the car is destroyed. However, Newton's Third Law states that both objects exert equal force on each other. Therefore, students wonder why such an event can happen because it doesn't make sense. Hence, it is essential to tackle not only mathematical equations or force reaction pairs but also collision-related problems (Sujarwanto & Putra, 2018). Most of students still tend to believe that the force exerted by two objects interacting or colliding with each other may not always be of equal magnitude (Suwasono et al., 2023). Additionally, they believe that "faster" or "more massive" objects exert greater force on other objects (Mansyur et al., 2020).

Conclusion

The research achieved a Significance value (2-tailed) of 0.000 for high schools in Malang and Batu, which is below 0.05. This outcome implies the acceptance of the alternative hypothesis and the rejection of the null hypothesis. Consequently, there is a significant enhancement in students' physics sense following their engagement in learning using the teaching module. Furthermore, there is a substantial elevation in the level sense of physics, especially in the description and mechanism indicators. However, the improvement in the pattern indicator is comparatively modest, as most students continue to be at level 1. Hence, efforts are still needed to elevate students' physics sense level on each indicator.

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