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Mathematical Logic for the Development of Logical Reasoning in Engineering Students

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In this article a didactic strategy is proposed to develop logical reasoning in engineering students. This problem arose because the students in the differential calculus course did not understand certain concepts because they said they did not know how to infer. After having applied the proposal and subsequent application of the tests and questionnaires, it was observed that there was an improvement in the students when reasoning correctly.

Keywords*:* Mathematical logic; logical reasoning; mental dexterity; didactic; strategy

I. INTRODUCTION

Mathematical logic is one of the branches of mathematics that has been studied for many centuries, but if we compare mathematical logic with other branches of mathematics, such as geometry, and algebra, among others; that are much older, we can say that mathematical logic has had and has a fundamental role for the development of the different branches of mathematics and even other areas of knowledge, it is from here, that from the development of logic Mathematics, there have been significant advances in mathematics, which have allowed researchers to continuously develop this science. However, the application of mathematical logic in other areas of knowledge is true, which is why it is important to develop this ability in university students, since, from here. They are provided with tools, which will allow them to solve any problem in which they are involved. In this article, when we mention 'problems', it does not refer only to mathematical problems that involve problem-solving, it also refers to situations other than academic ones, such as social and work.

Taking into account the aforementioned, when a person says, 'I made it logically, is it correct to make this statement?', Orozco and Díaz (2009) carried out a study where they mention that people when they are faced with a situation asked' 'How did you solve it?'. They usually answer, 'I did it by logic', but the reasoning they applied is not always correct, this is why it is very important to know the meaning of logic. Sarmiento (2018), in his book on formal logic and mathematical logic, defines logic as the study of those principles and methods that make it possible to differentiate valid reasoning from apparent reasoning and that, consequently, increase the probability of thinking correctly. In other words, everything we say logic is not always logic.

To give a better understanding of the meaning of logic, Russell's paradox will be shown, which gave rise to the creation of the reasonings that are used daily:

"Suppose you work in the departmental library in your city, there you have been tasked with creating a catalogue with all the names of the existing texts in the library where you work. Once the task is finished, your boss asks if you have included the title of the same in the catalogue, it turns out that you did not do it, and it is too late to fix your mistake".

"Suppose that this situation has occurred in the last ten years with other libraries in the country, after this time, a young worker is assigned the task of creating a catalogue with the titles of all catalogues whose title has never been included. Would you include the title of the catalogue you are creating this time?".

As the catalogue that you are must does not include itself, the most logical thing is that it began by including it, with

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the problem that, by including it, that catalogue would no longer be part of the catalogues that do not include its own title, since the most reasonable is that you have to exclude it, but when you do this, you have to include it because it is a catalogue that does not include its title and this way it will repeat the loop over and over again. From this and more paradoxes, the study and advancement of the concepts of logic and mathematical logic began.

From the above-mentioned, different ways of inferring or reasoning have been developed, the main types of reasoning are inductive, deductive, and analogue.

Davila (2006), mentions that inductive reasoning is characterised because its conclusions do not necessarily derive from the premises, the two or more premises it contains are individual and its conclusion is a generalisation of the premises, for example:

"Suppose we have the following sequence: contextualising the example, I know several hypotheses, that there are several$p_1 \in J, p_2 \in J, p_3 \in J, \ldots, p_n \in J$ p they are in, applying inductive reasoning everything, that is, everything is in. $Jp \in JpJ$".

Davila (2006) also mentions that deductive reasoning is characterised because the conclusion is necessarily derived from its hypotheses and its conclusion cannot be outside the extension of any of its premises, for example:

"All mammals have lungs, all rabbits are mammals, applying deductive reasoning, it is concluded that they conclude that all rabbits have lungs".

Ramírez and Bolívar (2017) mention that analogous reasoning is the attribution of a category to a subject that is within an observed set, for example:

"Four women live in a family home: María, Andrea, Paola and Camila. We were able to determine in them that: María is tall, pretty, and intelligent; Andrea is tall, pretty, and smart; Paola is tall, pretty, and smart and Camila is tall and pretty. Applying analogous reasoning and observing that they all have the same characteristics within a set except one, by this type of reasoning we have that Camila is intelligent. It should be noted that in this type of reasoning, the conclusion may be an invalid argument.

In relation to this topic, the concept of mathematical logic will be introduced, it is a branch of mathematics that originated at the end of the 19th century and the beginning of the 20th century, in order to give a structural order to mathematics, but it has principles or notions the above-mentioned reasoning, taking into account that mathematics is considered an exact science, at the time of reasoning or inferring, deductive or inductive reasoning is used, the analogue does not apply because its conclusion is not considered in all cases, a valid argument, and this would generate endless contradictions, indeed, mathematical logic studies what happens with the truth value when two or more propositions are related, in this article we will refer to truth values, if we can determine if something Is true or false, but not both.

First, let's define what a proposition is, it is a statement that we can determine some truth value, for example:

1. All odd numbers are prime numbers.
   It is a proposition because 9 is an odd number and is not a prime, therefore its truth value is false.
2. What are you doing?
   It is a question that we cannot determine if it is true or false, therefore it is not a proposition.

Taking into account the aforementioned, relationships can be created between these propositions and since they are propositions, their relation is also a proposition and they are known as compound propositions, what is not known, and we must determine is their truth value. Suppose I am eating and doing homework propositions, then we will create relationships as follows:

- I am eating or doing homework.
- I am eating or doing homework, but not both.
- I'm eating and I'm doing homework.
- I'm eating, so I'm doing homework.
- I'm eating, yes and only yes, I'm doing homework.

Or, and, then and if and only if, they are called logical connectives, there are more connectives, but for this article, we will consider these four.

Each of these connectives has a particularity, which is commonly used with error. That is why the objective of this research is for students to use and correctly identify logical connectives, in this way when they are reading, speaking, or listening, it will allow them to have a better understanding of the topic they are dealing with.

On the other hand, in the following paragraph, the didactic tools that have been designed in any grade of schooling to develop the skills of inferring and reasoning through mathematical logic are shown, and then the importance of the development of thought will be shown. mathematical logic in students and professionals in the field of engineering.

Mathematical logic has allowed educators to potentiate reasoning and inferring skills in their students, which is why it has been essential to develop it from an early age. Alsina (2019) shows how mathematical logic allows students aged 3 to 6 years to understand abstract concepts, which are important for the successful development of the curriculum. Additionally, Espinoza *et al.* (2019) and, Granados and Padilla (2021) through the teachers who taught mathematics in preschool, observed the way in which they developed these skills in the students, and later trained them to know the importance of these and some improvement actions to be applied.

On the other hand, when students at an early age do not begin to develop these skills, it can be a disadvantage for them because in high school and middle school courses, optimal development of these skills will allow the student to understand mathematical concepts in a better way, and even these skills can be applied in other areas. But what should be done when students are in basic secondary and middle school and these skills are not developed? Many authors have created different teaching tools to stimulate and develop skills in these types of students. Medina (2017) created a strategy through ICT for his students to develop and learn about the importance of reasoning for life. Further,

In another instance, the acquisition of these skills is applied after the school stage when it is decided to study a university career. Those students who decide to study a career in the area of engineering must have a minimum development to reason correctly. Serna and Polo (2014) through their research, concluded that the development of the logical-interpretive and abstractive capacity as a basic component for the professional practice of engineers, therefore that, from the first educational cycles in engineering students, stimulate and develop reasoning skills are essential for the effective development of their university career, as well as their work performance. Furthermore, Soheila *et al.* (2012) and Granados (2021) recommend that teachers who teach a subject related to mathematics during the development of their classes and their evaluations, stimulate these skills, because in this way this objective can be achieved.

II. METHODOLOGY

The approach used for this research is qualitative because it is based on an inductive process that describes and creates conclusions from theoretical perspectives that go from the particular to the general (Hernández-Sampieri, 2010). This research seeks to collect data from the perspective and points of view of each of the participants. Hernández-Sampieri (2014) mentions that the researcher interviews a person, analyses the data obtained and from there draws some conclusions; Next, another person is interviewed, the information provided by this new participant is analysed, and the other participants continue to be interviewed, and in this way the results and conclusions are obtained from a more general perspective.

On the other hand, the research design for the development of this proposal is hermeneutical-interpretive (Hernández-Sampieri, 2014) and consists of three phases in design, the first is the choice of the topic that was selected from the work field of research the development of mathematical logic in systems engineering students, since it was observed that some systems engineering students confused the logical connectives and did not know when each of them was applied; the second phase consists of applying the proposal to the students and observing if it allows the students to have a better understanding and reasoning by applying it in their area of study and social life; the third and final phase consists of an interview.

Similarly, the population selected for the application of this research. The sample was four students from a differential calculus course at a private university located in the town of Riomar in the city of Barranquilla. The choice of the sample was given under the criteria mentioned by Hernández-Sampieri (2014), and to fulfil this purpose, a non-probabilistic sample or directed sample was selected, with a type of sampling 'voluntary or self-selected participants' which consists of Several individuals apply and are selected by the researchers according to their criteria. This type of sampling is used in qualitative studies where the objective is to deepen the experiences of each of the participants.

A. Instruments for Data Collection

The instruments that were used to collect the data for the present investigation were an initial questionnaire, a final questionnaire, a competence test, and an interview. The initial questionnaire applied a survey type to observe the previous knowledge that the students had regarding logic, the final questionnaire was applied after the application of the proposal, and in the same way as the initial questionnaire, a survey type was applied, and in this way compare in a numerical way the results. Additionally, the competence test was applied, taking into account the proposal mentioned in the previous section, which can be seen in the next section. This consists of open questions where the student applied what he learned in the proposal. Further, the interview was used to interact in an open way, making use of the type of unstructured interview, which indicates that the information obtained from it is the result of the simultaneous construction from the responses of the interviewer with the students (Hernandez-Sampieri, 2014).

B. Proposal for the Development of Logical Thinking

This section shows the proposal applied to the students. This proposal was developed as a master class through two stages. The first was called the motivational stage, which consists of the application of these connectives in society and how to identify them. The second stage, which is called the development stage, is divided into two sub-sections, the first is where students perform interactive games supported by technological tools such as PowerPoint presentations, Kahoot and Quizziz to consolidate these concepts and thus identify if the students master each of these concepts, and the second part which consists of the application of a test. This proposal allowed students to understand the basic structure of mathematical logic (see analysis and discussion of the results).

1. Understand logical connectives

To improve logical reasoning, you must understand each of the logical connectives mentioned in the introduction.

2. Logical connective O

The O is true as long as one or both propositions have true truth value, example #1:

Proposition: Maria has a boyfriend or wins the lottery.

Analysis of the proposition, it is very common to see that when we see the connective or we only choose one of the two options, and it is correct, but few know that if you choose both, it is also still correct because it is telling me that the first or the second can happen, but implicitly, both can happen and it is still true, if Maria has a boyfriend along with winning the lottery, my argument is still valid.

Example #2: Suppose you are very hungry, and you go to a restaurant for lunch, in the menu, you find the following:

- Roast beef + ripe banana = $ 25,000
- Roast beef + patacones = $ 25,000
- Roast beef + patacones or ripe banana = $ 25,000

Which of the three options do you choose?

If I am very hungry and I like to see a lot of food on my plate, I would choose the last option, taking into account that the logical connective allows me to select both, and I would pay for both what I would pay for the price of one.

3. Logical or exclusive connective

The O has truth as long as one of the propositions, but not both have true truth value.

Example #3: Let's refer to example # 2, and the restaurant owner decides to change the menu:

- Roast beef + ripe plantain or patacón, but not both = $ 25.0000
- Roast beef + French fries or fried cassava, but not both = $ 30,000

The exclusive o has the characteristic that I can choose one of the two options, and that is guaranteed when I write but not both, if you do not write that part, it can be interpreted as OR the previous point.

4. Logical connective AND

The AND is true as long as both propositions have true truth value.

Example #4: Suppose you are doing your thesis, monograph or degree project to meet the last requirement and obtain your university degree, a friend asks you, ‘What will you do after your degree work is approved?', and you answer: 'My degree work is approved and I graduate next semester'. If you observe, one proposition is linked to the other because if one is not fulfilled, the other will not be fulfilled either, because what happens if the degree work is not approved, it is not graduated, and what happens if it does not graduate, logically not he approved his degree work.

5. *Logical connective THEN*

This logical connective is widely used since it means implication, that is, you take a path, and it takes you to the desired destination, but you cannot return by that same path, it has its characteristics because if one of the propositions is false, it has veracity and if both are false, it also has veracity, for this we will perform the following example.

Example #5:

Proposition B = I have electricity in my house.

Proposition A = I am watching a movie on my television.

Relating the proposition A and B, the following is obtained:

- If A is true and B is true, we have:
  I am watching a movie on my television, so I have a light in my house.
- If A is true and B is false, we have:
  I am watching a movie at my house, so I have no light in my house.

If you look at this point, it makes no sense to be watching a movie in my house if I have no light. Therefore, this proposition is false.

- If A is false and B is true, we have:
  I'm not watching a movie on my TV, so I have a light in my house.

If you observe, the fact that I do not see a movie in my house does not imply that I have no light, but having light in my house and at the moment of wanting to see a movie, I can do it; therefore, this proposition is true.

- If A is false and B is false, we have:
  I'm not watching a movie on my TV, so I don't have a light in my house.

Taking into account that if I want to see the movie, this proposition is true because I am not watching it for the reason that I do not have electricity.

6. *Logical connective IF AND ONLY IF*

The yes and only if it is true as long as both propositions have true truth value or both propositions have false truth value, to have a better understanding of this connective, we carry out the following example:

Example #6:

Suppose we are in the year 2020; María is going to celebrate her 15 years, if and only if she was born in 2005. Unlike the logical connective then, in this, you can go from one proposition to the other in the sense you want, in addition, this connective has the particularity that it can be written as follows: Maria is going to celebrate her 15th birthday, so she was born in 2005, and Maria was born in 2005, so she is going to celebrate her 15th birthday.

7. *Apply logical connectives*

After having understood the definitions of the logical connectives, it is necessary to talk with the students and propose situations in which can be identified that in speaking and writing, the students have mastery of the subject, in this way, the students will appropriate each of these concepts. Subsequently, a test will be applied where students put what they have learned into practice.

Proof:

- Write a short essay on any topic where you apply at least three times each of the logical connectives.
- 'What can be inferred from the following statement?': You cannot enter the classroom eating or drinking soda.
- Yesterday I was 15 years old, and next year I will be 16 years old. If my birthday is tomorrow. On what day and month was I born?
- Five women, when questioned about a crime committed by one of them, stated the following:
  María: It was Camila.
  Andrea: It was Maria.
  Camila: Maria is lying.
  Paola: I didn't go.
  Carla: I went.

If only one of them is telling the truth, who committed the crime?

- A man is asked the time, and he answers: "In 20 minutes, my watch will show 10:52." If the clock is 5 minutes ahead of actual time, what time was it exactly 10 minutes ago?
- Maria, who is 1 year less than one day older than Andrea, was born on January 1, 2010. What day was Andrea born?
- If the day before yesterday of tomorrow the day after tomorrow is Tuesday, what day was yesterday the day before yesterday?

III. ANALYSIS AND DISCUSSION OF THE RESULTS

This section will analyse the results of the proposal and the interview with the students. It will begin by analysing the results of the proposal.

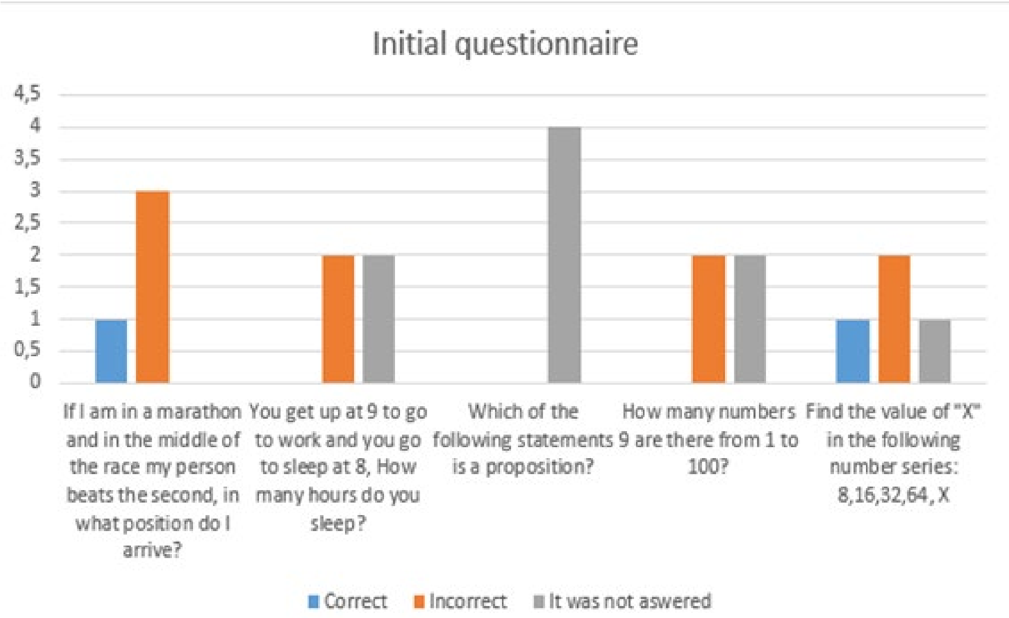

Figure 1. Result of the initial questionnaire.

Taking into account Figure 1, we can observe that students have difficulties in solving these problems where logical reasoning is applied due to the fact that there was an assertiveness rate of 10%. In this instance, the students said they did not know how to solve these problems, which were simpler than those they dealt with in calculus classes, and that is why they felt that this career was not the right one for them and it was one of many reasons why it was demotivated for them to study. Regarding motivation in math classes and the understanding of these concepts, Castro and Miranda (2019) commented:

"In students, two needs are also identified that need to be satisfied so that students feel motivated. Students want, on the one hand, to feel capable of understanding mathematical content and, on the other, to know that they are recognised by their peers or even by their teachers. From an effective point of view, meeting these needs not only helps students to be motivated to study mathematics but also to positively value their sense of belonging to a group of people who are dedicated to what they have imagined or desired to be. In other words, by wanting to "be an engineer" or "be like the teacher", students recognise that one of the specific characteristics of "being an engineer" is to understand the meaning of mathematical concepts." p. 90.

Taking into account the aforementioned, it is important that engineering students have the necessary skills or abilities to be able to function effectively during their time at the higher-level educational institution.

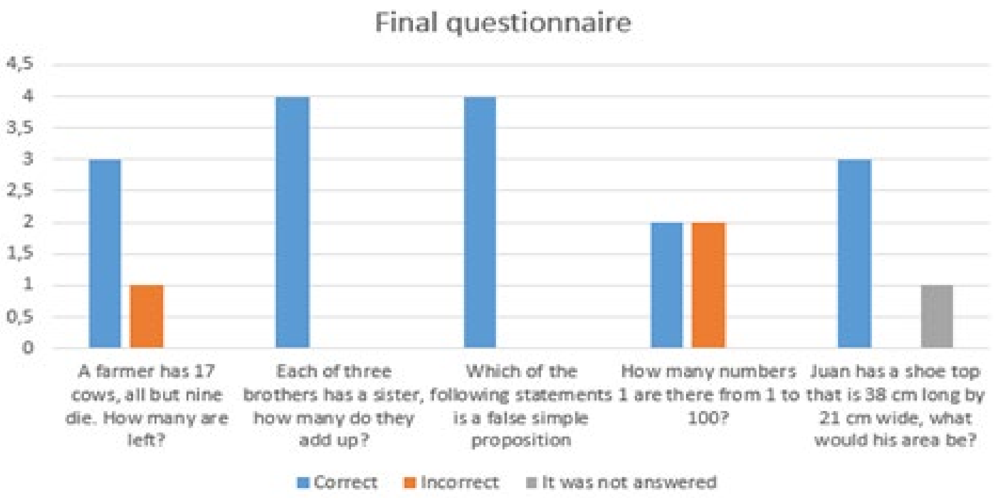

Figure 2. Result of the final questionnaire.

Taking into account Figure 2, when comparing these results with those obtained in Figure 1, we can observe that the students significantly improved their abilities to reason and solve problems correctly. In this instance, the students expressed feeling happy and more self-confident, because they do have the skills to successfully develop those subjects where it is required to use these skills.

Table 1. Proficiency test analysis.

Question	Description	Analysis
Write a short essay on any topic where you apply at least three times each of the logical connectives.	Identify the writing skills that students developed and the successful use of logical connectives.	The students showed a clear understanding of these connectives. In addition, it was evidenced how they confirmed the hypotheses from the ideas they presented and thus validated the veracity of the specific issue raised by each of them.
'What can be inferred from the following statement?': You cannot enter the classroom eating or drinking soda.	Observe how students' reason.	In this question, the way in which the students applied the logical connectives in conjunction with the reasoning to solve this problem was evidenced. Additionally, they proposed different solutions to make the statement clearer and more explicit so that anyone could read it and no counter-arguments were created.
Yesterday I was 15 years old, and next year I will be 16 years old. If my birthday is tomorrow. On what day and month was I born?	Observe how students' reason and identify the way they pose and solve a problem.	In these questions, the way in which the students reasoned and posed the problems to solve them was evidenced. It should be noted that each student applied different methods to find the result of each of these problems. However, two out of four
Five women, when questioned		

about a crime committed by one of them, stated the following: María: It was Camila. Andrea: It was Maria. Camila: Maria is lying. Paola: I didn't go. Carla: I went. If only one of them is telling the truth, who committed the crime?		students had difficulties in solving the last question because they could not find a way to solve it. However, minutes later, they were able to solve the problem, one of them applied a tree diagram to find their solution, and the next a drawing. In this way, we can argue that logic gave them the necessary skills to find the solution to each problem.
A man is asked the time, and he replies: "In 20 minutes, my watch will show 10:52." If the clock is 5 minutes ahead of actual time, what time was it exactly 10 minutes ago?		
Maria, who is 1 year less than one day older than Andrea, was born on January 1, 2010. What day was Andrea born?		
If the day before yesterday of tomorrow the day after tomorrow is Tuesday, what day was yesterday the day before yesterday?		

Taking into account Table 1, when the test ended and the interview was conducted, the students gave their opinions about the test they took, and some of the comments were: "I didn't really know if I was going to be able to solve everything, but I'm proud of myself for having done it before I saw that and my mind was blank" (Student # 1). “I thought that mathematics was useless, but seeing that mathematicians use this on a daily basis, I already understand how they manage to understand the concepts of differential calculus I am learning, and while I was receiving the class on logical connectives, I remembered why my teacher told me why I couldn't do both because it was a contradiction and now I understand what he meant.". (Student # 2). “On the internet, there are many exercises on these and when you see them, you think, how to do it, but now I realise that there are some that do not have valid reasoning and now I feel with the ability to argue about the veracity of something and say it Safely." (Student # 3).

The results of the interview applied to the students are shown below.

Table 2. Analysis of the interview.

Questions	Description	Analysis
What was the most beneficial for you during the development of the proposal?	Know the perspective of the students during the development of the proposal.	The students stated that the motivational stage was the best part of the proposal, since in this way they were able to understand the importance of mathematics and observing how to identify or recognise them in their daily life was something useful. Serna and Flórez (2013) comment that all students must have a development of logic and their reasoning, since when they program and create algorithms, this ability is essential. In addition, Briceño and Bonilla (2006) conducted a study which showed how mathematical logic allowed systems engineering students to create algorithms and apply them in computer programs.
If you compare a before and after the proposal. What could you conclude?	Identify if students had an advance in their knowledge.	The students argued that before they did not feel sure what they were thinking, if what they were thinking was right or not, and this generated internal conflicts. In addition, they added that they decided to study systems engineering because they wanted to program games or cell phones but were unaware of the mathematical background that it has. This is why Melo de Alonso (2003) mentions the importance of mathematics in engineering and its transversality to solve any type of problem in this area. On the other hand, they stated that when the proposal was being made, they were thinking about things that they had thought about, and they did not know if they were doing things well or badly, and here they realised which of those things were right and which were wrong.

IV. CONCLUSION

The main idea of this article was to design a proposal that would stimulate and develop logical reasoning in engineering students. Taking into account the results, we can see that the results obtained after applying the proposal were satisfactory, because the students knew the application and understood each of the concepts taught in the proposal. On the other hand, it is recommended that engineering students in different subjects stimulate this thinking skill, since it will be very useful for the effective development of their university career and in the workplace (Serna & Polo, 2014). Additionally, higher-level educational institutions where they develop engineering programs.

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