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The Effectiveness of E-Module STEM Biotechnology to Empower Metacognitive Skills and Science Process Skills of High School Students with Low Academic Ability in Industrial Agriculture Areas

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Abstract: Metacognitive skills are vital for empowering students, especially in subjects like biology that are intertwined with scientific activities. Science process skills are crucial for enhancing the learning process in science. This study aimed to assess the impact of STEM e-modules in Biotechnology on metacognitive and science process skills among students in the industrial agricultural sector, particularly those with low academic proficiency. The research followed a quasi-experimental, non-equivalent control group design with a pretest-posttest research structure. The study population comprised public high schools in Jember, with class XII students from SMAN 1 Jember selected as the sample through cluster random sampling and class equivalence testing using ANOVA. Data collection involved essay tests, and prerequisite tests ensured homogeneity and normality. Hypothesis testing employed a two-way ANCOVA at a 0.5% significance level. The findings revealed that significant differences in metacognitive and science process skills when STEM e-modules were used in Biotechnology material, variations in metacognitive and science process skills based on students' academic abilities, and an interaction between STEM e-modules and academic ability on metacognitive and science process skills. This research suggests exploring the effects of STEM Biotechnology e-modules and academic ability on other dependent variables.

Keywords: Biotechnology; Industrial agriculture; Metacognitive skills; Science process skills; STEM e-module

Introduction

To face the global challenges of the 21st century requires metacognitive skills (McDowell, 2019). Metacognitive skills have the potential to form quality human beings, because these skills play a very important role in helping a person to control his thinking ability, problem solving ability. According to Zhang (2017) students who develop their metacognitive abilities have the ability to understand learning better, remain open to various approaches and points of view and are able to control themselves about what they should believe and be able to control what should and should not be done (Velzen, 2015; Huzaifah et al., 2022).

The application of metacognitive skills is not only relevant in an educational context, but also has a far-reaching impact on the formation of individuals who are able to deal with the dynamics of change and the complexity of the modern world (Az-Zahra et al., 2021; Chee Choy et al., 2020). Education that pays special attention to the development of these skills will help students to become more independent, creative and adaptive thinkers, which are key attributes for success in today's globalized era (Zhang, 2018). Therefore, this research not only contributes to the level of education,

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but also has the potential to have a positive impact on students' future personal and professional development (Ningrum et al., 2021; Siswati & Corebima, 2017; Wicaksono & Widoretno, 2015).

A certain learning model is needed by teachers to train students' skills in learning biology. Learning that is supported by a teaching material will maximize the learning process carried out. According to Mithans (2020) function of textbooks or textbooks is as reference material; for educators and students, the function of textbooks for teachers is to direct all activities in the learning process as well as a substance of competence that should be taught to students. The meaning of textbooks is also usually used to support the creation of an environment or atmosphere that allows students to learn. Usually, this textbook contains learning materials that are instructional in nature and in it there is material that contains knowledge, skills, and attitudes that must be learned.

In the context of biology learning, the utilization of STEM Biotechnology electronic modules, as discussed in this study, can be an innovative and effective approach (Hidayat et al., 2023). The module can not only present learning materials in a more interactive and engaging way for students, but can also act as a tool to develop metacognitive skills and science process skills (Net et al., 2022). By integrating technology into learning, teachers can create a more dynamic learning experience and support students with low academic ability to be more engaged and successful in learning biology.

Many textbooks in the form of text books have been given to students. To face the challenges of this century, the use of IT is very necessary, this can also be used in textbooks (Wulandari, 2023). One of the IT applications in learning is the creation of e-modules. One of the benefits of e-modules is to provide solutions for students to be able to use information and communication technology wisely and provide choices for teachers to answer the challenges of technological and information advances. It is hoped that it will directly and indirectly have an impact on the world of education and learning. Electronic module learning media (e-module) is a learning media based on Flip PDF Professional which is equipped with an attractive appearance like an electronic book (Kurnianto et al., 2022). This media is in accordance with the 2013 curriculum at the senior high school level which optimizes technology in the learning process.

The use of e-modules in STEM biotechnology learning, as studied in this research, is an appropriate step in utilizing the potential of technology to improve the quality of learning. E-modules are not only an interactive source of information, but can also be a means for students with low academic ability to be actively involved in the learning process (Hidayat & Firmantika, 2020). Through the attractive appearance and technological approach used, it is expected that the e-module can provide a more interesting and in-depth learning experience, motivating students to understand biotechnology concepts better.

In Biology, one of the learning materials that can be applied to e-modules is biotechnology material. Biotechnology is a branch of science that utilizes living things (bacteria, fungi, viruses, etc.) as well as products and living things (enzymes, alcohol) in the production process to produce goods and services. This material can also be applied to STEM-based learning. The function of using STEM in learning, for example, is preparing students so that they are ready to work according to the field they are engaged in (Chen & Soldner, 2013). In addition, the use of STEM in learning will be able to increase global competitiveness in science and technological innovation and to increase understanding of education for all citizens (McDowell, 2019).

The application of biotechnology materials in e-modules provides an additional advantage, as it allows students to understand complex concepts through an interactive technological approach. Through e-modules, students can engage directly in simulations, virtual experiments and other multimedia content that enriches their learning. This not only makes learning more interesting, but also facilitates a deeper understanding of biotechnology applications in daily life and industry (Nurdiyanti & Wajdi, 2023). Thus, the use of e-modules to integrate biotechnology materials is a strategic step in improving the quality of biology education and equipping students with knowledge and skills that are relevant to the demands of the times (Jusniar, 2023).

Thus the application of STEM-based e-modules in the Biotechnology course is expected to be able to train students' abilities in terms of skills related to science process skills. Science process skills are techniques that can be used by students in obtaining information based on first experiences from student learning activities or activities (Canzi, 2016). One form of learning that can provide learning experiences is practicum activities. Biotechnology learning can accommodate simple practices for science process skills, one of which is the process of making tape, tempeh, and so on (Xu & Ouyang, 2022).

Becoming an educator is expected to be able to train students equally, both students who have high academic ability as well as students with low academic ability. Students with low academic abilities require different treatment so it is hoped that the application of learning using STEM-based e-modules can help students with low academic abilities learn, so that their understanding of the subject matter can increase.

Method

This research is categorized as quasi-experimental research. The design used is a pretest-posttest non-equivalent control group design.

Table 1. Research Table

Academic Ability/Learning	E-Module STEM Biotechnology (Y1)	Non E-Module STEM Biotechnology (Y2)
High (X1)	X1Y1	X1Y2
Low (X2)	X2Y2	X2Y2

X1Y1: Treatment of high academic abilities with Biotechnology STEM e-modules
X2Y1: Treatment of low academic ability with STEM Biotechnology e-modules
X1Y2: Treatment of high academic ability with conventional learning
X2Y2: Treatment of low academic ability with conventional learning

The population in this study were all high school students in the city of Jember for the 2022/2023 Academic Year. The determination of the sample was carried out using the Simple Random sampling technique, from 6 classes, 2 classes were selected which were used as a sample with a total of 61 students which was carried out in October - November 2022. Data collection techniques were obtained through tests given to students as the treatment class twice, namely before (pretest) and after (posttest) learning series. The research instrument was in the form of multiple-choice questions and description questions. Data analysis technique on cognitive learning outcomes is by using the scoring of multiple-choice questions and essay questions. Each raw score is converted to grades using a scale of 0–100. The prerequisite test is carried out before the hypothesis test, namely the normality test and data homogeneity as a prerequisite for parametric statistical tests. The data that has been tested for prerequisites is followed by a two-way ANACOVA test (two factors), namely to determine the main effect and interaction of the STEM Biotechnology e-module and academic ability applied to the dependent variable. Then to see the effect of differences in treatment and interaction, further tests were carried out with LSD (Least Significant Difference). To simplify the analysis of hypothesis testing, namely by using SPSS version 23 for window with a significant level of 5%. The covariance used in this study is the pretest.

Result and Discussion

The effectiveness of the Biotechnology STEM E-Module on the Metacognitive Skills of Students with Different Academic Abilities

The data obtained was carried out by testing the two-way ANCOVA hypothesis. Prior to testing the hypothesis, a prerequisite test was carried out, namely using the Kolmogorov-Smirnov test to test the normality of the data and Levene's test to test the homogeneity of the data. The results of the prerequisite test can be said that the data is normally distributed and the variance of the data is homogeneous in the control class and the experimental class. Data were analyzed with the help of SPSS 23.00 program for Windows. Table 2 shows a summary of the analysis of covariance from the influence of the STEM Biotechnology E-Module on the metacognitive skills of students with different academic abilities.

Table 2. ANCOVA Results of the Effect of the E-Module STEM Biotechnology on Metacognitive Skills

Tests of Between-Subjects Effects

Dependent Variable: YMeta

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	16089.95a	4	4022.48	301.60	0.00
Intercept	1029.30	1	1029.30	77.17	0.00
XMeta	154.40	1	154.40	11.57	0.00
Module	139.73	1	139.73	10.47	0.00
Academic	181.36	1	181.36	13.59	0.00
Module* Academic	2.27	1	2.27	0.17	0.68
Error	746.86	56	13.33		
Total	359493.97	61			
Corrected Total	16836.81	60			

a. R Squared = 0.95 (Adjusted R Squared = 0.95)

Based on table 2 it can be seen that the significant level value for the learning model is 0.002 less than 0.05. This means that the statistical hypothesis is rejected and the research hypothesis is accepted, that is, there is a difference between classes that are given the STEM Biotechnology E-Module and those that are not given it in terms of their metacognitive skills. As for academic ability, there is a significant level value of 0.001 which means it is smaller than 0.05. This means that there is a difference between students with high academic ability and students with low academic ability in relation to their metacognitive skills. However, in the interaction between the Biotechnology STEM E-Module and academic ability, the significant value is 0.681, which means greater than 0.05, meaning that there is no interaction between the Biotechnology STEM E-Module

and students' academic abilities on students' metacognitive skills.

Table 3. Corrected Average Score of Metacognitive Skills in the E-Module STEM Biotechnology

Module	XMeta	YMeta	Differences	MetaCor	LSD Notation
Experiment	47.99	88.57	40.58	81.54	a
Control	23.83	60.86	37.03	67.99	b

Based on table 3 it can be seen that the corrected mean value for the experimental class (STEM Biotechnology E-Module) is 81.54 and 67.99 for the control class. Based on the results of this study related to metacognitive skills in the experimental class before and after treatment the students increased by 84.56% and the comparison between the experimental class and the control class was 19.93%.

Table 4. Corrected Average Score of Metacognitive Skills in Different Academic Level

Academic	XMeta	YMeta	Differences	MetaCor	LSD Notation
Low	29.20	66.26	37.06	70.27	a
High	42.80	83.35	40.55	79.26	b

Based on table 4 it can be seen that the corrected average score for students with high academic ability is 79.26 and 70.27 for students with low academic ability. Based on the results of this study, students with low academic ability before and after treatment experienced an increase of 126.92% and the comparison between high and low AC was 12.79%.

Based on the results of the data analysis conducted, the researchers revealed that there were significant differences in the metacognitive skills of students who were taught using the STEM Biotechnology E-Module and those who did not use it. This is in line with research conducted by Hapsari et al. (2016) which revealed that the use of textbooks can improve the metacognitive abilities of class XI high school students. Metacognition has an important role in regulating and controlling one's cognitive processes in learning and thinking, so that one's learning and thinking becomes more effective and efficient. Metacognition includes how to reflect what we know, how to analyze what is taught, how to solve what is analyzed, and how to apply what has been learned. According to Septiyana et al. (2013) that metacognition ability can help students understand the material and solve the problems they face.

These findings provide strong support for the idea that the integration of the STEM Biotechnology E-Module in learning contributes positively to the development of students' metacognitive skills. This is not just about improving understanding of the material, but also helping students develop more effective and independent thinking strategies (Kayan-Fadlelmula et al., 2022). The use of technology in the form of STEM Biotechnology e-modules opens up new opportunities to create dynamic and inclusive learning environments, advancing education in a direction that is more adaptive to contemporary needs and challenges (Suwardi, 2021).

Metacognition knowledge and skills can be trained, taught and developed through teaching materials that can support successful learning. Teaching materials that are interesting and have the potential to empower students' knowledge and metacognitive skills are activity-based teaching materials, one of which is teaching materials oriented towards constructivist-metacognitive learning. Where students can construct their own knowledge and students can practice their metacognition abilities. Yeager et al. (2014) explained that in teacher learning that integrates what students need in learning (for example in relation to textbooks) can help develop students' metacognitive awareness. In his research, Graham et al. (2013) also explained that a professional teacher is a teacher who is able to understand the needs of students and can meet these needs in learning.

The importance of teaching materials that support this constructivistic approach highlights the important role of teachers as facilitators in developing students' metacognitive skills (Omodan, 2022). Teachers who understand students' needs and are able to provide teaching materials that are interesting and appropriate to the constructivist-metacognitive learning approach can make a major contribution to students' cognitive and metacognitive development (Jaeger & Fiorella, 2023). Therefore, investing in the development of teaching materials that support metacognition not only impacts student learning directly, but also builds a strong foundation for the long-term development of independent and critical thinking skills in students (Siswati & Corebima, 2020).

In the context of general primary and secondary education in many countries, including Indonesia, only science and mathematics subjects are part of the conventional curriculum. Meanwhile, technology and engineering subjects are only a small part or even absent in the curriculum. Therefore, STEM education is more focused on science and mathematics. According to Li, (2014) the application of STEM characteristics to the national curriculum will be maximized and can motivate teachers so that it has a positive impact on learning activities and outcomes. Deeper integration of STEM disciplines into the form of transdisciplinary subjects requires overall curriculum restructuring, making it relatively difficult to implement in the context of conventional curriculum structures in Indonesia.

Therefore, one possible integration pattern is embedding technology, engineering, and mathematics content in STEM-based science learning (Wang et al., 2022). Feola et al. (2023) in his research proved that classes that are given STEM learning can improve student learning outcomes by 39% and 46% of learning that is carried out is more effective than classes that do not use STEM.

In Indonesia, steps to integrate STEM into the national curriculum need serious attention to ensure that students can develop skills that are in line with global demands. A deeper understanding of the application of STEM in learning can provide a foundation for curriculum development that is more relevant and responsive to developments in science and technology. It can also help prepare students to enter a world of work that is increasingly connected to science, technology and engineering. At the same time, STEM-based learning opens up opportunities for improved student learning outcomes and increased global competitiveness in innovation and technology (Dökme et al., 2022).

This was also explained by (Bybee, 2013) who explained that STEM which is integrated in learning has a good impact on learning, including being able to improve students' academic abilities. In this study, it can also be seen from the results of the analysis that the academic ability of students who receive STEM Biotechnology E-Module learning increases. One of the reasons for the increase in students' academic abilities is the influence of the use of the STEM E-Module. Several related studies, for example by Roberts et al. (2012) which explain that the use of STEM in learning can increase students' domain knowledge both in the same and different disciplines. This is also supported by other research, for example by (English, 2s016).

These findings provide further understanding of the positive potential of STEM learning, particularly by utilizing E-Modules in the context of biotechnology. In addition to enriching students' knowledge, this approach also proved its positive impact on academic performance. With the direct contribution to the improvement of students' academic ability, the implementation of STEM E-Module becomes more relevant and urgent in the face of current educational dynamics. Hopefully, these findings will provide a strong foundation for the development of STEM-based learning strategies, which can not only improve students' skills in biotechnology concepts, but also promote progress in overall academic outcomes.

The Effectiveness of the Biotechnology STEM E-Module on the Science Process Skills of Students with Different Academic Abilities

As with the metacognitive skills for science process skills data, a two-way ANCOVA hypothesis test was also carried out first. Prior to testing the hypothesis, a prerequisite test was carried out, namely using the Kolmogorov-Smirnov test to test data normality and Levene's test to test data homogeneity. The results of the prerequisite test can be said that the data is normally distributed and the variance of the data is homogeneous in the control class and the experimental class. Data were analyzed with the help of SPSS 23.00 program for Windows. Table 5 shows a summary of the analysis of covariance from the influence of the STEM Biotechnology E-Module on the science process skills of students with different academic abilities.

Table 5. ANCOVA Results of the Effect of the E-Module STEM Biotechnology on Science Process Skills

Tests of Between-Subjects Effects					
Dependent Variable: YScience					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	37083.91[a]	4	9270.97	541.16	0.00
Intercept	354.71	1	354.71	20.70	0.00
XScience	1035.78	1	1035.78	60.46	0.00
Model	95.78	1	95.78	5.59	0.02
Academic	93.90	1	93.90	5.48	0.02
Model * Academic	3.96	1	3.96	0.23	0.63
Error	959.37	56	17.13		
Total	198556.88	61			
Corrected Total	38043.28	60			
a. R Squared = 0.97 (Adjusted R Squared =0.97)					

Based on table 5 it can be seen that the significant level value for learning is 0.02 less than 0.05. This means that the statistical hypothesis is rejected and the research hypothesis is accepted, that is, there is a difference between classes that are given the STEM Biotechnology E-Module and those that are not given it in terms of science process skills. As for academic ability, there is a significant level value of 0.02, which means it is smaller than 0.05. This means that there is a difference between students with high academic ability and students with low academic ability in relation to their science process skills. However, in the interaction between the Biotechnology STEM E-Module and academic ability, the significant value is 0.63, which means greater than 0.05, meaning that there is no interaction between the Biotechnology STEM E-Module and students' academic abilities towards students' science process skills.

Table 6. Corrected Average Score of Science Process skills in the E-Module STEM Biotechnology

Module	XScience	YScience	Difference	ScienceCor	LSD Notation
Experiment	54.01	73.19	19.17	56.44	a
Control	16.63	28.66	12.03	45.90	b

Based on table 6 it can be seen that the corrected mean value for the experimental class (STEM Biotechnology E-Module) is 56.44 and 45.90 for the control class. Based on the results of this study related to science process skills in the experimental class before and after treatment the students increased by 35.49% and the comparison between the experimental class and the control class was 22.94%.

Table 7. Corrected Average Score of Metacognitive Skills in different Academic level

Academic	XScience	YScience	Difference	ScienceCor	LSD Notation
Low	27.29	41.12	13.82	48.69	a
High	43.70	61.14	17.43	53.65	b

Based on table 7 it can be seen that the corrected mean score for students with high academic ability is 53.65 and 48.69 for students with low academic ability. Based on the results of this study, students with low academic ability before and after treatment experienced an increase of 50.65% and the comparison between high and low AC was 10.20%.

Based on the results of data analysis it was revealed that there was a significant influence of academic ability on students' science process skills in the industrial agricultural area. Subagyo et al. (2009) defines that science process skills are a skill in learning science which assumes that science is formed and develops through a scientific process which must also be developed in students as a meaningful experience and can be used as a provision for further self-development (Fuente et al., 2015). Bundu (2006), argues that science process skills (science process skills) are a number of skills to study natural phenomena in certain ways to gain knowledge and further development of that knowledge.

The importance of the relationship between academic ability and science process skills suggests that improved academic ability can positively contribute to the development of students' skills in understanding and exploring science concepts in industrial agriculture (Canzi, 2016). The science process taught through the STEM Biotechnology E-Module becomes increasingly relevant, not only helping students understand biotechnology concepts, but also providing a foundation for the development of essential science process skills. Thus, the implementation of E-Module in STEM Biotechnology learning is expected to create a holistic learning environment, help students link theory with real-world applications, and stimulate the development of science process skills that they can bring into various life contexts.

Karamustafaoğlu (2011) stated that being a science teacher should be aware that learning science needs to involve many things. Not just acquiring knowledge. Things that need to be involved besides knowledge can be in the form of practical skills to develop an understanding of the world around humans in the form of physical phenomena and living things. In accordance with the opinion of Tanel et al.(2011) the collection of knowledge that we call science has been built for centuries through observation, investigation and experimentation. As a science teacher, you have an obligation to teach students the skills needed to become future scientists (Susanti et al., 2023). Students need strong knowledge, but also need to have practical skills to broaden understanding of the world around them, whether it is related to physical phenomena, matter, or living things (Kurniawan et al., 2023). In the process of studying the world around science requires a skill.

In the context of STEM Biotechnology learning, where E-Modules are used as a learning tool, it is important for science teachers to integrate practical elements that include science process skills (Li et al., 2020). The use of E-Modules not only provides students with theoretical knowledge of biotechnology, but also helps them develop the practical skills needed to understand, investigate and experiment with the concepts (Pratama et al., 2023). Therefore, the integration of practical skills in science learning through E-Modules not only stimulates the understanding of concepts, but also equips students with the ability to apply their knowledge in real-life contexts. This creates a more solid foundation for science learning that is sustainable and relevant to the demands of science and technology development (Fitri, 2023).

According to Rauf et al. (2013) the study of science from a process standpoint is also called science process skills or simply science processes. In addition, according to Rauf's view further through science process skills, students can learn science like science scientists, namely observing, classifying, inferring, formulating hypotheses, and conducting experiments. According to the Big Indonesian Dictionary, skill is the ability to complete a task. In addition, Firdaus et al. (2022) stated that skill is the ability to use thought, reason and action efficiently and effectively to achieve a certain result, including creativity. In education, there are skills in the process. According to Maksong et al. (2019) process skills are skills that involve cognitive or intellectual, manual and social skills. Cognitive or intellectual skills are involved because students perform skills using their minds (Fitri & Nasir, 2023; Pandia et al., 2023). Manual skills are also involved in process skills because they involve the use of tools and materials, and social skills students can interact with fellow students in carrying out teaching and learning activities using process skills, for example discussing the results of observations (Rahmad et al., 2018).

Science Process skills are an approach used in learning. According to Ibrahim et al. (2018) explained that the process skills approach is a learning approach that aims to develop a number of physical and mental abilities as a basis for developing higher abilities in students (Purtadi & Rohaeti, 2023; Suhartini & Rachman, 2023). In addition, the process skills approach is also a treatment applied in learning that emphasizes the formation of skills to acquire scientific knowledge. It was further explained by Rauf et al. (2013), science process skills provide advantages in the learning process. Bhakti et al. (2018) revealed that the purpose of process skills in learning science is to develop students' creativity in learning so that students can actively develop and apply their abilities. In addition, the purpose of training process skills in science learning is to increase student motivation and learning outcomes, because in this training students are encouraged to participate actively and efficiently in learning, completing student learning outcomes simultaneously (Fricticarani & Maksum, 2020).

According to Semiawan, using process skills in learning, children will be able to discover and develop their own facts and develop the required attitudes and values (Andaru, et al., 2019). The use of science events in science learning helps in solving problems and making decisions, according to the statement explained in his research that is very important for students to develop understanding of, and the ability to, identify and use relevant scientific evidence in solving problems and making decisions (Andani & Utami, 2019). There are two kinds of science process skills, namely basic science process skills and skills.

The importance of developing science process skills in science learning not only helps students understand scientific concepts, but also forms critical and analytical skills that are indispensable in everyday life (Li et al., 2024). Science process skills help students to understand and apply the scientific method in exploring the world around them. Through the use of scientific events as learning tools, students are given opportunities to hone their critical thinking, observation and experimentation skills, all of which contribute to the development of scientific thinking. Therefore, this approach can help students build a strong foundation in various aspects of science process skills, from observation to analysis of scientific evidence, which can be applied in various life contexts.

Conclusion

Based on the results of this study it can be concluded that the STEM Biotechnology E-Module significantly influences students' metacognitive skills and science process skills and students' academic abilities affect metacognitive skills and science process skills. The interaction between the STEM Biotechnology E-Module and students' academic abilities has no effect on the metacognitive skills and science process skills of students who attend schools in industrial agricultural areas. Based on this research, it can be suggested that future researchers can use the STEM Biotechnology E-Module to be used in the learning process because it is proven to be able to improve students' metacognitive skills and science process skills. In addition, researchers can measure other skills as the dependent variable that tests the effectiveness of the STEM Biotechnology E-Module at the high school level.

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Author Contributions

This research team contributed to the writing of this scientific work, namely: ideas, conception, data collection, analysis and interpretation of results, manuscript preparation, article writing, revision process and funding of this research.

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Conflicts of Interest

The authors declare that there is no conflict of interest in the publication of this article.

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