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Towards Improving The French's Teaching By Mathematical Logic in The High School Second Class in Madagascar

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ABSTRACT

This study proposes a pedagogical innovation aimed at introducing formal logic, traditionally applied in mathematics, into the French course in the second class of high school in Madagascar. Conducted in a secondary school in Mahajanga, this research examines the effects of this approach on students' reasoning abilities and linguistic comprehension skills. Through classroom experimentation and Implicative Statistical Analysis (ISA) using the Implicative and Cohesive Hierarchical Classification based on M_{GK}) (ICHC-M_{GK}) tool, students were exposed to logical concepts such as implication, equivalence, and the logical connectors AND, OR (inclusive/exclusive) within French language modules. The students' performance indicated that this integration strengthened their reasoning skills, particularly among those with a strong linguistic foundation. However, some students continued to struggle with complex logical concepts, highlighting diverse pedagogical needs. This study thus demonstrates the interdependence between a non-linguistic discipline (mathematics) and a linguistic discipline (French). This approach has the potential to enhance the Malagasy secondary education system by fostering logical reasoning as a tool for learning French as a language of instruction. It also advocates for policymakers to implement this method in other secondary schools across Madagascar and invest in teacher training, thereby equipping students with the interdisciplinary reasoning skills essential for their future.

INTRODUCTION

Since 2018, the subject of formal logic has been introduced into the mathematics syllabus for high school second class in Madagascar, with the primary aim of providing students with a solid foundation in mathematical reasoning and introducing them to computer science. This subject is taught in French, a crucial factor in understanding non-linguistic disciplines (Cavalli *et al.,* 2009).

It has been demonstrated that the success of learning a subject largely depends on the professional gestures adopted by the teacher during instruction. Several studies have examined the interdependence between teacher postures and students' learning postures in the context of mathematics education (Ravelomanana *et al.,* 2024a; Ravelomanana *et al.,* 2024b; Ravelomanana *et al.,* 2024c; Razafindrabehita *et al.,* 2024a; Razafindrabehita *et al.,* 2024c).

The work in Razafindrabehita *et al.* (2024b) highlights that "[...] students with a very high level in logic are generally those with a strong proficiency in French [...]," and that "[...] an average level in French generally leads to an average level in logic [...]". These findings suggest a correlation between proficiency in French and logical skills, reinforcing the idea of collaboration between French and mathematics teachers to subtly integrate logical concepts into French language lessons.

To explore the possibilities of this integration, we conducted a cross-analysis of the French and logic syllabuses for the second year of secondary school in Madagascar, posing the question: How can logic be incorporated into the teaching of French in an imperceptible way, so that students feel they are studying French rather than explicit logical concepts?

To address this question, we designed a lesson plan aimed at integrating elements of logic into French language instruction while considering the appropriate teacher postures. This approach was then tested in an experimental study conducted in a second-year class at Mangarivotra High School in Mahajanga. Finally, the results of this experiment were analyzed using the ICHC-M_{GK} tool, enabling insightful discussions, the formulation of recommendations for policymakers, and a deeper understanding of the impact of this innovative teaching approach.

MATERIALS AND METHODS

Tools used

An analysis of the curricula for mathematical logic (Annex 2) and French (Annex 1) for the second year of secondary school was conducted. This analysis convinced us that it is possible to teach formal logic concepts alongside French language instruction, particularly within the "Note-taking" chapter of the linguistic program. This approach enables learners to develop logical skills naturally while focusing on the linguistic content, exploring in greater depth concepts such as implication, equivalence, and logical connectors such as AND, OR (inclusive/exclusive).

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Let us first consider the concept of logical implication. In logic, an implication means that if a first proposition is true, then a second proposition is also true. For example, in note-taking, instead of writing “If a person works hard, then they succeed”, one might write “Hard work → success”. The notation “→” symbolizes the implication: hard work leads to success. This structure can be extended to other situations, thereby reinforcing students’ understanding of how one condition can lead to another. For example, “Smoking → health risks” shows the implication that smoking leads to health risks. Thus, students learn not only to condense information but also to visualize cause-and-effect relationships logically.

Logical equivalence, on the other hand, means that two propositions are either both true or both false at the same time, meaning they are interchangeable. In note-taking, this can be illustrated by expressions like “being honest ↔ telling the truth”. Here, the symbol “↔” indicates an equivalence, meaning telling the truth is equivalent to being honest, and vice versa. Another example might be “Breathing ↔ living”, showing that the act of breathing and the act of living are logically equivalent, with one not being possible without the other. This form of notation helps students understand bidirectional relationships where two ideas depend on each other to be true.

Logical connectors such as AND, OR (inclusive/exclusive) also play a crucial role in logically structuring information. The AND connector (∧) is used to combine two propositions that must both be true for the whole to be true. For example, in note-taking on health, one might write “Eating healthily AND exercising → good health”. Here, “AND” indicates that both conditions must be met to achieve good health.

The OR connector can be more subtle, as it exists in two forms: inclusive and exclusive. The inclusive OR (∨) means that either one or the other proposition, or both, can be true. For example, “Movie night OR dinner out” would mean that either one of these activities or both could take place. Students could note this as “Film ∨ dinner” to indicate this flexibility. The exclusive OR (⊕), on the other hand, stipulates that only one of the propositions can be true, not both. This could be illustrated by a sentence such as “Trip to Antsiranana OR Tananarive”, where only one of these destinations can be chosen, but not both. In notes, this could be represented by “Antsiranana ⊕ Tananarive”, showing that one excludes the other. This distinction between inclusive and exclusive OR helps students understand mutually exclusive choices versus situations where multiple options are possible.

By applying the concepts of implication and equivalence, students not only learn to synthesize and structure information effectively, but also develop logical reasoning that enhances their understanding of the complex relationships between ideas.

After preparing the lesson plan, incorporating logic as an object of linguistic French instruction while also considering the postures to be adopted (Table 1), we trained and supported the French teacher in using and applying it. The lesson plan was then handed over for the teacher to experiment with this new approach in class. The class, consisting of 31 ethno culturally diverse students, receives French instruction in a multilingual setting, including French, official Malagasy, and the Tsimihety dialect.

Two assessments (pre-test and post-test) were conducted during the instruction. The pre-test aimed to determine the general level of the students in understanding and writing sentences in French, in order to adjust the pedagogical approaches. This evaluation revealed that only 20% of the 31 students were capable of writing a correct sentence, which led the teacher to provide targeted assistance based on the needs of the learners throughout the teaching process. The post-test was conducted after the lesson to assess the competencies acquired by the students as a result of the intervention. The competencies of each student observed during the post-test were recorded in an Excel file, allowing for the creation of a binary table on the competencies observed, which was then subject to analysis (Table 2).

The competencies to be observed are as follows:

- Comp1: Identify a logical implication in a sentence.
- Comp2: Identify a logical equivalence in a sentence.
- Comp3: Identify the use of the logical connector “AND” in a sentence.
- Comp4: Identify the use of the logical connector “inclusive OR” in a sentence.
- Comp5: Identify the use of the logical connector “exclusive OR” in a sentence.
- Comp6: Recognize logical connectors in a text.
- Comp7: Use logical connectors correctly in a sentence.
- Comp8: Write a correct sentence.
- Comp9: Know the general structure of a sentence: Subject + Verb + Complement “S+V+C”.

MATERIALS AND METHODS

The data collected from the teaching-learning activities during the experiment are processed and studied using Implicative Statistical Analysis (ISA) (Gras, 1979), which is a non-symmetrical method of data analysis crossing subjects or objects with variables of different types (in our case of Boolean type). The technique of the extension of the Implicative and Cohesive Hierarchical Classification -ICHC (Ratsimba-Rajohn & Gras (1992) called Implicative and Cohesive Hierarchical Classification based on (ICHC-M_{GK}) (Rakotomalala, 2019) is applied to the analysis of these collected data to deal with the numerical and graphical problems required by the use of ASI. This application also serves to classify the rules - valid according to the cohesion index based on (Rakotomalala and Totohasina, 2018) in order to obtain meta-rules to facilitate the interpretations of the results of the analysis.

Table 1: Lesson preparation sheet for French course integrating mathematical logic

Class: 10th grade
Subject: French
Title: Structuring and summarizing information

Duration: 2 hours
Resources: Curriculum book on logic and French, 10th grade level

Objectives: By the end of the lesson, the student should be: Able to structure and summarize information using logical connectors, Proficient in comprehension and writing and Capable of applying logical reasoning to text analysis and note-taking

Duration	**Steps**	**Teaching-Learning activities and expected postures**		**Support/ Materials**	**Support/ Materials**
		Teacher	**Analysis:**		
5min	Rappel	Ask students about the coordinating conjunctions they know. Expected Teaching Postures: ● Weaving: The teacher connects students' prior knowledge (coordinating conjunctions) with upcoming concepts (logical connectors). ● Task Management: Guide students through the recall exercise. ● Accompaniment: Assist students in their responses, guiding them towards more precise answers.	The "AND" connector links two conditions (work hard AND persevere), indicating that both are necessary to succeed.	Q/A Participative	Blackboard
10min	Situation scenario	Explain to students that coordinating conjunctions can have logical symbols and serve as useful tools for organizing ideas during note-taking. Introduction example: ● Fluent French: If I do my homework, I will get good grades. ● Logical form: "Doing homework → Good grades" (Implication). Expected Teaching Postures: ● Weaving: Linking logical symbols to coordinating conjunctions. ● Scaffolding: Explaining the importance of logical connectors in structuring ideas. ● Magician: Simplifying a complex concept (logical symbols) by adapting it to the context of the French language.		Explicit Participative	Blackboard
Duration	**Steps**	**Teaching-Learning activities and expected postures**		**Support/ Materials**	**Support/ Materials**
		Teacher			
40min	Written trace	Explain and apply logical concepts to note-taking; Involve learners in creating examples. Expected postures: ● Teaching: Teach the concepts of logical implication and equivalence. ● Accompaniment: Encouraging student participation through practical examples.	Taking notes; Listen to the explanation; Participate in the answers to the examples.	Participative/ Explicit	Blackboard

		● Task management: Guide the students in formulating notes and understanding logical connectors. 1. Logical implication (→) Implication is used to show that if a first proposition is true, then so is the second. This can be applied in the conditional contexts often found in reading or summarizing. Example: "If you read a lot, you will understand better" "Read a lot → Better understanding". 2. Logical equivalence (↔) Equivalence shows that two propositions are true or false at the same time, so they are interchangeable. Example: "Telling the truth is equivalent to being honest"; "Telling the truth ↔ Honesty". 3. Logical connectors: AND (∧), inclusive OR (∨), exclusive OR (⊕) ● AND (∧): Both propositions must be true. Example: 'Eat healthily AND exercise → good health'. ● OR inclusive (∨): One or both propositions can be true. Example: 'Go out tonight OR stay at home' → 'Go out ∨ stay'. ●Exclusive OR (⊕): Only one of the two propositions is true, but not both. Example: 'Travelling to Paris OR Rome' → 'Paris ⊕ Rome'.	Postures expected: ● Reflexive: Analyze and integrate concepts independently. ● First (doing): Take part in practical activities, reformulating sentences.		
Duration	**Steps**	**Teaching-Learning activities and expected postures**		**Support/ Materials**	**Support/ Materials**
		Teacher	**Students**		
25min	Practical exercises 1	Give exercises and supervise learners during corrections. Expected postures: ● Control: Evaluate and correct students' exercises. ● Accompaniment: Guide students in their understanding of concepts during corrections. ● Letting go: Allow students to work independently while intervening as needed. Exercise 1: Reword the following sentences using logical implication to make them more concise and direct. 1. If you pay attention in class, you'll learn better. 2. If you drink enough water, you'll be healthy. 3. If you study regularly, you'll do well in your exam.	Doing exercises. Expected postures: ● Scholar: Follow instructions and apply knowledge. ● Reflexive: Check their understanding of logical concepts through the exercises. Expected answers (Exercise 1): 1. "Pay attention in class → Better understanding". 2. "Drink water → Good health". 3. "Regular revision → pass exam".	Q/A Participative	Paper's copy of the exercises/Blackboard

		Exercise 2: Identify the sentences that have an equivalence relationship. Rewrite them using the "↔" symbol. 1. To tell the truth is to be honest. 2. Being a model citizen means obeying the law. 3. Resting after hard work is recuperation. Exercise 3: Use AND (∧), inclusive OR (∨), exclusive OR (⊕) and complete the sentences by inserting the appropriate logical connectors. 1. You have to read the text carefully _____ listen to the teacher's explanations to understand it properly. 2. You can choose to go to the cinema _____ stay at home to rest. 3. You can visit the seaside _____ Notre-Dame cathedral, but not both at the same time.	Expected answers (Exercise 2): 1. "Tell the truth ↔ Be honest". 2. "Model citizen ↔ Respect for the law". 3. "Rest ↔ Recuperation". Expected answers (Exercise 3): 1. "Read carefully ∧ listen" (AND). 2. "Cinema ∨ stay at home" (OR inclusive). 3. "The seaside ⊕ Notre-Dame" (exclusive OR).		
Duration	**Steps**	**Teaching-Learning activities and expected postures** **Teacher**	**Students**	**Support/ Materials**	**Support/ Materials**
10min	Socio-cognitive exchange	Organise a debate where the pupils have to use logical connectors in their arguments (implication, equivalence, AND, OR). Expected postures: ● Atmosphere: Create an environment conducive to discussion and debate. ● Accompaniment: Guide the pupils in the correct use of logical connectors during the debate	Taking part in the debate. Expected postures: ● Creative: Participate in the debate by structuring arguments using logical connectors. ● Reflexive: Analyzing other people's arguments and proposing counter-arguments using logical connectors.	Participative	Blackboard
25min	Practical exercises 2	Give exercises and supervise learners during corrections. Expected postures: ● Control: Monitor and assess understanding of logical connectors in a textual context. ● Accompaniment: Help students identify connectors and understand their role in structuring ideas Exercise 4: Read the following text and identify the logical connectors used. Text: "To succeed in life, it is essential to work hard and persevere. If you put in the effort, you will see the results in the long run. However, you can choose to continue your studies or start working, but it is impossible to do both at the same time." Exercise 5: Write a short text (about 5 sentences) integrating logical connectors to structure the arguments.	Doing exercises. Expected postures: ● Scholar: Apply the concepts learnt in analysis and writing. ● Creative: Write a text using logical connectors to structure their ideas. Expected answers (Exercise 4): Connectors found: "AND", "If... then", "OR", "but". Analysis: The "AND" connector links two conditions (work hard AND persevere),	Q/A Participative	Paper's copy of the exercises/Blackboard

				both are necessary to succeed. "If... then" shows involvement (effort → results). "OR" is used exclusively to indicate a mutually exclusive choice (study OR work), reinforced by "but".		

Table 2: Extract of binary table

	Comp1	**Comp2**	**Comp3**	**Comp4**	**Comp5**	**Comp6**	**Comp7**	**Comp8**	**Comp9**
el1	0	1	1	1	1	1	1	0	1
el2	1	1	1	0	0	1	0	0	1
el3	1	1	1	1	1	0	1	1	1
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
el29	1	1	1	1	1	1	1	0	1
el30	1	1	1	1	1	1	1	0	1
el31	1	1	1	1	1	1	1	1	1

Let (K,D,C) be a binary context (Table 2). Consider the set of students D= {el1,el2,…,el31} and the set of items (Competencies) C= {Comp1,Comp2,…,Comp9}.

The association rules between two Boolean variables are defined by analyzing the contingency table obtained by crossing them (Table 3).

Table 3: Table of contingence and the conjoint probability associate.

	B	$\underline{B}$	Σ			B'	$\underline{B'}$	Σ
A	n_{AB}	$n_{A\underline{B}}$	n_A	⇒	A'	$P(A' \cap B')$	$P(A' \cap \underline{B'})$	$P(A')$
$\underline{A}$	$n_{\underline{A}B}$	$n_{\underline{AB}}$	$n_{\underline{A}}$		$\underline{A'}$	$P(\underline{A'} \cap B')$	$P(\underline{A'} \cap \underline{B'})$	$P(\underline{A'})$
Σ	n_B	$n_{\underline{B}}$	n		Σ	$P(B')$	$P(\underline{B'})$	$\frac{Card(D)}{n} = 1$

Mathematical Modeling

Consider a discrete finite probability space (E,T(D),P) such that for any event X in T(D),P(X)=(card(X))/(card(D)). Let us note the set of n students, over which we have measured m Bernoulli random variables, let I be the set of items $I = \{i_1, i_2, i_3, ..., i_n\}$ and V the set of the variables V={vi} of size c such i = {1, .., c}. For all X∈P(I) \ {∅ ; I}, for all $x_i \in X$, x_i is an application from D to {0 ; 1} and P(xi= 1)=((card(xi-1) (1)))/n, where n = card(D). Any non-empty part of I will be called a motif of I. So, for the motif A, $A'=A^{-1}(1)$ and nA=card(A'). For the motifs A and B, n_{AB}=card(A'∩B') the number of transactions that use both A and B. Agree to $\underline{A}$ = I - B be the logical negation of a motif U. The real number P(A') will be called the support of the motif A noted supp(A)=(card(A'))/n (Agrawal *et al.,* 1993).

A probabilistic interest measure is a real function μ of T(I) ×T(I) such that for any association rule A→B , with A∩B = ∅, the value of μ (A→B) is computed from the four quantities n = card(D), P (A'), P (B') and P(A'∩B'). Finally, for two motifs (or items) A and B in a binary context, the measure of interest M_{GK} is defined by

$$M_{GK} = \{M^f_{MGK}(A \to B) = \frac{P(\frac{B'}{A'}) - P(B')}{1 - P(V')} \text{ ,if } A \text{ favours } B; \quad 0 \text{ ,cases of independence ; } M^d_{MGK}(A \to B) = \frac{P(\frac{B'}{A'}) - P(B')}{P(B')} \text{ ,if } A \text{ disfavours } B.$$

Extraction of Association Rules According to the M_{gk} Measure

The theoretical research in Rakotomalala *et al.* (2017) and Rakotomalala *et al.* (2018) allowed us to develop an M_{GK} -valid association rule extraction algorithm (Rakotomalala & Totohasina, 2018).

The extraction of association rules is based on the MGK measure of interest, which detects a possible non-symmetrical relationship between two of the variables, the validation of the extracted rules is done with respect to the favorable component M^f_{GK} which is implicative and the critical value M^f_{GK} (α) having a relationship with the χ2 statistic of independence or dependence of degree of freedom 1 at the risk threshold α chosen by ourselves such that $M_{GK}^f > M_{GK}^f(\alpha)$ with $M_{GK}^f(\alpha) = \sqrt{}((1/n) \ ((n-n_A)/n_B)\ (n_B/(n-n_B))\ \chi^2_{Theorical(\alpha)})$. In our case, α=10%, which gives the critical value of $\chi^2_{Theorical(\alpha)}$) equal to 2.7;

The value of the support according to M_{GK}^f is generally small (Rakotomalala *et al.,* 2017), such that

$$supp^f_{MGK}(A \to B) = supp(A)[(1 - supp(B))M^f_{GK}(A \to B) + supp(B)]$$

It is therefore essential to normalize this value (Rakotomalala & Totohasina, 2018), and we denote it by $supp^f_{(n)\ MGK}$, such that its matrix of size c×c is given by:

$$supp^f_{(n)M_{GK}}(A \to B)[i][j] = \frac{supp^f_{M_{GK}}(A \to B) - P(A')P(B')}{P(A')(1 - P(B'))}, i, j \in \{1, \dots, c\}$$

Construction of Implicative Graph According to The M_{GK} Measure

An implicative graph, denoted G_{MGK}=(V,E), consists of a finite set of student competencies representing the vertices of the graph, and edges associated with the normalized support value of valid rules. For ease of interpretation and to highlight meaningful relationships, only implications with a support value $supp^f_{(n)MGK}$ (A⟶B)[i][j]≥β are retained; in our case, β=0.5. This threshold reflects that the implicative tendency of A over B is preferred to neutrality (Gras *et al.,* 2001).

Here are a few definitions:

Definition 1: A graph G = (V, E) is the pair consisting of a set of vertices V, and a family of edges E, such that: $V \times V = \{(v_i, v_j) | vi \in V, v_j \in V\}$.

Definition 2: A graph G = (V,E) is said to be directed if E is a set of ordered pairs is, $E \subset V^2$. An arc is made up of two vertices having distinct roles, an origin and a terminal end. We call the order of a graph, notedc = |V|, the number of vertices of the graph. The size of a graph, notedm, corresponds to the number of edges: m = |E|.

Definition 3: Let be G = (V, E, φ)a directed graph. A chain is a sequence $v_1\ e_1\ v_2\ e_2\ v_3 \dots e_k\ v_k$ with $\varphi(e_i)$ = v(i-1) v_i for i=1,…,k. This chain is said to be of length k and connects v_1 to v_k.

Definition 4: The relation "to be connected by a chain" is an equivalence relation on the set of vertices ofG. The subgraphs generated by this relation are the connected components of G. The connected component of the vertex v_i is then the set of vertices of G connected to v_i by a chain knowing that v_i is connected to it by a chain of length zero. We say that G is a connected graph if it has only one connected component i.e. if any two vertices are connected by a chain.

Definition 5: The transitive closure of a graph G is the graph having the same vertices as G and whose edges (arcs) connectv_i to vjif it exists in G a chain (path) from v_i to v_j.

First, we construct the adjacency matrix M[i][j]of the graph, of size c×c , defined as follows:

M[i][j]={1,si $supp^f_{(n)MGK}$ (A⟶B)[i][j]≥β 0,sinon

Second, we transform M[i][j] into an adjacency matrix representing the transitive closure of the graph by applying Warshall's algorithm (Warshall (1962)). From this new matrix, we construct the graph G_{MGK}=(V,E), formally defined as follows: ∀i,j∈{1,…,c}, si M[i][j]=1, then (vi,vj)∈E and V={v1,…,vc}.

Implicative and cohesive hierarchical classification method according to the M_{GK}

The value of $supp^f_{(n)MGK}$]0.5;1] is used to establish the value of cohesion between two items, denoted coh $supp^f_{(n)MGK}$ (Rakotomalala &Totohasina, 2018) with:

$$coh_{supp_{(n)M_{GK}}}(A, B) = \{\sqrt{1 - (supp^f_{(n)M_{GK}}(A \to B))^2}, \ if\ supp^f_{(n)M_{GK}}(A \to B) > 0.5 \quad 0 \quad , if\ supp^f_{(n)M_{GK}}(A \to B) \leq 0.5\ 1 \quad , if\ supp^f_{(n)M_{GK}}(A \to B) = 1$$

The implicative and cohesive hierarchical classification method according to the M_{GK}(ICHC-MGK) measure of interest is based on the cohesion coh $supp^f_{(n)MGK}$ (Rakotomalala *et al.,* 2018).

RESULTS AND DISCUSSION

In this section, we will analyze the characteristics of the variables. We will then talk about the implicative graph of the postures and the interpretation of the rules extracted by the ICHC-M_{GK}. Finally, we are opening the discussions about the results.

Variable's Information

Table 4 below shows the occurrence and the average number of pupils who achieved the 9 competencies examined during the two classroom experimentation activities. In this second-year class at the high school Mangarivotra in Mahajanga, all the pupils knew when to use the logical connector "AND" in a sentence (Comp3). On the other hand, 96.77 % of the class were able to identify logical connectors in a text (Comp6), 93.54 % knew how to use logical connectors in a sentence (Comp7), 83.87 % knew the general form of an 'S+V+C' sentence (Comp9) and 80.65 % could identify a logical equivalence in a sentence (Comp2).

Furthermore, 77.41 % of the students knew when a logical connector 'inclusive OR' (Comp4) and 'exclusive OR' (Comp5) was used in a sentence, while only 61.29 % could identify a logical implication in a sentence (Comp1). The table also shows a small percentage of students able to write a correct sentence (Comp8).

Table 4: Characteristics of the variables

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6	Comp7	Comp8	Comp9
Occurrence	19	25	31	24	24	30	29	08	26
Moyenne (%)	61,29	80,65	100	77,41	77,41	96,77	93,54	25,80	83,87

Observation: 80.65% know the structure of a sentence, but only 25.80% can formulate a sentence correctly.

Results obtained by ICHC-M$_{GK}$

Based on our data concerning the 9 competencies observed during the two activities of the classroom experiment, analyzed with ICHC-M$_{GK}$, we extracted a total of 30 rules, 14 of which were positive and 16 negatives. With a 10% risk of error, this analysis identified 2 directed pairs, i.e. card(coh supp$_{(n)MGK}$)=2, withsupp$^{f}_{(n)MGK}$ (U→V)=1 and cohsupp$_{(n)MGK}$) (U→V)=1. The value of supp$^{f}_{(n)MGK}$ (U→V) andcoh supp$_{(n)MGK}$) (U→V)for the two pairs of variables is shown in Table 5.

Table 5: The MGK normalized support and MGK normalized cohesions of the pairs of the variables

	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6	Comp7	Comp8	Comp9
Comp1									
Comp2									
Comp3									
Comp4					1				
Comp5				1					
Comp6									
Comp7									
Comp8									
Comp9									

Table 5 above shows the normalized support and normalized cohesion values for the variable pairs. The normalized support for the skills "knowing when to use a logical or inclusive connector" (Comp4) and "knowing when to use a logical or exclusive connector" (Comp5) is identical (equal to 1). This indicates a strong relationship and dependency between the understanding of the "or inclusive" and "or exclusive" connectors.

Among the 14 positive rules valid according to the M$_{GK}$ measure, with a minimum normalised support of 0.5, we obtained a graph G(M$_{GK}$) = (V, E) with 2 vertices and 1 bidirectional arc (Figure 1). One arc starts at the "Comp4" vertex and goes to the "Comp5" vertex, goes from the "Comp5" vertex to the "Comp4" vertex. This arc have a normalized support value of 1, indicating a strong dependency: understanding the "exclusive OR" logical connector systematically leads to understanding the "inclusive OR" connector.

It should also be noted that seven (7) out of the nine (9) observed variables are independent (isolated). This isolation is due to the fact that Comp1, Comp2, Comp3, Comp6, Comp7, Comp8, and Comp9 do not have any valid relationships with the other variables (Table 5), according to the M$_{GK}$ measure, at a risk threshold of α=10%, i.e., with 90% of confidence.

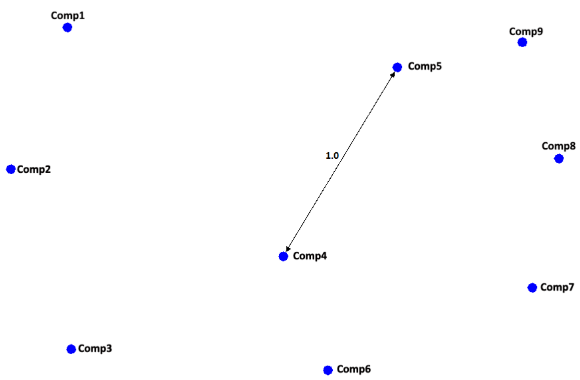

Figure 1: The implicative graph G_(M_GK) of student's competencies

After the hierarchical classification of valid rules, we obtained the following meta-rule, presented in Table 5 and represented in the dendrogram in Figure 2.

R(1): (Comp5 → Comp4): The skill 'knowing when to use an exclusive OR logical connector in a sentence generally implies the skill 'knowing when to use an inclusive OR logical connector in a sentence'.

Table 6: Hierarchical rules with interclass cohesion, interclass implication and significative value

Level	Rule	Intra-class cohesion	Interclass implication	Significative value
1	(Comp5→Comp4)	1.0	1.0	0.02406090259404961

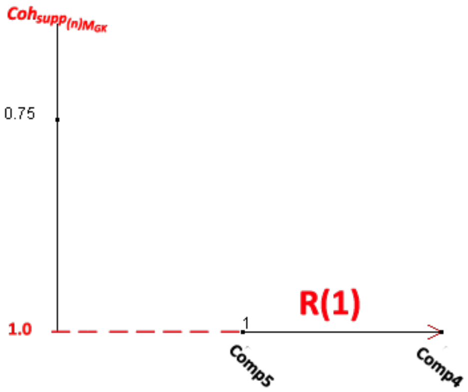

Figure 2: Dendrogram of student's competencies rule

Discussions and Suggestions

Our project to integrate formal logic into French language teaching for second-year students in Madagascar is particularly innovative and seems relevant in the current educational context. This study reveals interesting results concerning the interaction between linguistic and logical skills in learners, and the way in which logic can strengthen the understanding and structuring of ideas in French.

In the Malagasy context, teaching logic alongside French seems necessary because, as studies show in Razafindrabehita *et al.,* 2024b, language level is often correlated with logic competencies. An integrative approach makes it possible not only to overcome language barriers but also to introduce students to the formal concepts essential to the development of logical thinking, such as that applied in mathematics and computer science.

Using analysis methods such as Implicative Statistical Analysis (ISA) in ICHC-M_{GK}, this research highlights interesting associations between competencies. For example, it appears that students have a good level in the use of the 'AND' connector, but encounter difficulties with the 'OR' logical connectors (inclusive and exclusive) (Figure 3, Figure 4), as well as with logical implication, which could indicate areas for improvement in the way these concepts are introduced and practiced.

It is also interesting to note that the students had difficulty

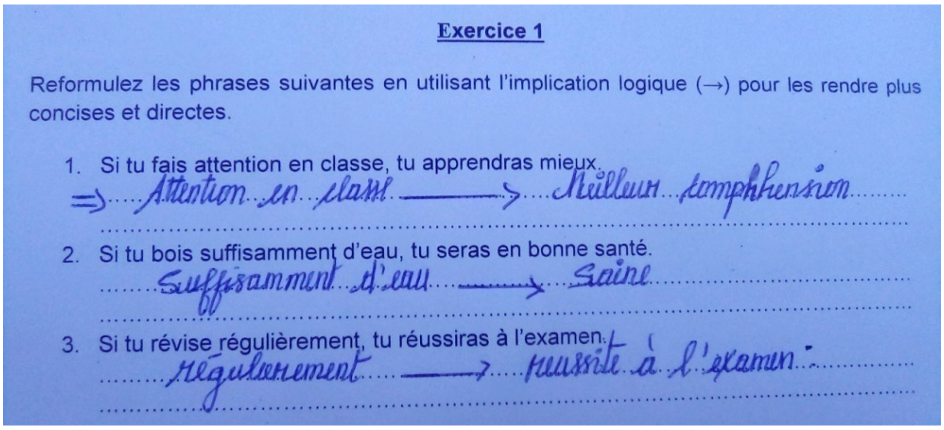

Figure 3: Student's work on finding logical implications in a sentence

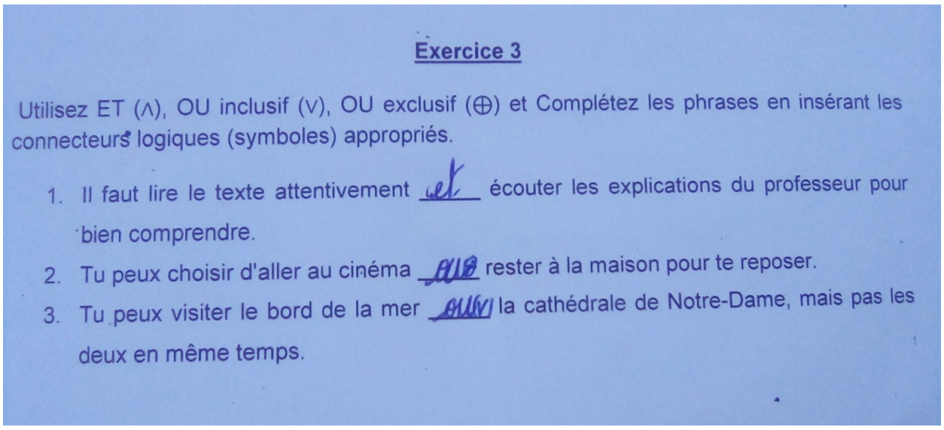

Figure 4: Student's work on logical connectors: AND, "OR" (inclusive and exclusive)

writing correct sentences despite their logic skills (Figure 5), which could mean that the acquisition of syntactic skills does not automatically go hand in hand with that of logic. This observation shows the importance of differentiated teaching and the need for close monitoring of writing skills in parallel with the teaching of logic.

According to Table 4, more than half the students know the basic structure of a sentence in French. However,

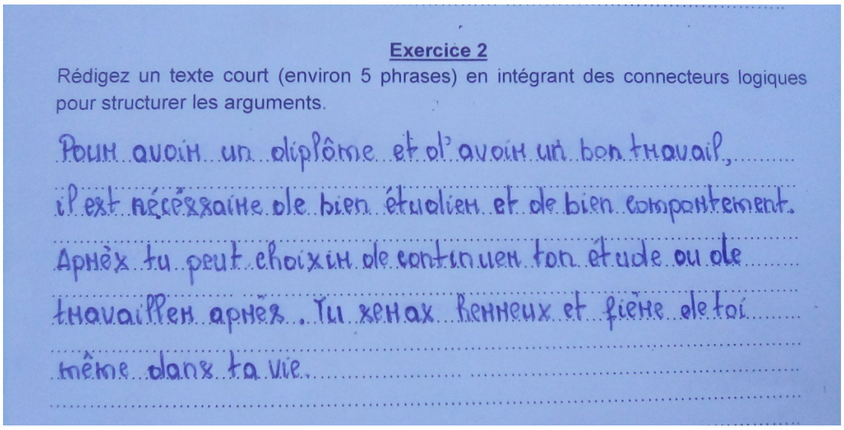

Figure 5: Student 1's work on writing using logical connectors

only a quarter of the class were actually able to form complete sentences. This finding can be explained by the complexity of the French language: it is not enough to master the structure of a sentence (subject + verb + complement, or S+V+C). Correctly formulating a sentence in French also involves mastering the rules of conjugation, gender and number agreement, as well as other essential grammatical aspects.

With a view to improvement, it might be useful to:

- Develop more interactive modules on logical connectors "or" and implication, using concrete examples in French to make them easier to understand.
- Strengthen training for French teachers to enable them to better integrate logic into their teaching, in particular by exploiting digital tools and simulation platforms.
- Organize collaborative workshops for French and logic teachers to design integrated exercises together, such as writing structured arguments or creating logical summaries.

CONCLUSION

The aim of this research was to improve the teaching of logic in Malagasy second-year classes by integrating logical concepts into French lessons. Our experiment showed that this integrative approach enables pupils to become familiar with the principles of formal logic in a subtle and natural manner, while at the same time strengthening their language competencies.

Analysis of the results using the ICHC-M_{GK} tool revealed significant correlations between students' logical and linguistic skills, confirming the value of an interdisciplinary approach. In particular, competencies in syntax, the use of logical connectors and sentence structure were shown to be essential for developing learners' logical reasoning skills. Identifying the implicit links between these skills opens up new prospects for designing more coherent educational programs in which logic and language reinforce each other.

Finally, this study also revealed specific difficulties encountered by some students, particularly in constructing grammatically correct sentences and identifying logical implication. These aspects could be addressed through targeted pedagogical strategies. In the future, broader experiments with more diverse samples could yield additional data, thereby reinforcing the effectiveness of this approach.

In conclusion, our work constitutes a first step towards an innovative and promising educational model, aimed at enhancing both the logical and linguistic skills of Malagasy students, and promoting a stronger command of analytical reasoning, an essential competency in the fields of science and computer science.

This approach could also be applied to various communication-based language disciplines, such as English, Spanish, and others.

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Annex 1: French language program, chapter taking notes

Duration: 14 weeks

General objectives: The learner must become an independent reader.

Learning objectives	Contents	Observations
● Transcribe a speech using a custom code	• Distinguishing the essential elements of a speech and presenting them in an organized manner in the form of notes • Note-taking technique: Abbreviations, common and personal symbols, telegraphic style, etc. • Articulators (logical, temporal, spatial, etc.) • Nominalisation/other substitutes • Infinitive sentence	A topic to be covered for at least a month: • violence; (speech related to sexual abuse) • social facts (early pregnancy, early marriage, etc.) • corruption • women in society (gender) • social networks (communication) • Menstruation • Hygiene • Climate change

Annex2: Logic program

Duration: 2 weeks

General Objective: The learner must be able to recognize a proposition and use logical connectors and quantifiers.

Learning objectives	**Contents**	**Observations**
● Know and correctly use logical connectors ● Know and use quantifiers correctly	● Definitions - Statement - Proposal ● Logical connectors: AND, OR (inclusive/exclusive), implication, equivalence. ● Quantifiers: existential (∃), universal (∀)	Examples: ● Application of logical equivalence connectors. ● A right triangle has a right angle (P→Q) ● A triangle with a right angle is a right triangle (Q→P) therefore (P↔Q) ● Use of the truth table to argue or demonstrate ● Negation of quantifier and proposition ● Translation of a sentence by quantifiers and vice versa.