The impact of visual schematization in enhancing comprehension and memory of graphic organizers' artifacts

O impacto da esquematização visual na melhoria da compreensão e memória dos artefatos dos organizadores gráficos

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design for education,
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multimedia learning theory

This study investigates how different visual schematization methods – linear text (LT), Rule of Composition Systems (RoCS), and Graphic Reference Frames (GRF) – influence comprehension of educational content, and how this interacts with learners' cognitive styles. Sixty-one university students were divided into three groups, each exposed to a different schematization prototype. Cognitive styles (visual/verbal and global/analytical) were assessed through a validated questionnaire. Findings show that preferred cognitive style (visual vs. verbal) does not significantly affect comprehension within the same group. However, significant differences emerged between schematization methods: while GRF and linear text yielded comparable results, RoCS led to lower comprehension scores across styles. This suggests that RoCS may be less effective than GRF or LT in early learning contexts. Overall, the results highlight that instructional design – not cognitive style alone – plays a central role in learning outcomes, emphasizing the importance of aligning schematization strategies with cognitive tendencies.

*design para educação,
sintaxe gráfica,
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teoria da aprendizagem multimídia*

Este estudo investiga como diferentes métodos de esquematização visual – texto linear (LT), Regras dos Sistemas de Composição (RoCS) e Referenciais Gráficos (GRF) – influenciam a compreensão de conteúdos educacionais e como esses efeitos interagem com os estilos cognitivos dos aprendizes. Sessenta e um estudantes universitários foram divididos em três grupos, cada um exposto a um protótipo distinto de esquematização. Os estilos cognitivos (visual/verbal e global/analítico) foram avaliados por meio de um questionário validado. Os resultados indicam que a preferência de estilo cognitivo (visual versus verbal) não afeta significativamente a compreensão dentro de um mesmo grupo. No entanto, surgiram diferenças significativas entre os métodos de esquematização: enquanto GRF e texto linear produziram resultados semelhantes, o RoCS resultou em escores de compreensão mais baixos em todos os estilos. Isso sugere que o RoCS pode ser menos eficaz do que o GRF ou LT em contextos iniciais de aprendizagem. De modo geral, os achados ressaltam que o design instrucional – e não apenas o estilo cognitivo – desempenha um papel central nos resultados de aprendizagem, destacando a importância de alinhar estratégias de esquematização às tendências cognitivas dos estudantes.

1 Introduction

Communicative artifacts often feature a defined spatial organization of graphic elements, as seen in educational tools like concept maps (Novak & Cañas, 2006).

Many other forms of graphic artifacts simultaneously contribute to the processing and transmission of knowledge. A notable example is the Cartesian graph, an indispensable tool in scientific contexts, which is so pedagogically effective that it may transform the perceptual process in learning (Chumachemko, 2014).

Analyzing the graphic artifacts found in university textbooks and educational support materials reveals two types of graphical artifacts based on their spatial organization.

Some artifacts are organized based on a Graphic Reference Frame (GRF), which assigns value to the graphic elements arranged within it (e.g., a Cartesian graph, a table, a map, Figure 1). Other artifacts are organized using a System of Composition Rules (RoCS), which allows for the spatial arrangement of elements in a way that makes their relationships meaningful (e.g., a graph diagram, a flowchart, a concept map, Figure 2).

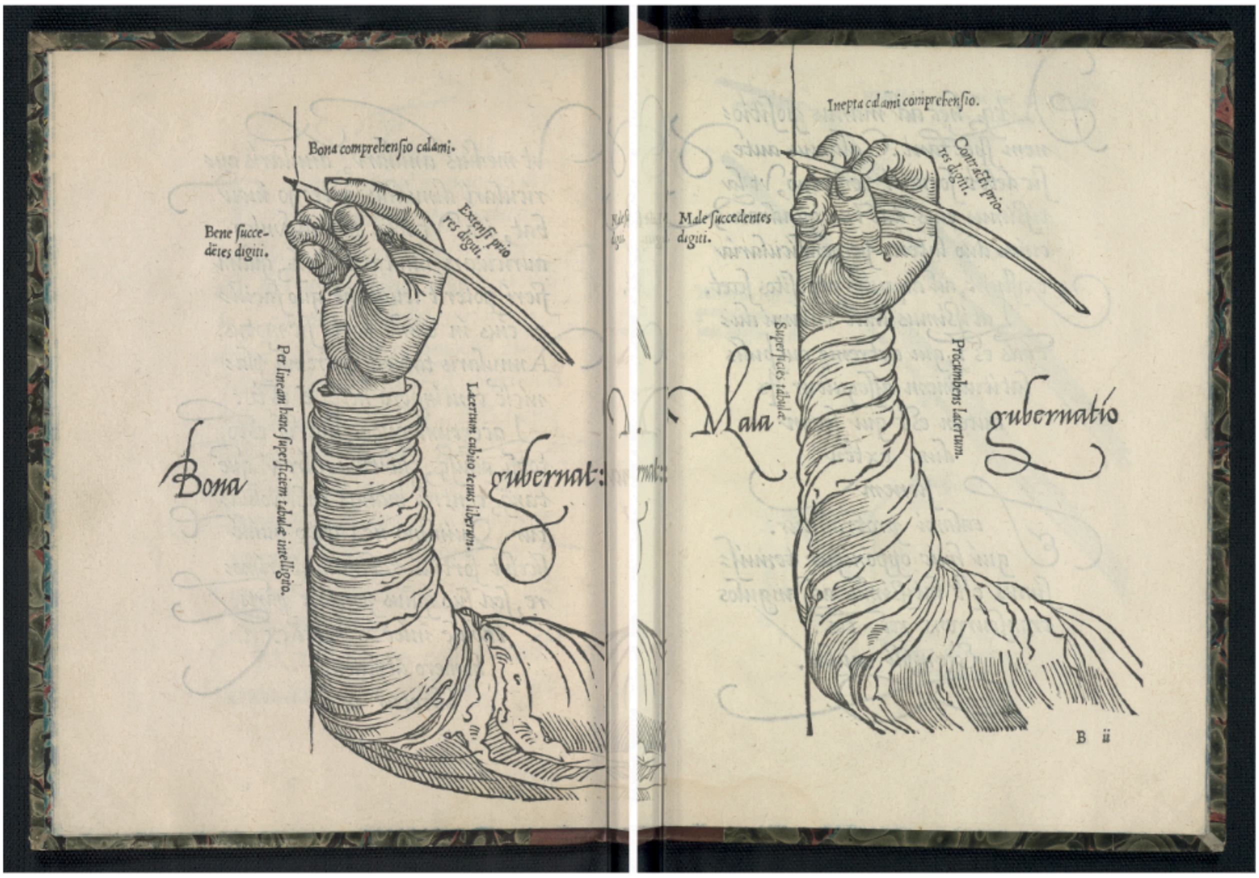

Figure 1 Mercator, G., Rescius, R., Arenberg, P. L. & Lessing J. Rosenwald Collection. (1540) Literarum Latinarum, quas Italicas cursoriasque vocāt, scribendarū ratio. Louanij, ex officina R. Rescij. https://www.loc.gov/item/65059036/ Library of Congress, Rare Book and Special Collections Division.

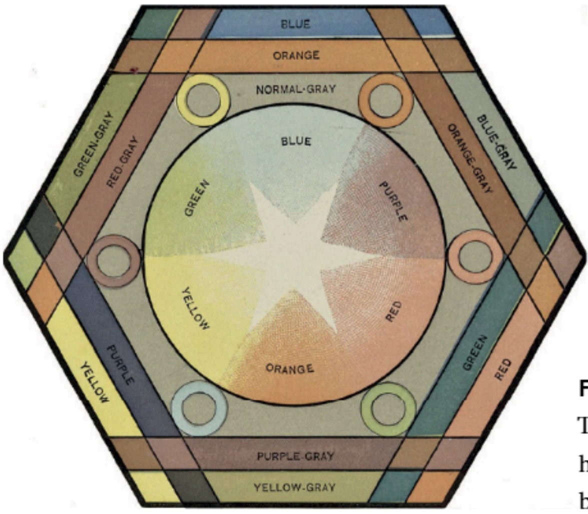

Figure 2 Babbitt, Edwin D. (1878). The principles of light and color, Plate II, https://library.si.edu/digital-library/book/principlesofligoobabb.

An example illustrating this difference is the comparison between a family tree and a circle generation chart (Figure 3). Despite containing the same information, these two organizational forms result in artifacts that are completely different in shape and in the type of information they emphasize.

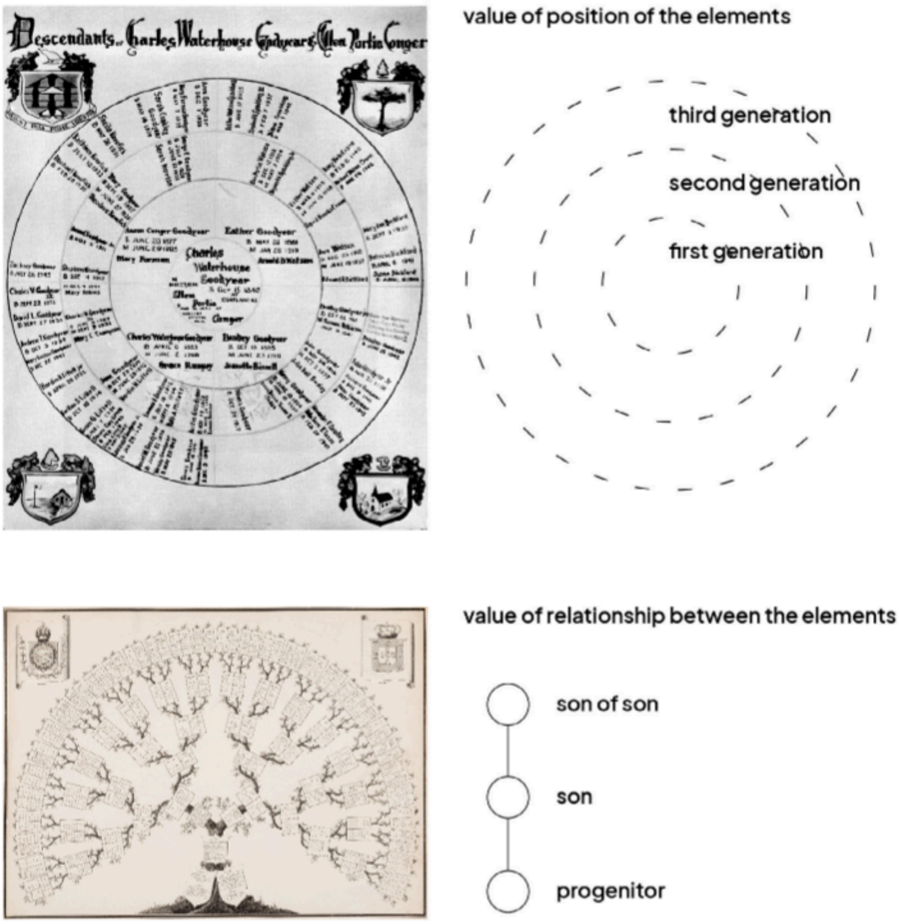

Figure 3 An example of family tree and of a circle generation chart. Family tree of D. Pedro I (attributed), 1842, lithograph on paper, 50,5 × 68,2 cm. Collection of the Pinacoteca de São Paulo. Brasiliana Collection/Fundação Estudar. Donated by the Fundação Estudar, 2007. The Goodyear family tree is documented in Bogalusa Story (Goodyear, 1950, p. 85).

The family tree is a graph that shows relationships through arcs and nodes, where spatial position is irrelevant, but the contiguity between arcs and nodes is significant. In contrast, the circle generation chart uses a graphic reference frame (a series of concentric rings), which assigns specific value to the position of each graphic element.

The graphical organization of elements in space to create meaningful graphical artifacts is defined as "sinsemia" (Bonini, 2010).

In educational settings, readers' comprehension can vary depending on how information is presented. If a reader can effectively process a diagram, it can help compensate for limitations in working memory (Kosslyn, 1980). Even when conveying the same information, the relationship between text and diagrams can be redundant, complementary, or supportive (Hegarty, Carpenter, & Just, 1991).

1.1 The role of graphical displays in learning and the role of different graphic arrangements as a variable in the learning process

The hypothesis that some graphic arrangement supports learning must be placed within a theoretical framework and supported by evidence.

Vekiri (2002) reviews studies that explain the role of graphical displays in learning and synthesizes relevant findings into principles for effective graphic design. Three theoretical perspectives provide the framework for the review: dual coding theory, visual argumentation, and conjoint retention. Although these theories are based on different assumptions, they are compatible. Research suggests that graphics are effective learning tools only when they allow readers to interpret and integrate information with minimal cognitive processing. We adopt a predominantly cognitive approach (Ertmer & Newby, 1993; Schunk, 2012) and refer to the Theory of Multimedia Learning (MLT) (Mayer, 2005), as it most directly addresses the role of graphical tools among accredited learning theories. However, this theory has faced certain criticisms, which are discussed in this study.

The fundamental premise of the cognitive MLT is that images and texts are processed by two distinct channels that are limited in capacity of processing. Dividing attention among multiple simultaneous information sources can cause cognitive overload, thereby reducing learning effectiveness.

When applied to graphical artifacts, the consequences are that if a student must read a text while simultaneously viewing a related figure on a different page, attention is divided. This division can hinder the integration of information.

The MLT is based on the existence of two distinct channels: verbal and visual. However, the written text is not clearly situated within this model, as it does not completely overlap with spoken words. According to Coltheart's dual-route model (1978), lexical and semantic processing of written words does not require phonological processing. This implies that the processing of written words is partly independent of phonological processing and thus does not coincide with that of spoken words.

Furthermore, the processing of written words does not overlap with that of images, even in less alphabetic writing systems, such as Chinese script (Huang et al., 2015). Image processing appears distinct from the processing of written text. However, the same experiment observes stimulation and interaction of linguistic areas during the processing of images.

Schroeder and Cenkci (2020) examined whether cognitive load measures support the spatial split-attention principle, suggesting that close presentation of related words and images enhances learning compared to a spatially distant arrangement. Despite support from two meta-analyses, the mechanism remains unclear. The spatial split-attention principle, derived from Cognitive Load Theory, proposes that integrated graphics improve learning, but the review found no significant differences in cognitive load measures. In conclusion, the benefit lies in integrating the two channels, facilitating better information processing.

The evidence found by Huang et al (2015), together with the observations of Schroeder & Cenkci (2020), suggests that written/graphic forms might be partially overlapping with the two channels defined in the MLT. Since writing and images channels are partially overlapping, an advantage is created when the two channels are integrated instead of concurrent.

Based on the analyzed literature, written text processing can be conceptualized as an independent channel or one partially overlapping with the other two (Figure 4).

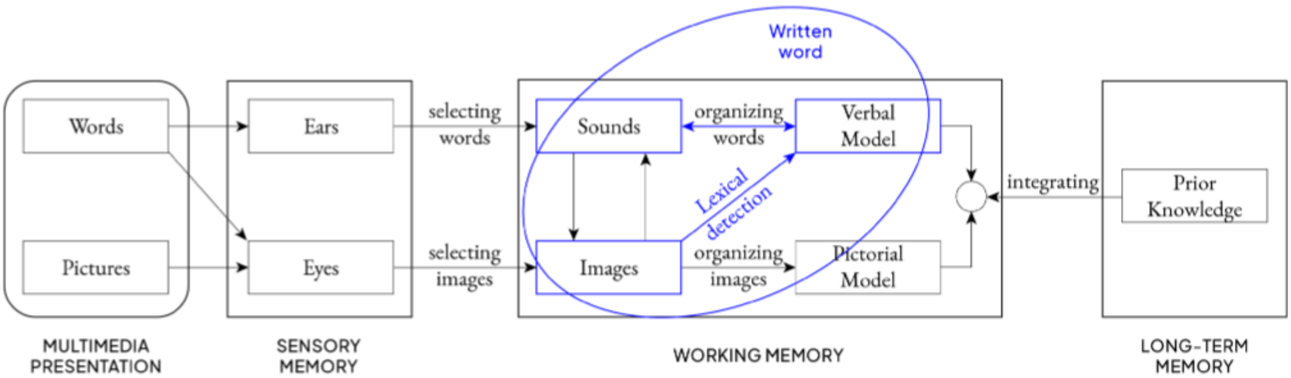

Figure 4 Possible role of writing in cognitive MLT integrated with dual-route model.

In the first case, writing is processed as an independent channel interacting with both the visual (graphic elements, images) and auditory (written-spoken language) channels. In the second, there may be no distinct written channel; instead, writing might overlap with and utilizes both channels, supporting integration where modalities converge (e.g., writing/images or spoken/written language) as per Schroeder & Cenkci (2020).

According to Schroeder and Cenkci (2020), the advantage of channel integration may stem from certain processes not requiring attention shifts or splits. Parallel processes can mutually benefit before higher-level processing, as shown by distributed attention and preattentive processing, where unfiltered information still impacts post-attentional stages.

Luck and Vogel's (1997) work suggests that graphical objects integrating multiple features may be processed as unified entities, aligning with Mayer's (2014) findings on graphic organizers and verbal cues enhancing learning by structuring information for better comprehension and memory. Additionally, listening while viewing related visuals is likely less cognitively demanding than alternating between reading text and interpreting visuals, highlighting an asymmetry between spoken and written language processing.

However, diagrams and figures differ significantly in graphic style and logical structure, varying across forms like linear texts, concept maps, and Cartesian diagrams (Anceschi, 1993). Therefore, generalizing findings across visual formats is inappropriate, as each has distinct properties. Mayer's (1989) claim that diagrams aid conceptual understanding but not verbatim recall should be validated individually.

1.2 Concept maps

Concept maps use nodes and arcs where element positioning carries no intrinsic semantic meaning; instead, meaning arises from relative positioning following composition rules (RoCS), akin to graph structure (Battista et al., 1998, pp. 11–12). Concept mapping requires authors to personally rework and connect concepts, creating highly individualized knowledge structures. For effectiveness, the map should be built from a well-understood knowledge domain (Novak & Cañas, 2006).

The literature provides evidence supporting this specific efficacy. For instance, no significant differences have been found between concept maps created by experts and those created by novices (Schwendimann, 2016). Moreover, expert maps vary greatly from one another, reflecting a high degree of individuality even with similar knowledge.

Stull and Mayer (2007) suggest that novice learners benefit from author-provided organizers to reduce cognitive load. However, with simpler material or more experienced learners, self-generated organizers may be more effective.

Novak and Cañas (2006) support the idea that concept map creation should start from a familiar knowledge domain. Their findings, along with cognitive load theory, suggest that constructing graphic organizers can add extraneous load, potentially hindering meaningful learning, especially for learners with limited prior knowledge (Stull & Mayer, 2007).

Research on multimodal learning has confirmed that certain design principles for educational materials can reduce extraneous cognitive load (Skulmowski & Xu, 2022).

However investing a small amount of extraneous cognitive load might facilitate the generation of certain types of mental schema processing. Understanding the acceptable limits of extraneous cognitive load could act on mental schema and generate benefit (Skulmowski & Xu, 2022).

1.3 Cognitive styles

When discussing cognitive styles, the term refers to an individual's preferred and habitual approach to organizing and representing information (Riding & Rayner, 1998).

The Felder-Silverman model identifies five dimensions: sensing-intuitive, visual-verbal, inductive-deductive, active-reflective, and sequential-global. Each dimension has two categories; for example, visual-verbal focuses on input mode, with visual learners preferring images and charts, while verbal learners favor text or speech. Sequential-global addresses information processing, where sequential learners use linear reasoning, while global learners make intuitive leaps and may need an overview for connections (Lucchiari, 2018).

These styles represent dichotomous extremes and do not precisely describe individuals, as most use both approaches with no strong preference. Cognitive style tends to stabilize over time; repeated use improves outcomes, encouraging conscious preference for certain strategies (Clapp, 1993; Alshammari, 2016).

1.4 Overview of theoretical insights

Recent literature emphasizes the pedagogical value of graphic organizers when effectively designed to reduce extraneous cognitive load and support dual-channel processing. While concept maps (RoCS) promote active knowledge construction, their effectiveness depends on learners' prior knowledge and cognitive style. GRF-based diagrams, though less explored, offer spatial anchoring that can enhance comprehension in early learning stages. Studies on multimedia learning, cognitive load theory, and visual-verbal preferences converge on the importance of integrating visual and textual elements without splitting attention. These findings underscore the need to tailor schematization strategies to both content complexity and learner characteristics.

2 Method

2.1 Research question and hypotheses

These hypotheses compare three modes of representing the chosen concept:

1. **Linear Summary Text (LT)**: A linear text accompanied by two graphs and a diagram.
2. **Concept Map Organization (based on RoCS)**: A concept map accompanied by two graphs and a diagram.
3. **Reference Frame-Based Information Organization (based on GRF composition)**: A labeled reference frame based on a representation conventionally adopted to explain the concept (the diagram), accompanied by two graphs.

This study seeks to answer the following research question:

How do different visual schematization methods – linear text (LT), Rule of Composition Systems (RoCS), and Graphic Reference Frames (GRF) – affect students' comprehension of educational content, and to what extent does this effect interact with learners' cognitive styles (verbal/visual and analytical/global)?

Based on the literature reviewed in Section 1, we formulated the following testable hypotheses:

H_0. There is no significant difference in student comprehension between the three schematization methods (LT, GRF, RoCS).
H_1. GRF does not differ significantly from LT, while RoCS leads to significantly different comprehension outcomes compared to LT.
H_2. RoCS does not differ significantly from LT, while GRF leads to significantly different comprehension outcomes compared to LT.
H_3. Both GRF and RoCS lead to significantly different comprehension outcomes compared to LT.
H_4. GRF and RoCS differ significantly from each other in their impact on student comprehension.

These hypotheses will be examined through both non-parametric and parametric statistical methods and discussed in relation to the final comprehension scores across experimental conditions.

2.2 Participants

The sample includes 61 second-year BA design students from IUAV University of Venice, aged 19 to 25. Gender distribution at the university is 39.8% male and 60.2% female, per Veneto Region statistics (Regione Veneto, n.d.).

The sample was tripartite: two experimental groups (23 subjects and 21 subjects) and one control group (17 subjects).

Age and gender were excluded, according to University policies and as directed by the ethics committee. The data collection and utilization adhered to current privacy regulations under the European GDPR framework.

An anonymous questionnaire revealed that none of the subjects had prior knowledge of the topic, allowing for the assessment of learning in a cohort with uniform baseline knowledge.

The students were administered the Cognitive Styles Questionnaire (CSQ) from the AMOS battery (De Beni et al., 2014), which allowed for the assessment of the sample's distribution across the analytical/global and verbal/visual axes. The scores reflect students' preferences rather than indicating any value differences.

2.3 Ethics

Each participant signed an informed consent form approved by the University's ethics committee. After consent, a unique five-digit code was assigned to match pre-test and final test results.

2.4 Materials

The assessments were administered online via the Lioness Lab platform.

2.4.1 Questionnaire 1

Questionnaire 1 was developed following the AMOS Battery "Questionario sugli Stili Cognitivi" (QSC) (De Beni et al., 2014). The QSC evaluates the student's position within the "global-analytical" and "verbalizer-visualizer" dimensions through two concrete learning situations.

The questionnaire consisted of several sections:

- **Likert scale questions**: The first part consisted of closed-ended questions where students rated their interest, competence, and enjoyment in optical physics on a 1–5 Likert scale.
- **Replication task**: The second part showed an image (De Beni et al., 2014) for 30 seconds, depicting a missile or pencil with detailed sections. Students were then asked to replicate the image on paper within the same time frame after it disappeared.
- **Timer display**: The third part included a timer indicating the remaining time to complete the task.
- **Self-evaluation questionnaire**: The fourth part included a Likert scale questionnaire for self-evaluating drawing and observation skills, assessing global and analytical competencies in the replicated image.
- **Recall task**: The fifth part displayed an image (De Beni et al., 2014) for 60 seconds, featuring figures and words. Students then transcribed all remembered elements within 60 seconds, without reviewing the image.
- **Verbal and visual competence evaluation**: The sixth part included Likert scale questions (1 to 5) for students to self-evaluate their verbal and visual competencies regarding the previously shown image.

2.5 Learning material

This one-page document was prepared for each group, summarizing the incident light flow on a surface.

Students studied their assigned material for 10 minutes.

The control group received a text summarizing the main concepts of luminous flux decomposition on a surface (Appendix 1), from which the other two prototypes were derived. To enhance information organization and space management in the prototype for experimental group 2 (Figure 5), the diagram was reoriented. The arrow colors matched those in the graph (Figure 6).

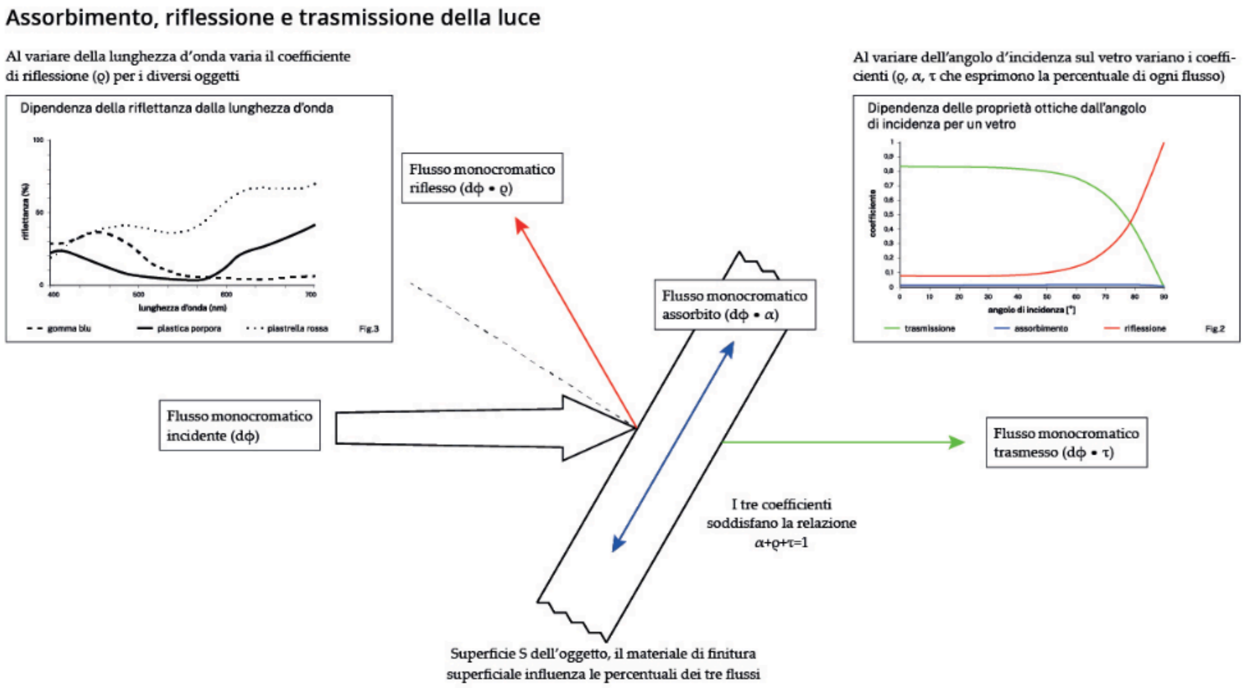

Figure 5 Prototype presented to experimental group 2.

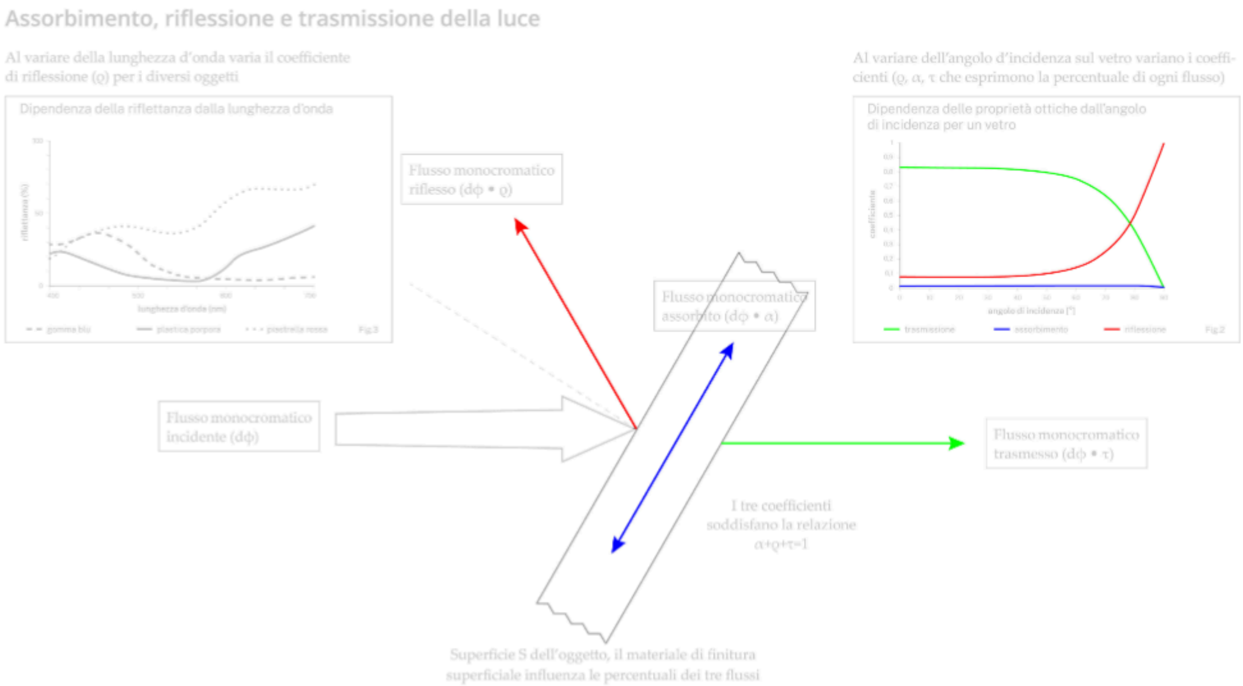

Figure 6 Correspondence between colors in the graph and diagram.

Three prototypes were developed, each corresponding to a different representation mode. Each included two charts and one diagram, with consistent forms and identical content and keywords (Table 1). In the experimental prototypes (GRF and RoCS), the text was deconstructed from standard Italian syntax and restructured graphically.

Table 1 Keywords used in the three prototypes.

Keywords
flusso monocromatico incidente (dϕ)
superficie S di un corpo
si scompone in tre aliquote
$\alpha + \rho + \tau = 1$
assorbimento, riflessione, trasmissione
percentuale di flusso espressa dai coefficienti
variazione del valore dei coefficienti
angolo di incidenza sulla superficie
lunghezza d'onda

Different documents have been prepared for different groups:

- **Control group (LT)**: The document was structured like a typical textbook page, featuring linear text, a separate diagrams, and two graphs (Figure 7).
- **Experimental group 1 (RoCS)**: A concept map of incident light flow was developed following Novak's principles (2009), integrating one figure and two graphs (Figure 8). This diagram was structured using a specific set of composition rules (RoCS).
- **Experimental group 2 (GRF)**: A diagrammatic visualization of the incident light flow was developed, integrating text and images. A reference system (GRF) was defined starting from the figure, with information juxtaposed (Figure 9).

The text and each prototype were validated by the physics teacher for content accuracy and alignment. The three visualization modes conveyed identical concepts with balanced content across modes (Figures 10 and 11), standardized to use consistent keywords (Figure 12) while varying only in arrangement to reduce confounding variables. Fonts, weights, and sizes were uniform across texts and graphs, and all elements were placed on 1790 × 980 px slides.

The learning materials, formatted as 1790×980 px slides at 72 ppi in .png format, were presented on individual laptop screens ranging from 13 to 15 inches. Despite minor variations in physical screen size and resolution, all devices provided consistent pixel density and visual hierarchy, ensuring comparable readability and perceptual experience across participants.

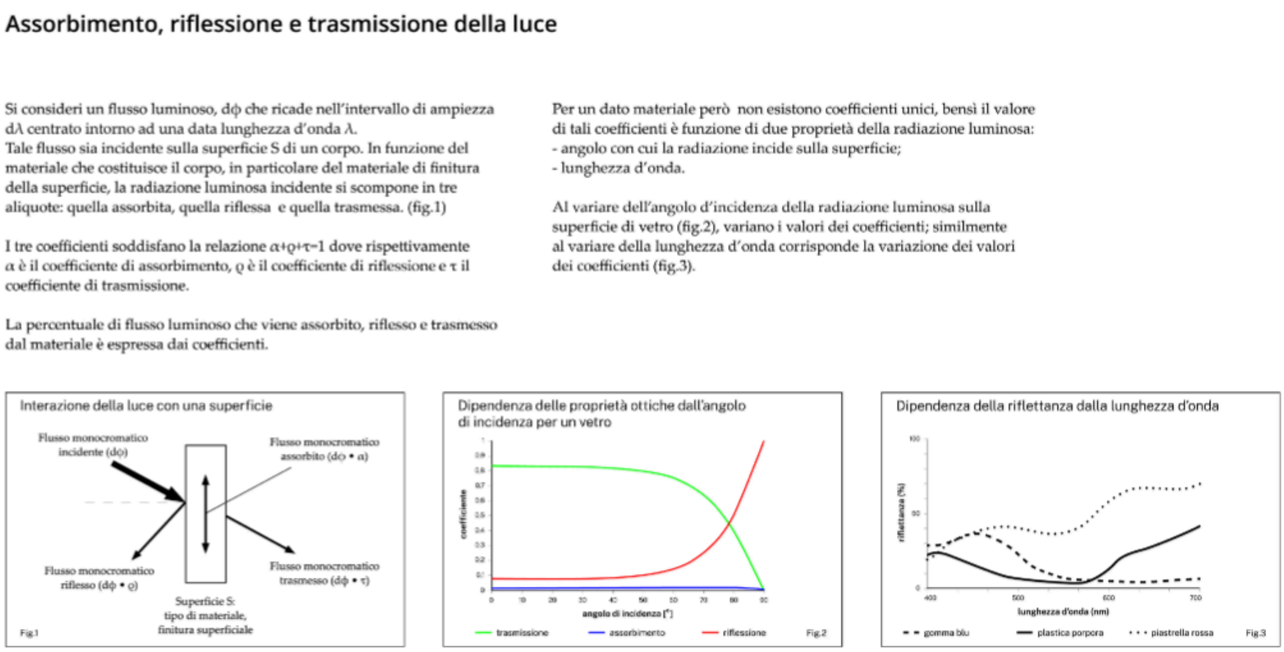

Figure 7 Prototype for the control group (LT), structured in a linear format, with images positioned after the corresponding text.

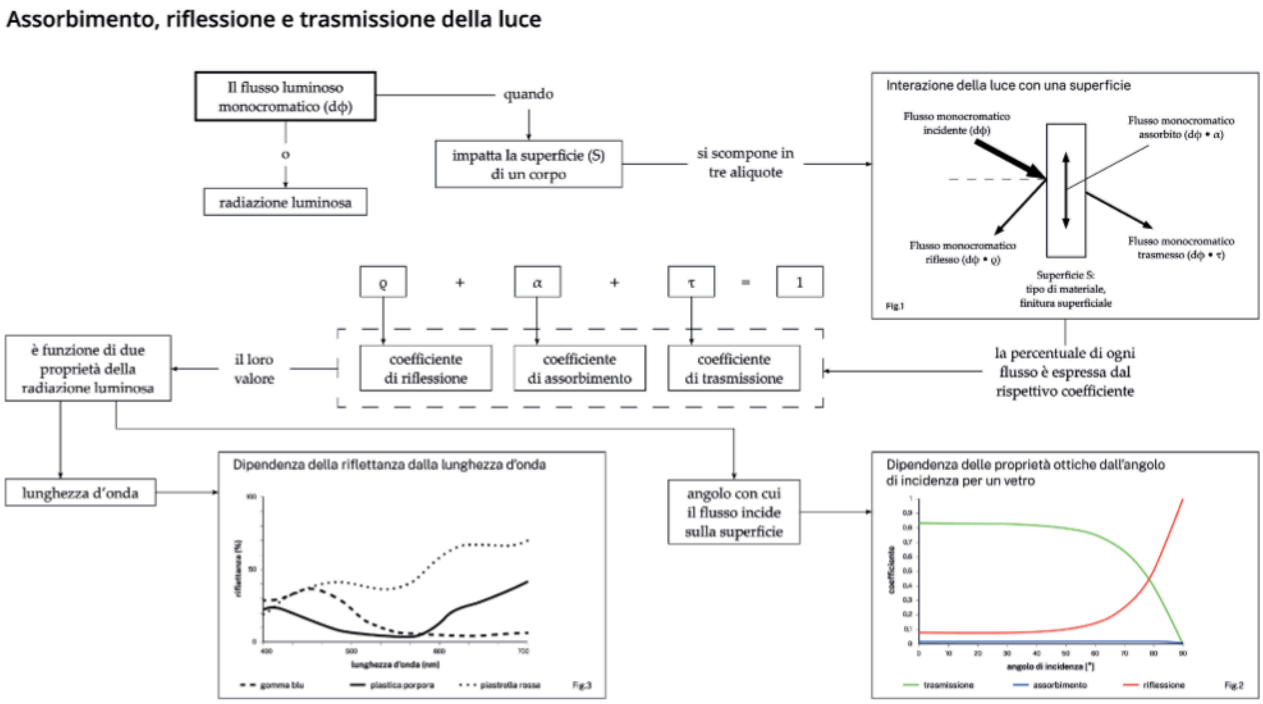

Figure 8 Prototype for experimental group 1 (RoCS), structured based on the principles of concept map theory.

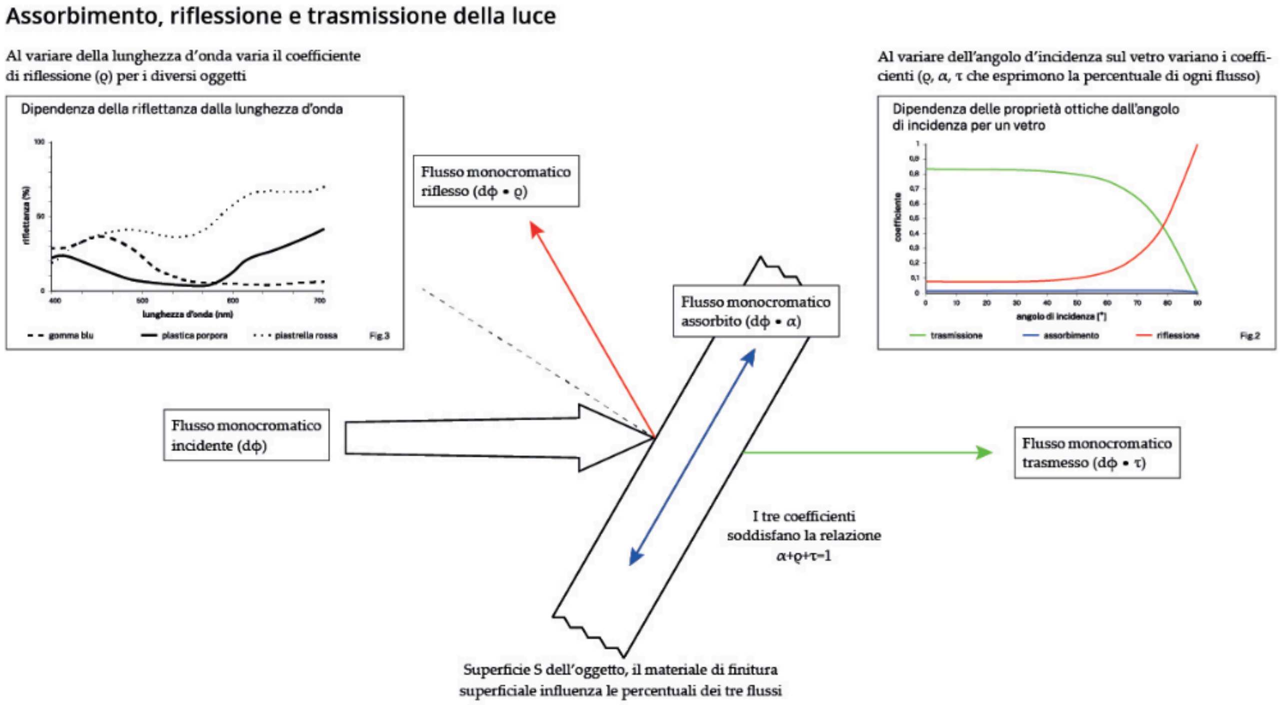

Figure 9 Prototype for the experimental group 2 (GRF), structured based on a reference system.

Titles were set in Open Sans Semibold at 30 px, body text in Palatino Linotype Regular at 20/26 px, and graphs used Open Sans in various weights and consistent sizes. Typeface and graphic elements were designed for legibility and proportionality within the specified screen range.

Considering the resolution of 227 ppi – the highest display resolution available on a laptop at the time of the experiment in 2021 (MacBook Pro 13", M1, late 2020–2021) – and assuming that the minimum x-height of a typographic character must subtend a visual angle of 0.2° for legibility (Legge & Bigelow, 2012), the required physical height of the x-height at a typical viewing distance of 40 cm gives a minimum x-height of approximately 1.396 mm.

This value is derived using the standard trigonometric relation between distance and visual angle.

The original slide (1790 × 980 px) was scaled by 163% to fill the height of the display (2560 × 1600 px). To preserve legibility under these conditions, the x-height on the original slide needed to be at least 11.5 pixels, corresponding to the minimum angular size of 0.2° at a 40 cm viewing distance on a MacBook Pro 13" Retina display.

Given that Open Sans has an x-height of 1012 units out of 2048 UPM, and Palatino has an x-height of 470 out of 1000 UPM, the corresponding minimum body sizes in the slide must be approximately 15.5 px for Open Sans and 16.2 px for Palatino. In practice, the font size used in the slide was 20 px – well above the minimum threshold for legibility.

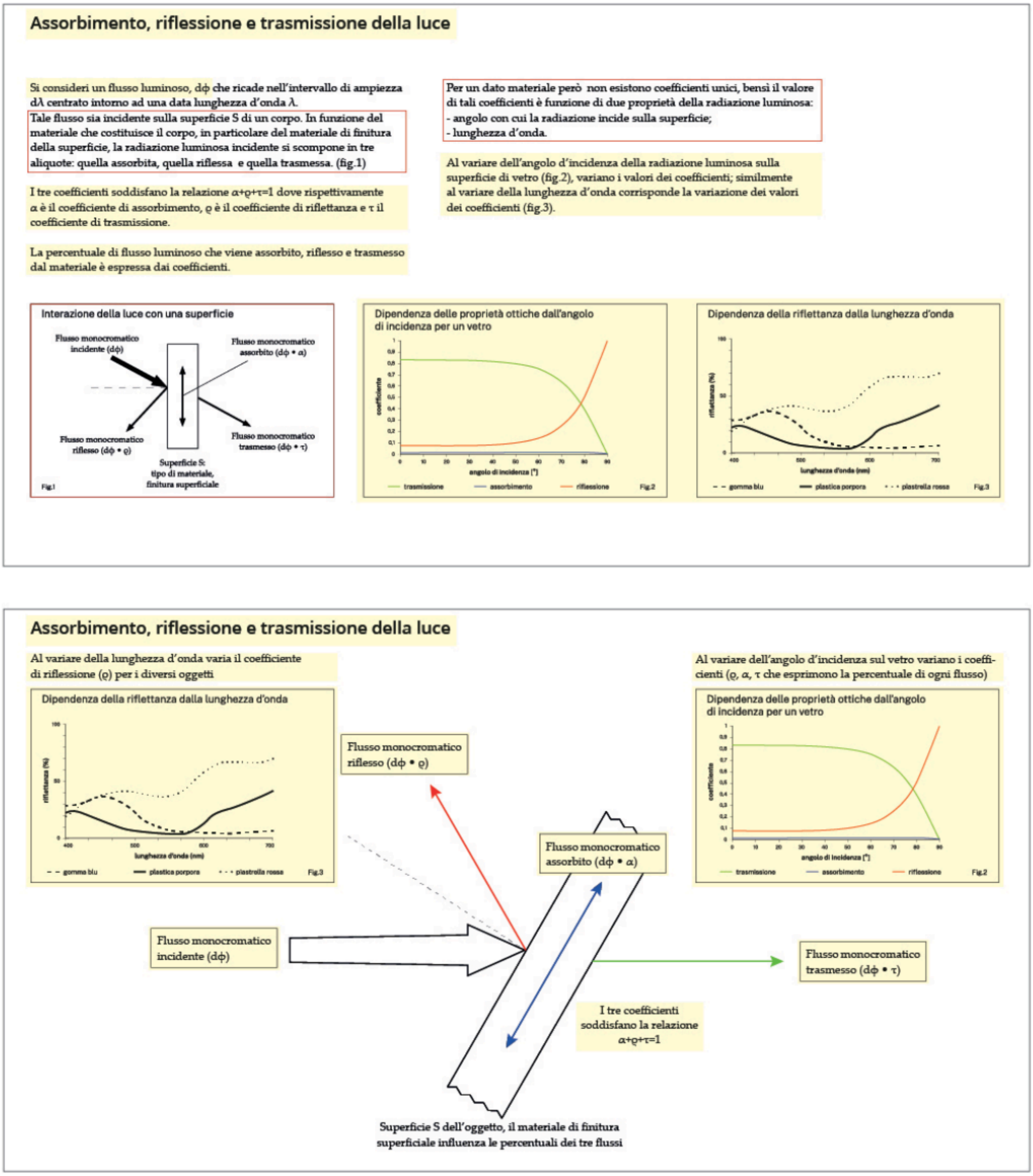

Figure 10 Comparison between contents of experimental prototype 2 and control prototype.

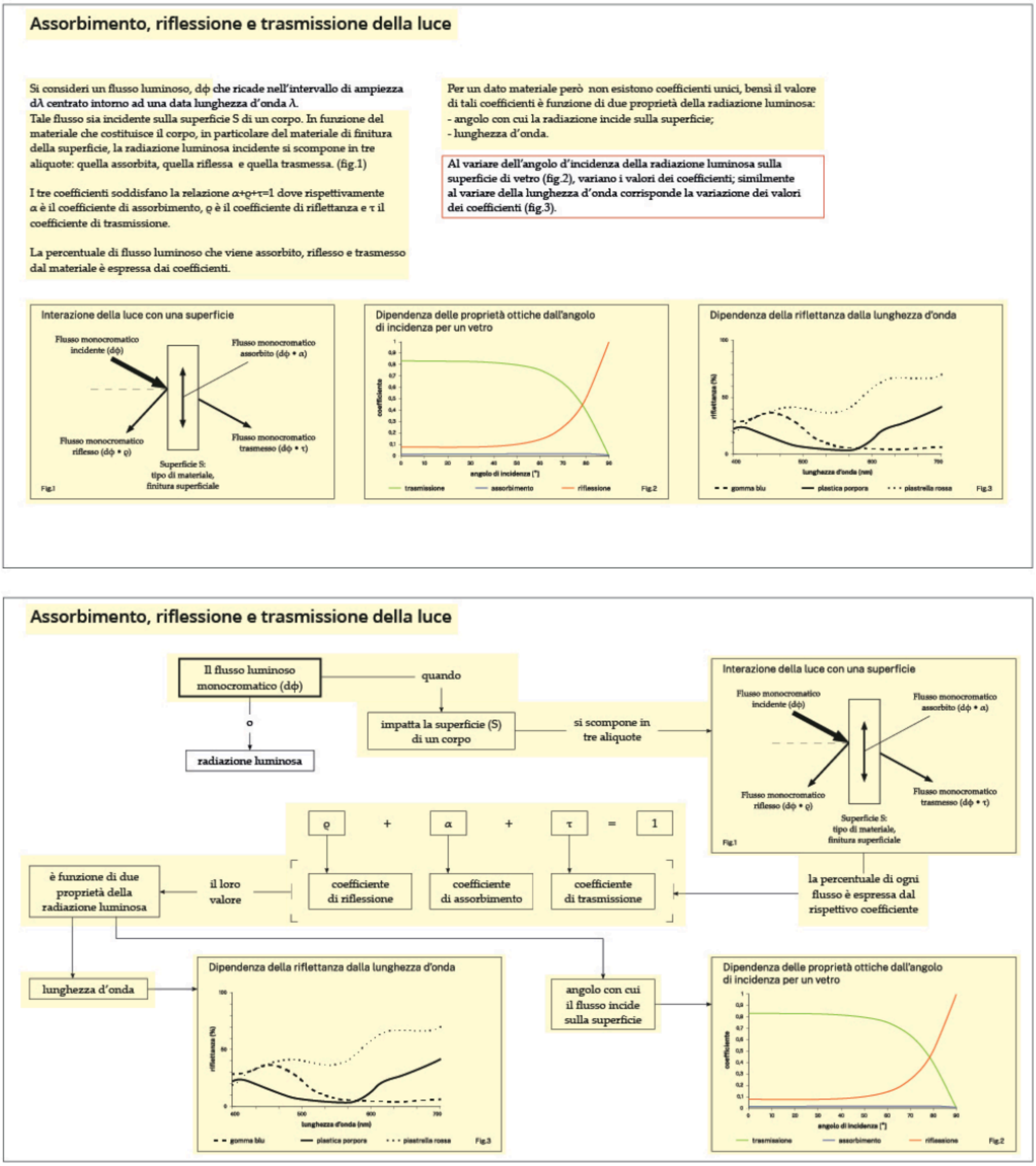

Figure 11 Comparison between contents of experimental prototype 1 and control prototype.

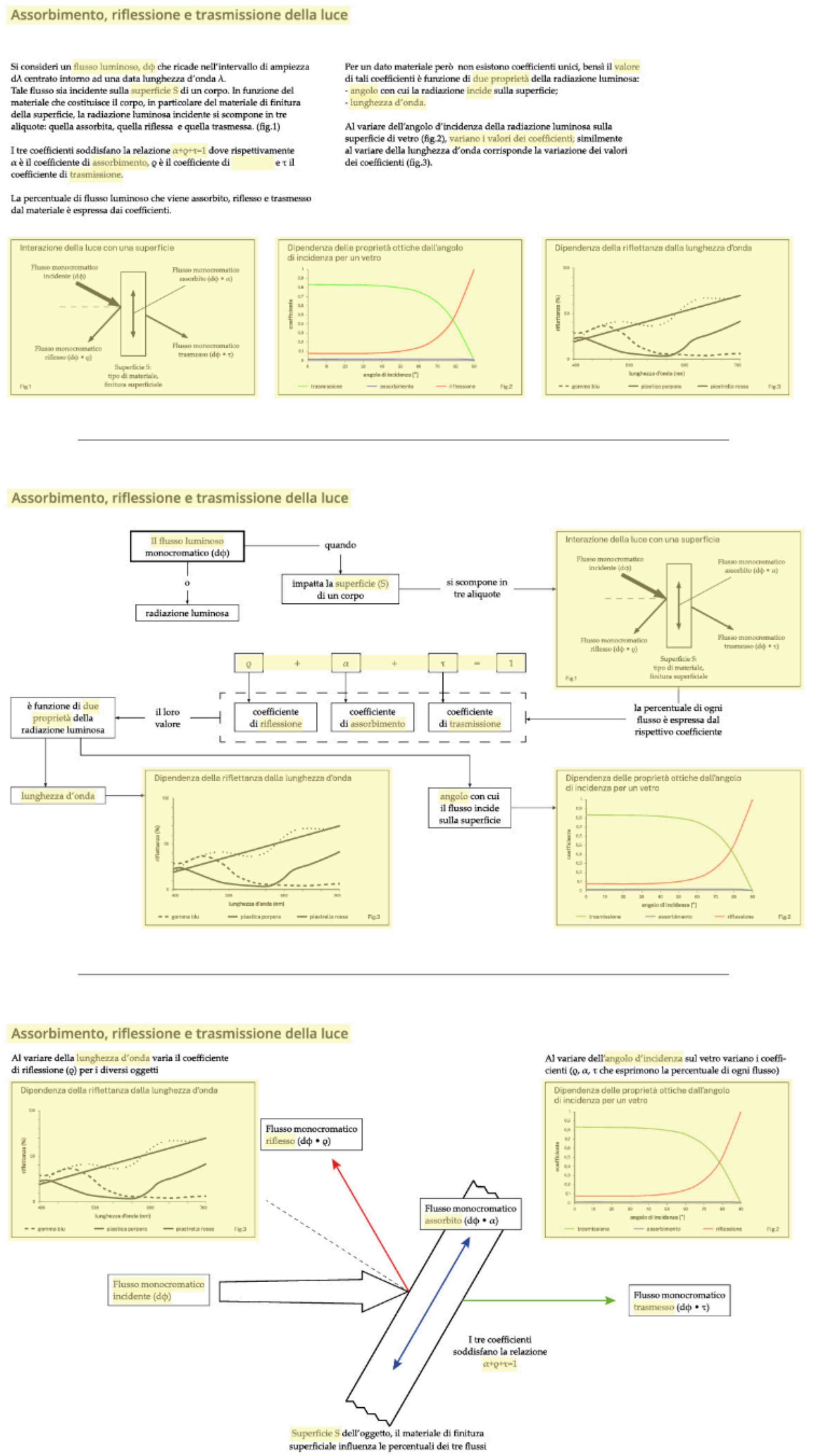

Figure 12 Consistent keywords and identical figures in prototypes.

2.6 Questionnaires 2

The questionnaires display a timer at the top for the remaining task time, with the study slide shown centrally.

The questionnaires consist of seven true/false questions aimed at evaluating text comprehension. Questions were developed specifically for this study, based on the first section of the Learning Assessment "The Prehistory of Africa" (De Beni et al., 2014). The statements directly relate to and paraphrase the content of the provided passage. The eighth question consists of a graph with an associated multiple-choice question (see Figure 13).

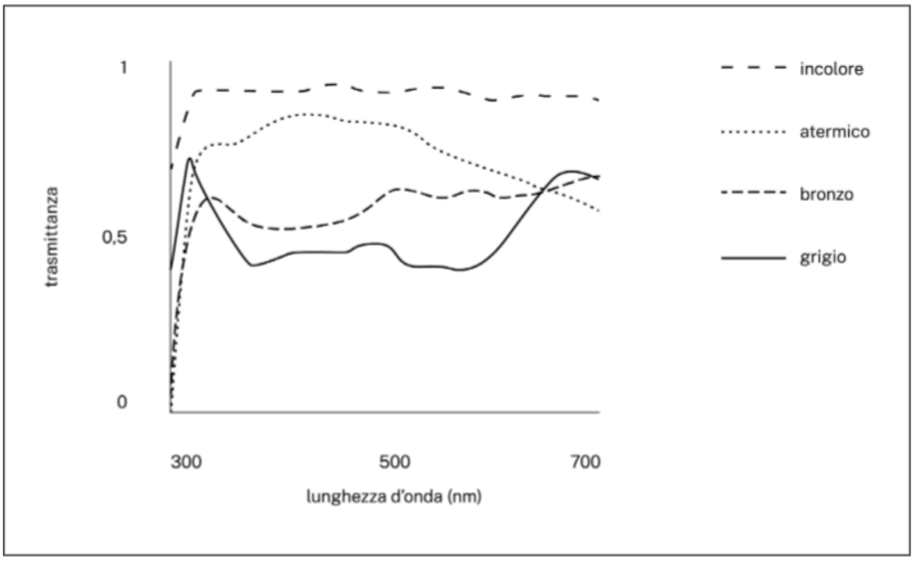

Figure 13 Graph of question eight from questionnaire 2.

2.7 Procedure

The professor delivered a lecture on technical physics, including topics such as the decomposition of luminous flux on a surface. At the end of the lesson, each participant received Questionnaire 1. Two weeks later, Learning Material and Questionnaire 2 were distributed so as to randomly divide the sample into the three experimental groups. Students studied their assigned material for 10 minutes before completing Questionnaire 2, without additional instructions to ensure their natural study approach was maintained.

3 Results

In a class of 120 students, 61 participated and were randomly tripartite: a control group and two experimental groups (Table 2).

Table 2 Distribution of sample.

Groups	Control	Experimental 1	Experimental 2
No. of participants	17	23	21

3.1 Questionnaire 1

Thanks to the results obtained from Questionnaire 1, it was possible to map participants' cognitive style preferences along the global/analytical and visual/verbal axes. This categorization does not correspond to the division into experimental groups, but it allows for an analysis of the distribution of these preferences across the entire sample in relation to learning.
The sample trends (Tables 3 and 4) aligned with cognitive style distribution percentages in the literature (De Beni et al., 2014). It is important to note that the division into experimental groups was made only after the administration of Questionnaire 1; however, we would like to provide a detailed overview of the distribution of cognitive styles within the sample. Participants with no strong preference were classified as non-oriented.
It should be noted, however, that cognitive style preference is neither fixed nor absolute; it is a dynamic process influenced by factors like cognitive adaptation to the presented information (Zhang & Sternberg, 2006).

Table 3 Distribution of preferences in global-analytical cognitive styles dimension.

Groups	Control	Experimental 1	Experimental 2	Total *n.* preferences
Global	6	8	9	23
Analytical	5	5	9	19
Not oriented	6	10	3	19

Table 4 Distribution of preferences in visual-verbal cognitive styles dimension.

Groups	Control	Experimental 1	Experimental 2	Total *n.* preferences
Verbal	5	9	8	22
Visual	6	6	6	18
Not oriented	6	8	7	21

3.2 Questionnaire 2

The comprehension variable underwent the Shapiro-Wilk test, yielding a p-value below 0.05, indicating a significant result and suggesting that the variable's distribution deviates from normality (see Table 5 and Figure 14).

Due to the non-normal distribution, attempts to normalize the comprehension variable using square root, logarithmic, and inverse (1/x) transformations were unsuccessful. Thus, only non-parametric tests were used for data analysis. Internal consistency of comprehension scores across groups was assessed with Cronbach's alpha, resulting in a value of 0.594 (see Table 6), indicating uncertain reliability, as it falls within the 0.4–0.6 range.

The Mann-Whitney *U* test was used to compare the two groups, assessing response homogeneity. All pairwise comparisons among the three groups were performed. For comparisons between Experimental Group 1 (RoCS) and the Control Group, as well as between Experimental Group 1 (RoCS)

Table 5 Shapiro-Wilk test scores.

Participants	61
Mean	7.36
Skewness	−1.05
Std. Error skewness	0.306
Kurtosis	0.778
Std. Error kurtosis	0.604
Shapiro-Wilk *W*	0.880
Shapiro-Wilk *p*	<.001

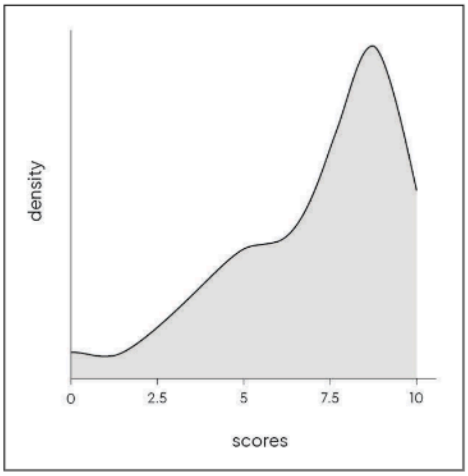

Figure 14 Shapiro-Wilk test density and scores.

Table 6 Cronbach's alpha excluding the item.

Item 1	0.544
Item 2	0.573
Item 3	0.552
Item 4	0.567
Item 5	0.530
Item 6	0.574
Item 7	0.606
Item 8	0.540
Cronbach's alpha of scores	
Scale	0.594

and Experimental Group 2 (GRF), the *p*-value was less than 0.05, indicating a violation of the homogeneity assumption and precluding further testing.

However, for the comparison between the Control Group and Experimental Group 2 (GRF), the *p*-value met the criteria for conducting the Mann-Whitney *U* test, as shown in Tables 7, 8, and 9. The test results reveal no significant score differences between these two groups, with similar mean values observed in both. Thus, the Control Group's results align closely with those of Experimental Group 2 (GRF).

Table 7 Mann-Whitney *U* test between the control group and the experimental group 2.

		Statistic	*p*		Effect size
Scores	Mann-Whitney *U*	155	0.475	Rank biserial correlation	0.132

Table 8 Test of homogeneity of variance (Levene's)

	F	*df*	*df2*	*p*
Scores	0.154	1	36	0.697

Table 9 Values of scores between groups compared.

Groups	*n*	Mean	Median	*SD*	*SE*
Control	17	8.31	8.75	1.46	0.355
Experimental 2	21	8.75	8.75	1.34	0.293

The Kruskal-Wallis test was used to assess differences in scores among the three experimental groups, due to the non-normal distribution of the score variable.

The *p*-value from the test was significant, indicating a significant difference in scores among the three groups (Table 10).

Pairwise comparisons were conducted to identify which specific groups exhibited significant differences.

The results of the pairwise comparisons, as shown in Table 11, indicate that there is no significant difference in scores between the Control Group and Experimental Group 2 (GRF). However, in the other two pairwise comparisons – between Experimental Group 1 (RoCS) and the Control Group, and between Experimental Group 1 (RoCS) and Experimental Group 2 (GRF) – the differences in group scores were found to be significant.

The mean scores indicating the understanding of the concept are similar between Experimental Group 2 (GRF) and the Control Group, whereas Experimental Group 1 (RoCS) shows different mean values compared to the other two groups.

Table 10 Kruskal-Wallis test.

	X^2	*df*	*p*	ε^2
Scores	9.45	2	0.009	0.158

Table 11 Pairwise comparison – scores.

		W	*p*
Control	Experimental 1	−3.76	0.022
Control	Experimental 2	−1.03	0.746
Experimental 1	Experimental 2	3.47	0.038

To further investigate score variations across the groups, the preferred cognitive style (global or analytical), as determined by the cognitive test administered to the experimental subjects, was included as a grouping factor.

A two-way ANOVA was conducted to determine whether there is an interaction between these factors and their effect on the score variable.

The *p*-value for the division of the three groups (Tables 12 and 13) is significant, indicating that the methods of conceptual schematization affected learners' comprehension. However, the division based on cognitive style preference (global vs. analytical) is not significant, with score values showing little difference across styles within the same group.

Table 12 ANOVA-scores.

	Sum of squares	*df*	Mean square	*F*	*p*
Group	50.45	2	25.22	6.114	0.004
Global – analytical	7.68	2	3.84	0.930	0.401
Group *g. – a.	15.98	4	4.00	0.969	0.433
Residuals	214.53	52	4.13		

Homogeneity of variances (Levene's)				Normality test (Shapiro-Wilk)	
F	*df1*	*df2*	*p*	Statistic	*p*
1.54	8	52	0.167	0.964	0.066

Table 13 Post hoc comparison-group.

Comparison	Mean difference	*SE*	*df*	*t*	Bonferroni's *P*	Cohen's *d*
Control – Experimental 1	2.108	0.663	52.0	3.180	0.007	1.038
Control – Experimental 2	0.296	0.706	52.0	0.419	1.000	0.146
Experimental 1 – Experimental 2	−1.881	0.670	52.0	−2.702	0.028	−0.892

Similarly, the interaction between the two factors was not significant, indicating that the primary factor influencing the scores is the method of schematization.

Only the Post Hoc values for group division were considered, revealing significant *p*-values between the Control Group and Experimental Group 1 (RoCS), as well as between Experimental Group 1 (RoCS) and Experimental Group 2 (GRF). These results show significant differences between these groups. However, no significant difference was found between Experimental Group 2 (GRF) and the Control Group.

The distribution of scores indicating the comprehension of the concept, categorized by experimental group and preferred cognitive style (global vs. analytical), as shown in Figure 15, reveals a significant difference in mean comprehension scores within Experimental Group 1 (RoCS) between different cognitive styles. Specifically, individuals with a global cognitive style exhibit significantly lower scores compared to those with an analytical or non-oriented cognitive style.

The same analysis was conducted to examine participants' preference for a visual or verbal cognitive style, yielding the following results: the *p*-values also indicate a significant difference between Experimental Group 1 (RoCS) and the other two groups in the Post Hoc analysis. It is noteworthy that, unlike the previously observed global-analytical style, the different orientation in preferred cognitive style (visual vs. verbal) does not significantly influence score values within the same group (Table 14 and 15 and Figure 16). Regardless of the preferred cognitive style, whether along the global-analytical or visual-verbal axis, the scores are consistently lower for Experimental Group 1 (RoCS), which was exposed to the prototype designed according to the structural rules of a concept map.

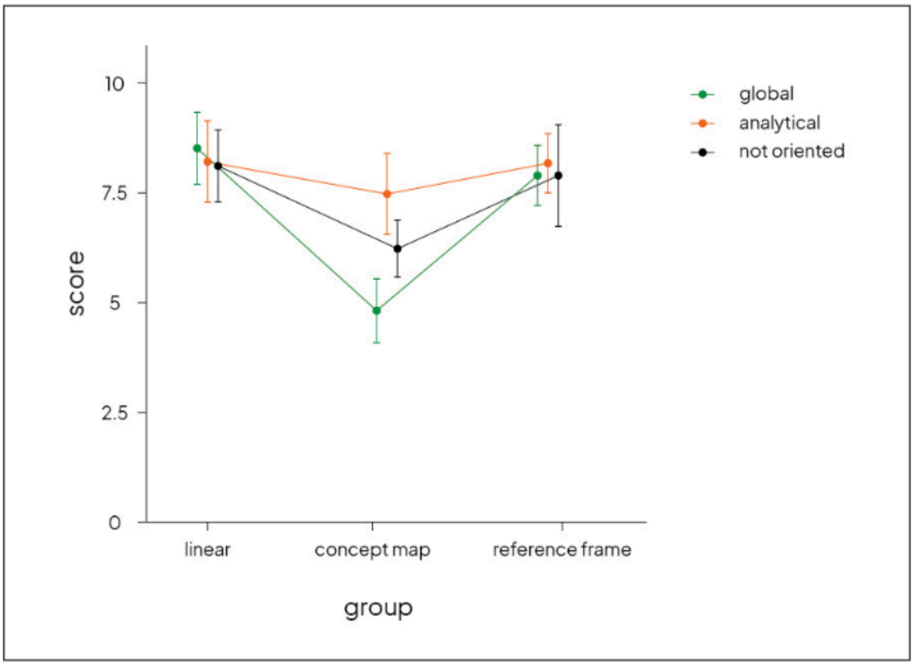

Figure 15 Distribution of scores global-analytical.

Table 14 ANOVA-scores.

	Sum of squares	*df*	Mean square	*F*	*p*
Group	64.57	2	32.283	7.303	0.002
Visual – verbal	5.79	2	2.893	0.654	0.524
Group *v. – v.	2.73	4	0.682	0.154	0.960
Residuals	229.86	52	4.420		

Homogeneity of variances (Levene's)					Normality test (Shapiro-Wilk)	
F	*df*1	*df*2	*p*		Statistic	*p*
2.92	8	52	0.009		0.975	0.255

Table 15 Post hoc comparison-groups.

Comparison	Mean difference	*SE*	*df*	*t*	Bonferroni's *P*	Cohen's *d*
Control – Experimental 1	2.242	0.678	52.0	3.306	0.005	1.0663
Control – Experimental 2	0.183	0.689	52.0	0.265	1.000	0.0868
Experimental 1 – Experimental 2	−2.059	0.641	52.0	−3.211	0.007	0.9795

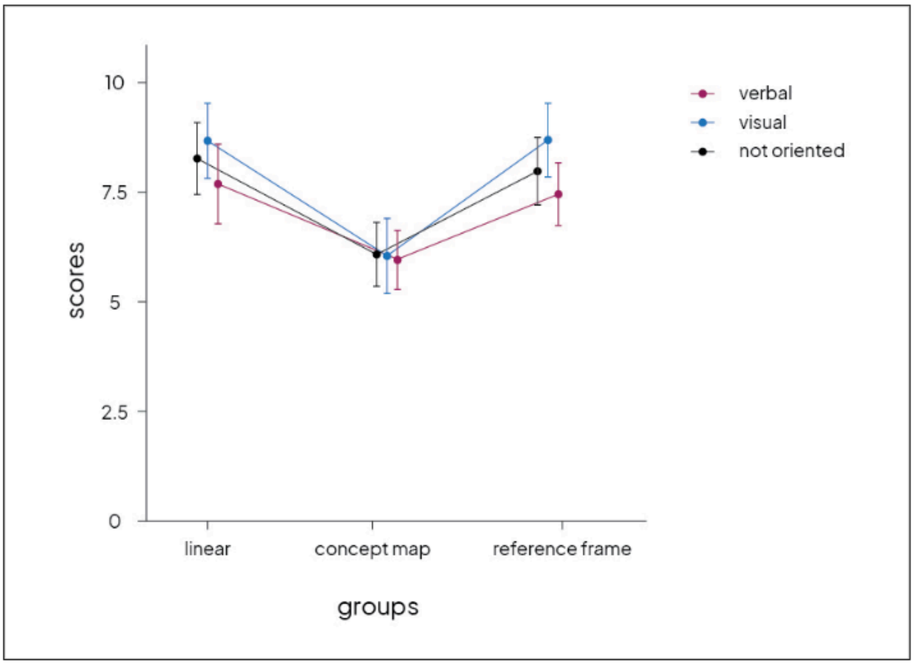

Figure 16 Distribution of scores verbal-visual.

4 Discussion

To test H_0, we examined whether there were any statistically significant differences in comprehension scores among the three schematization methods: linear text (LT), Graphic Reference Frames (GRF), and Rules of Composition Systems (RoCS).

The Kruskal-Wallis test yielded a significant *p*-value, indicating that at least one method differed from the others in its impact on comprehension.

This result provides evidence against the null hypothesis, suggesting that the choice of schematization method does, in fact, affect comprehension outcomes.

Therefore, H_0 is rejected.

To evaluate H_1, we compared GRF and RoCS individually against LT. Results indicated that comprehension scores for students using GRF did not significantly differ from those using LT, while students exposed to RoCS showed significantly lower scores.

This pattern supports the hypothesis that RoCS negatively impacts comprehension relative to LT, whereas GRF performs comparably to the control condition.

Thus, H_1 is confirmed.

H_2 was tested by examining whether GRF improves comprehension relative to LT while RoCS does not produce a significant difference. The results showed that GRF significantly outperformed LT, whereas RoCS did not differ significantly from LT in this comparison.

These findings partially support the expected outcome, but are in conflict with other hypotheses showing RoCS as less effective.

Therefore, H_2 is not supported, as the data suggest RoCS actually underperforms rather than remaining equivalent to LT.

H_3 predicted that both GRF and RoCS would lead to significantly different comprehension outcomes compared to LT. However, the statistical tests revealed that while RoCS differed significantly from LT, GRF did not.

This indicates that only one of the two alternative schematization methods deviated from LT in its effect on comprehension.

As a result, H_3 is only partially supported, and cannot be fully confirmed.

H_4 posited that GRF and RoCS would significantly differ from one another in their effects on comprehension. Pairwise comparisons confirmed that students using GRF scored significantly higher than those using RoCS.

This suggests a differential impact of these two non-linear formats, with GRF being more effective.

Consequently, H_4 is confirmed.

4.1 Cognitive style preferences

The analysis of Questionnaire 1 highlighted that the participants' cognitive style preferences, categorized as global-analytical or visual-verbal, were consistent with distribution trends reported in the literature (Zhang & Sternberg, 2006).

4.2 Comprehension scores and group differences and influence of cognitive style on scores

Comprehension scores from Questionnaire 2 showed significant differences, especially between Experimental Group 1 (RoCS) and the other groups. RoCS, using a concept map-based prototype, consistently had lower scores than both the Control Group and Experimental Group 2 (GRF). This suggests that while RoCS may work in some contexts, it was less effective than linear text or the GRF framework for enhancing comprehension in this group.

A two-way ANOVA revealed no significant interaction between cognitive style and group division, $F = .969$, $p = .433$ (see Table 12). Global and analytical learners performed similarly within groups, with schematization method being the main factor affecting comprehension (see Table 12).

In Experimental Group 1 (RoCS), a tendency can be observed whereby participants with a global cognitive style show lower comprehension scores compared to their analytical or non-oriented peers (see Figure 15). While this pattern is not statistically significant on its own, it suggests that the concept map structure – requiring relational and rule-based navigation – may pose greater challenges for global learners, who typically benefit from holistic overviews.

4.3 Visual-verbal cognitive styles

The analysis of visual and verbal cognitive styles revealed no significant influence on comprehension scores within the same group, suggesting that the preference for visual or verbal learning did not play a decisive role in the participants' performance ($F = .654$, $p = .524$, see Table 14). Regardless of their orientation toward visual or verbal learning, participants in Experimental Group 1 (RoCS) consistently performed worse than those in the other groups ($p = .005$ vs. Control Group; $p = .007$ vs. Experimental Group 2; see Table 15), reinforcing the idea that the concept map prototype was less effective across different cognitive styles.

5 Conclusion

The GRF composition is as effective as linear text, showing no inherent superiority of linear text over non-linear graphic methods. While RoCS is effective in other contexts, it is less effective here, particularly for global learners. These results highlight the importance of schematization methods in enhancing comprehension, with the interaction between cognitive styles and visual representation affecting learning. This relationship warrants further investigation. The findings support the literature on aligning schematization methods with cognitive styles but focus on inclusive content presentation during the initial learning phase for all students.

This study suggests that cognitive style alone does not account for variations in comprehension; instead, the interplay between instructional methods and cognitive tendencies plays a pivotal role in determining learning outcomes.

In conclusion, content schematization can be effective even in the early stages of learning. However, this study highlights that following the principles of GRF (Graphical Reference Frame) is preferable to RoCS (Rule of Composition System) for creating more inclusive instructional materials.

6 Limits and validity

This study provides valuable insights on methods of conceptual schematization in learning outcomes. Several limitations must be considered in interpreting the results, particularly. Sample Size and Generalizability: the relatively small sample size (n = 61) limits the generalizability of the findings. Non-Normal Distribution of Data: the non-normal distribution of comprehension scores posed a methodological limitation. Despite attempts to normalize the data through various transformations, the negative skewness persisted, requiring the use of non-parametric tests.

6.1 Conclusion on validity

Despite these limitations, the study presents valid findings regarding the relationship between cognitive style and conceptual schematization methods. The use of established cognitive assessments and the careful application of statistical methods ensure a reasonable level of internal validity. However, caution is advised in generalizing the results beyond the specific sample and context studied. Further research, with larger and more diverse samples, enhanced reliability measures, and a longitudinal approach, is needed to strengthen the external validity of these findings.

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