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Learning Mediated by Social Network for Education in K-12: Levels of Interaction, Strategies, and Difficulties

Aluisio José Pereira [1], Alex Sandro Gomes [1], Tiago Thompsen Primo [2], Rodrigo Lins Rodrigues [3], Ronaldo Pereira Melo Júnior [4] and Fernando Moreira [5,6,*]

1 Centro de Informática, Universidade Federal de Pernambuco, Recife 50740-600, Brazil
2 Centro de Desenvolvimento Tecnológico, Universidade Federal de Pelotas, Pelotas 83321-270, Brazil
3 Departamento de Educação, Universidade Federal Rural de Pernambuco, Recife 52171-900, Brazil
4 Departamento de Educação, Colégio Militar do Recife, Recife 50740-035, Brazil
5 REMIT, IJP, Universidade Portucalense, 4200-072 Porto, Portugal
6 IEETA, Universidade de Aveiro, 3810-193 Aveiro, Portugal
* Correspondence: fmoreira@upt.pt

Abstract: This study aims to capture evidence on the effectiveness of emergency remote learning mediated by educational technology according to the interaction levels of K-12 students. The study involved students from a public institution that adopted emergency remote learning during the COVID-19 pandemic. From a mixed approach that used quantitative and qualitative methods, data from 963 students were collected and analyzed on the domain and use of the virtual learning environment Redu. Data were collected through student interactions and classified according to eleven classes that were used to identify the level and characteristics of those interactions between students and educators. We also performed interviews with 13 students based on their interaction patterns (highly interact, sporadically interact, rarely interact) to characterize the students' interaction strategies within the virtual learning environment and strategies without the use of the virtual learning environment. It was found that students seek other means to interact and to send requests for help, regularly interact about school content, participate in discussions, and contact peers and teachers. The results can serve as a basis for proposing new functionalities for virtual learning environments.

Keywords: remote learning; interaction; K-12; educational technology

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1. Introduction

With the restrictions and measures of social distancing imposed by the COVID-19 pandemic, educational institutions adopted remote teaching as an emergency teaching strategy [1–3]. This teaching modality is characterized by the physical–spatial distance between students and teachers, and its advantages and disadvantages have been analyzed in several studies [4–10]. The use of digital technologies was fundamental during the closing period of universities and schools [11].

Using technologies to improve the teaching and learning process is commonly known as e-learning [12]. However, remote learning adopted in an unplanned, emergency way and through the sudden transition from face-to-face to remote classes created a different situation than e-learning in normal circumstances [13–15]. This represents an opportunity to assess the limits of the use of digital technologies and virtual learning environments (VLEs) and to be able to expand and evolve these products [16].

Given the conditions of transition from face-to-face to remote teaching, interactions between students, teachers, and school content emerge that transcend perceived relationships. Theories such as transactional distance explain these processes from the concept of transaction, which expresses the distance between environment, individuals, and behavioral patterns in each situation of dialogue (interaction) that occurs when teachers exchange words and other symbols with students, which allows for the creation of knowledge [17].

However, these interactions may have been affected because the interactions are direct with a degree of proximity between the subjects in a dialogue structure without the distancing factor (face-to-face interaction) [15,18]. Facing the social deprivation imposed by physical distancing meant the reduction of face-to-face social interactions and an increase in the use of digital media, which can harm teenagers' development and mental health [19].

Therefore, this work explores the use of the virtual environment Redu during its adoption in the pandemic caused by COVID-19. It is assumed that understanding the interactions involving students in the context of emergency remote teaching enables broadening of the knowledge about the teaching and learning experience in this modality and inspires the evolution of learning environments.

The study is organized into five sections. Section 2 presents the fundamentals of interactions in virtual learning environments described in the literature. Section 3 describes the method and processes of the quantitative and qualitative approaches. The results are exposed in Section 4. In Section 5, the discussions are deepened. Section 5 presents the final considerations of this study.

2. Theoretical Reference

Merriam-Webster's Dictionary (https://www.merriam-webster.com/dictionary/interaction, (accessed on 7 September 2020) defines interaction as action, mutual, or reciprocal influence. Interaction is constituted between humans as a need for contact with the environment (natural, artificial, or imaginary) and with other individuals. Some theories have emerged to explain these phenomena. Thompson [20] presents three basic types of interaction (face-to-face, mediated interaction, and mediated quasi-interaction) and adds a fourth type, online mediated interaction, given technological innovations. He describes that online mediated interaction is extended in space and time, has a range of symbolic and dialogic clues, and also a degree of interactivity for many individuals (ibid.). However, in the educational context, interactions must be associated with a formative perspective. For example, the interactions between peers benefit the learning of children and teenagers [21].

Including students as the central element, Moore [22] classified interactions in the educational context into three types: student–content, student–teacher, and student–student. Student–content interaction is linked to involvement with information and ideas conveyed by texts and other means. The student–teacher interaction is related to the didactic methods and strategies conducted by the teacher for the student to achieve better use in the teaching–learning process of content. On the other hand, student–student interactions reveal that students feel more motivated when working in pairs or groups, supported by the teacher [22].

Hirumi [23] did something similar but described three levels of interaction: (i) those that occur in the minds of students, (ii) those between students and human and non-human resources, and (iii) those that define e-learning strategies and guide the design and sequencing of interactions. At level (i), students individually establish a mental process for learning and a metacognitive process for self-regulation, which can be fundamental in online learning, as autonomy is important since the presence of instructors or colleagues to help is not constant. Level (ii) has the interactions (student–teacher, student–student, student–content, student–tool, student–environment, student–interface, student–other human interactions) related to student practices in an online course. Level (iii) is student–instruction interactions that involve the intentional planning of events to promote learning and guide the design and sequencing of level (ii) interactions. The author (ibid.) defends the intrinsic relationship between the three levels of interaction and emphasizes the importance of finding a balance between them to develop a course with acceptable results.

As for the interactions mediated online, other possibilities arise to be explored, for example, engaging several students in a discussion and collecting data that can be analyzed to provide an understanding of how they were constituted and what formative characteristics of interactions occurred to build models and capture learning patterns and provide adaptive support to students [24,25].

Thompson [20] indicates social networking sites (SNSs) as favorable scenarios to mediate online interactions. From an educational perspective, resources similar to those found on these sites are also available in virtual learning environments (VLEs), for example, in social networks in education that specialize in sharing resources (chats, forums, multimedia files, digital materials, possibility to make friends) that are similar to those found in SNSs [26–28]. They allow students to engage in activities such as following posts of digital materials and multimedia content, making comments and requests for help, performing exercises, sending and receiving messages, and participating in discussions in synchronous and asynchronous interactions.

Interactions through virtual environments can occur while students appropriate the resources available in the technologies, which happens differently [29–31]. Despite several studies about interactions in online learning, teachers often replicate interaction strategies from face-to-face courses in the online context [32]. However, the lack (or distortion) of multimodal communication elements to mediate technology-mediated interactions changes the form of communication [33,34]. Furthermore, the use of technologies can induce extra cognitive loads and reduce the capacity for social interaction [35]. It may be limiting factors in online-mediated interactions compared to face-to-face interactions. With this, instead of facilitating the dynamics of interactions, it increases the difficulties that students must deal with and consequently negatively affects their learning.

Thus, the literature brings some interesting aspects for understanding interaction processes. However, it is still incipient in terms of understanding the levels of interaction that are constituted by involving students. Specifically, the students suddenly moved to remote learning with interactions mediated by technologies and were used to educational contexts of basic education, traditionally organized in cycles of face-to-face activities. In this sense, this study differs as it aims to capture evidence of the levels and patterns of students' interactions in K-12 (elementary and high school) [36] at a public institution that adopted emergency remote education mediated by a virtual environment of a social network for education.

3. Methodology

3.1. Approach

To characterize the interactions between students who collaborate through virtual learning environments, we adopted a mixed methodological approach (sequential explanatory and exploratory strategy with collection and analysis of quantitative data in the initial stages of the research, followed by the collection and analysis of qualitative data) [37], descriptive and exploratory in nature, applied to a case study in an atypical context. The study was carried out during the pandemic caused by COVID-19, during which students practiced emergency remote teaching. This modality of completely remote interaction started to be practiced and circumstantially allowed collection of data on a virtual environment's use for eight months in K-12 (four K-9 classes in an elementary school and three K-12 classes in a high school). Data analysis allowed us to measure the impact of the virtual learning environment on the experimental population analyzed and allowed us to consider their interaction levels and perform categorization of student interaction strategies. The activities of understanding the problem domain, collecting, and analyzing data followed the flow shown in Figure 1.

For each step (Figure 1), the ways of collecting, processing, and analyzing the data from the virtual environment database are given (Sections 3.3 and 3.4), where the description of steps taken is presented, based on the CRoss Industry Standard Process for Data Mining (CRISP-DM) [38]. The collections, transcriptions, and analysis of the interviews followed the steps described (Section 3.5) and involved the organization, coding, and categorization through content analysis (interpretive content analysis: in this type of analysis, the objective is to interpret the meaning of the interviews and understand how the interviewees conceive the world), according to Bardin [39].

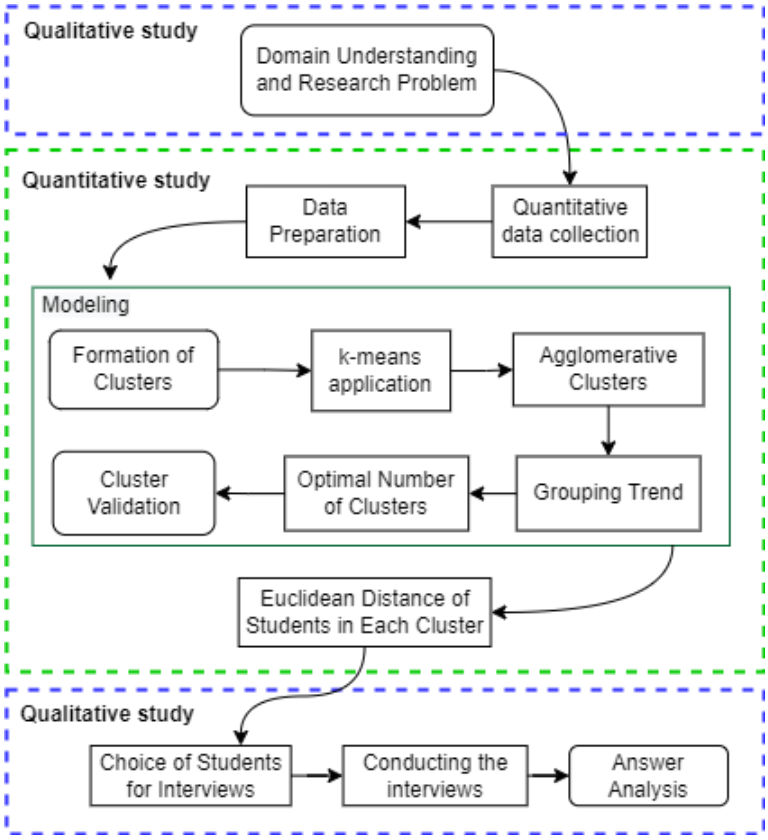

Figure 1. Process of data analysis from the use of the virtual environment.

This study aimed to characterize the interaction levels of students in K-12 who adopted a fully remote education on an emergency basis using the virtual learning environment Redu as a platform. The specific objectives were: to identify common behaviors and group students who use the virtual environment Redu in the context of the educational institution, based on their interactional patterns (quantitative analysis); to identify the essential needs of students in the interaction process in the virtual learning environment, and to categorize the unusual interaction strategies performed by students to overcome contingencies and meet their essential interaction needs (qualitative analysis).

3.2. Units of Analysis

The research was conducted during the year 2020. The pandemic caused by COVID-19 is a challenge for educational establishments. Isolation protocols, distancing, and suspension of activities in various sectors became initiatives to contain the advance of the health crisis. With schools closing in early April 2020, it was already possible to see the impact of COVID-19 [40].

In Brazil, legal regulations were instituted for students to remain in contact with the contents that would be taught at school through non-face-to-face activities defined by the Ministry of Education as "[. . .] *those to be carried out by the educational institution with students when physical presence in the school environment is not possible*" Parecer CNE/CP No: 5/2020 (Parecer CNE/CP No: 5/2020, 2020).

The implementation of the general legislation on remote teaching in Brazil was based on some regulations: Ordinance No. 343 of 17 March 2020, which allowed the teaching of traditionally on-site public schools to be carried out in a non-face-to-face teaching format [41]; Provisional Measure No. 934 of 1 April 2020 (converted into Law 14.040 of August 18, 2020), which established exceptional rules on the school year of basic and higher education resulting from measures to fight the pandemic [42]; and CNE/CP Opinion No. 5/2020, which established the reorganization of the school calendar and the possibility of

computing off-site activities to comply with the minimum annual workload, due to the pandemic [40].

In this context of discussions, the regulations made possible the flexibility of teaching practices and the inclusion of activities that were not allowed in the minimum workload. They made it possible for institutions to adopt mechanisms to provide continuity in teaching–learning practices. With this, a greater use of educational technologies was admitted as a pedagogical tool in remote learning. Thus, digital technologies have become essential tools for educational institutions to adapt to changes and assist students during the restrictions adopted to face COVID-19.

In March 2020, the Federal Public Institution of Basic Education, which is around 60 years old, located in Recife, Pernambuco, Brazil, adopted as a case study for this research, started to complete its school activities mediated by digital technologies considered as tools to promote teaching–learning replacing the functioning of on-site teaching in physical spaces. The Federal Public Institution has an infrastructure of 35 classrooms, laboratories, a library, exclusive room for reading, teachers and special assistance, a sports court, semi-Olympic swimming pool and outpatient sectors, support for inclusive education, teaching, and school community to serve a community of 963 students enrolled in the 2020 school year.

The virtual environment Redu is a social network for education, whose characteristic is to support the collaboration, discussion, and dissemination of multimedia content through specific communities that can be created in the environment to group people around issues or projects in common. In communities, members can interact with one or all members, enabling them to practice a mutual relationship of interaction around a subject from the materials (texts, documents, videos, presentations, and others) made available in the classroom.

3.3. Collection Techniques: Digital Data and Pre-Processing in the Virtual Environment

Documents requesting authorization to research the institution and access to the environment and their data on the use of the virtual environment Redu were prepared to carry out the collections. Student data in the virtual environment Redu were collected directly from the environment database from March to October 2020, a period in which most interactions were expected to occur in the virtual environment.

As they are academic and private data of users, before being passed on to researchers, they were anonymized by a team from the institution itself. Personal information (name, surname, email) and sensitive information (login and password), respecting the General Law for the Protection of Personal Data (http://www.planalto.gov.br/ccivil_03/_ato2015-2018/2018/lei/l13709.htm, (accessed on 1 October 2020), were replaced by information that would make them anonymous. In the names, surnames, and logins, the original information present in the database was replaced by "anonymous 1", "anonymous 2", "anonymous n". For the email, a similar approach was followed, replacing the username with "anonymous.{1, 2, . . . , n}@domain.com". Both cases followed a sequence up to the limit, according to the auto-increment associated with each identifier. For passwords, the information was removed from the copy of the database provided for conducting the research.

3.4. Analysis Processing: Digital Data Modeling and Clustering

It was sought to initially understand a set of 36 variables associated with users (students) present in the database, relating to constructs such as common objectives, interaction, communication, engagement, participation, collaboration, and time management to provide an analysis structure that would allow it to be directly associated with the research problem.

A group of experts in education, sociology, performance analysis, and educational data mining was mobilized to select the variables that could best produce evidence on the students' interaction profile. They acted in consensus to identify and group the variables whose descriptions could generate relevant knowledge about the interaction profiles.

To reach the consensus, the experts discussed among the 36 variables collected from the virtual environment Redu those that could help classify and identify the interaction profiles. The average of scores related to the relevance attributed by the experts to each variable was calculated after voting. The committee's work allowed the definition of 11 variables (VAR01 to VAR11) used as the basis for this study, as shown in Table 1. The virtual environment database was consulted, and values related to the variables were collected through SQL scripts.

Table 1. Selected variables to conduct the analyses.

Variables	Description
STUDENT_ID	Sequential unique identifier of the database for the student
CLASS_ID	Identifier of the class in which the student is enrolled
SERIES	Name of the class in which the student is enrolled
LEVEL_EDUCATION	Level of K-12 education that the student is at
LOGIN_COUNT	Number of accesses to the virtual environment performed by the student
REGISTRATION_YEAR_USER	Year in which the student was registered in the virtual environment
DAYS_LAST_LOGIN	Most recent access in the virtual environment
VAR01	The overall number of friends
VAR02	Number of friends who are students
VAR03	Number of different colleagues that the student sent messages to
VAR04	The overall number of messages sent by the student
VAR05	Number of messages sent (student–student)
VAR06	Number of messages sent (student–teacher)
VAR07	Number of exercises completed by the student
VAR08	Number of help requests
VAR09	Number of comments made by the student
VAR10	The overall number of responses to posts received by the student
VAR11	The shift of the day that the student commented the most

To better structure the data, carry out the clustering process, and allow for redundancy and traceability control, they were organized with the designations shown in Table 1: "STUDENT_ID", "CLASS_ID", "SERIES", "LEVEL_EDUCATION", "LOGIN_COUNT", "REGISTRATION_YEAR_USER", "DAYS_LAST_LOGIN", "VAR01", "VAR02", "VAR03", "VAR04", "VAR05", "VAR06", "VAR07", "VAR08", "VAR09", "VAR10", "VAR11".

During the pre-processing of the collected data, three duplicate records and 54 records of students who had been registered in the previous school year but had no access to the virtual environment in 2020 were removed. Therefore, there was no record to be consulted during the study period. Missing data values were removed or assigned, and the presence of outliers was attested. If no corresponding value was found in the query of numeric variables (VAR01 to VAR10), 0 (zero) was assigned, as this is the likely reason why the query did not find a result, that is, there was no quantity to be returned and assigned to a variable. As for categorical data (VAR11), a dummy class was created for missing data. That is, when there were no records for the variable (VAR09) because the user (student) did not make comments, there was no shift with more comments (VAR11). Data related to K-9 (elementary school students) were disaggregated from those of K-12 (high school students) to conduct the analyses separately. As a result of this process, 504 records were obtained for elementary school students and 459 records for high school students.

In the modeling phase, clusters were performed using the R (https://www.r-project.org/about.html, accessed on 11 December 2020) data analysis language. According to Kassambara [43], before applying clustering algorithms to the dataset, it is necessary to evaluate the clustering tendency to confirm whether the clustering application is adequate for the dataset and define how many clusters there are. The fviz_nbclust() (https://rdrr.io/cran/factoextra/man/fviz_nbclust.html, accessed on 11 December 2020) function allowed us to estimate the number of clusters based on data analysis. k = 4 was identified as the variation of clusters and in addition to this number of four clusters had little value for elementary and high school data.

The allocation of students to each group was performed in an unsupervised way, with the k-means algorithm assessing the clustering tendency, identifying the appropriate

number of clusters (k) for the collected data considering elementary and high school as a parameter. The algorithm used for this classification was that of Hartigan and Wong [44], which defines the total variation within the cluster as the sum of squared distances with the Euclidean distances between items and their corresponding centroids [45].

Considering the pre-specified number of clusters (k = 4) to be formed and that the numerical variables (VAR01 to VAR10) observed had equal weight to define the level of student interaction, the normalization of variables used the preProcess() (https://topepo.github.io/caret/pre-processing.html#the-preprocess-function, accessed on 17 December 2020) function, a range option that consisted of transforming the values of the variables in the same order of magnitude for the interval between 0 (zero) and 1 (one). The normalized base was assigned to a df variable by scaling only the numeric variables VAR01 to VAR10. The code in R described the association made: kmeans (df, x, iter.max = 10, nstart = 25), where: df: the data frame of the numerical variables VAR01 to VAR10; x: the number of clusters (k), x = 4 was used; iter.max: maximum number of iterations; default value of iter.max = 10; nstart: random partition numbers.

We arbitrarily specified nstart = 25 so that R would randomly look for 25 different ways to start selecting the best matching results for the algorithm. The formation of clusters was validated to assess the results of the grouping. The eclust() (https://rdrr.io/cran/factoextra/man/eclust.html) function in R: eclust(df, FUNcluster = c("kmeans"), k = NULL, k.max = 10, nstart = 25, graph = TRUE, hc_metric = "euclidean", hc_method = "ward.D2"), where: df: the data frame of the numerical variables VAR01 to VAR10; FUNcluster: the grouping function, in this case, the "kmeans"; k: number of clusters. By assigning the NULL value to k, the number of clusters was statistically estimated by the function to provide silhouette information for the k-means partitioning. k.max: maximum number of clusters which by default is 10; nstart: random partition numbers. We specified nstart = 25; graph: if TRUE, the graph was displayed; hc_metric: metric used, in this case, the Euclidean distance; hc_method: agglomeration method, in this case, ward.D2.

The Euclidean distance of each student to a centroid element for each cluster formed from the application of k-means was obtained after identifying the groups of students for elementary and high school. The centroid point was calculated as the mean values of each variable in each cluster. The Euclidean distance of each student in the respective cluster to this centroid point was calculated from the following metric:

$$D(x, c) = \sqrt{\sum_{i=1}^{n} (x_i - c_i)^2}, \quad (1)$$

where: D is the Euclidean distance between the patterns $x_i - c_i$ in the 2-dimensional space (also known as 2D space, 2-space, or Euclidean plane); x is the dimension (student) to be checked; c is the representative centroid point of the cluster. The calculated Euclidean distance served as the basis for the choices made by the students who participated in the semi-structured interviews. The following criteria were considered to characterize how each student moves away from the centroid point:

- nearest to the centroid (NC): students who are at the level of interaction closest to the center point of the interaction levels;
- farthest from the centroid (FC): students who are at the level of interaction farthest from the center point of the interaction levels between students in each group;
- centroid middle distance (CMD): students who are at an average distance relating to the closest and the most distant in each group;
- centroid median distance (CMeC): students who are in the larger half (closer to the center point and average distance) and smaller half (closer to the farthest and average distance).

Correlation matrices were also generated using the Pearson correlation coefficient through the cor() function of the ggcorrplot (https://briatte.github.io/ggcorr/, accessed on 1 December 2020) package with values between −1 and +1, to identify which variables correlated, where: correlation values equal to or close to −1 (i.e., $-1 \leq \text{corr} < -0.33$),

the variables correlate negatively; if close to or equal to zero (i.e., $-0.33 \leq \text{corr} \leq 0.33$), there is no correlation; if equal to or close to +1 (i.e., $+0.33 < \text{corr} \leq +1$), the variables are positively correlated.

3.5. Collection Techniques: Qualitative Data on Interactions between Participants

The qualitative stage of the research aimed to understand the interactions between members of the identified groups. A free and informed consent form was drawn up to conduct the interviews for students over 18 years and those responsible for students under 18 years. Steps to formalize requests for authorization to conduct the research based on ethical and moral precepts were carried out, a necessary criterion for researching with spontaneous volunteers.

The stage was carried out through semi-structured interviews guided by the questions presented in Table 2. From its answers, it was sought to identify the contingencies and strategies experienced by students through and outside the virtual environment to ensure the necessary interactions.

Table 2. Interview questions.

#	Questions
1	What changes have you noticed from face-to-face to remote classes?
2	How was your experience as a student in remote classes? Could you give examples of situations?
3	What were your principal difficulties in interacting with colleagues and teachers? Could you tell me how it happened?
4	Have learning groups (study groups) been formed for interaction among students? How did it happen? Could you tell/report it?
5	What kind of interactions with other peers or teachers did you enjoy most during remote classes? Detail remarkable cases.
6	How and through what means did you raise questions and resolve your doubts in remote classes? Try to describe examples.
7	When you needed help with some content or activity, how did you proceed (what did you do)? Could you give examples?
8	How did you go about tracking remote classes? How was it organized?
9	Tell us episodes in which you were interacting with colleagues or teachers to solve a learning difficulty. Describe how it happened.
10	What were the practices/methods of the teachers' performance that helped you in your studies? Mention it through examples and episodes.
11	What requirements do you consider essential for your studies and were unable to meet through the virtual environment Redu?

Note: #—enumeration of questions.

Nineteen elementary school students and twelve high school students were selected for interviews based on the criteria of distance from the centroid point (Section 3.4).

3.6. Analysis Processing: Qualitative Data on Interactions between Participants

They were distributed according to distance criteria, as follows: NC: three from high school and six from elementary school; FC: four from high school and four from elementary school; CMD: three from high school and four from elementary school; CMeD: two from high school and five from elementary school, with at least one representative student of each criterion per cluster. Thirty-one students were invited, selected through the institution's internal communication. Feedback from 24 students was collected, and among them, ten students did not volunteer, and one student canceled the scheduled interview. In the end, 13 students participated in the interviews, eight from elementary school and five from high school. Table 3 presents the profile of the 13 students interviewed.

The interviews occurred through videoconference and were recorded in a multimedia file for further analysis. The files were named from the sequence of execution for the pilot students (ApA, ApB, ApC) and other students (A01 to A10).

Each interview proceeded with its adapted transcript (standard) with corrections of verbal and nominal agreement and no record of interruptions (ahem, okay, cool), language vices (okay, yeah, then, so), and word repetitions (yes, yes). The documents resulting from the transcripts were separated by interviewees and grouped by questions asked, and stored in different files. The contents were analyzed using NVivo® 12 [46].

Table 3. Profile of students participating in the interviews [1].

Students	Class	Teaching	Cluster	Criterion	Length of Study at the Institution	Had Contact with Remote Learning	Interaction Level
ApA	2nd year	HS	Cluster 4	CMD	2 years	Previously	S. I.
ApB	2nd year	HS	Cluster 4	CMD	4 years	Only in 2020	S. I.
ApC	2nd year	HS	Cluster 3	CMD	4 years	Only in 2020	R. I.
A01	2nd year	HS	Cluster 4	FC	1 year	Only in 2020	S. I.
A02	9th year	ES	Cluster 2	NC	4 years	Only in 2020	S. I.
A03	8th year	ES	Cluster 2	CMeD	1 year	Previously	S. I.
A04	7th year	ES	Cluster 4	CMeD	2 years	Only in 2020	H. I.
A05	6th year	ES	Cluster 4	CMD	7 years	Only in 2020	H. I.
A06	9th year	ES	Cluster 2	CMeD	1 year	Only in 2020	S. I.
A07	9th year	ES	Cluster 3	FC	3 years	Only in 2020	R. I.
A08	8th year	ES	Cluster 2	CMeD	2 years	Only in 2020	S. I.

[1] ApA, ApB, and ApC: codification of the pilot students interviewed; A01 to A10: coding of interviewed students; ES: elementary school; HS: high school; NC: closer to the centroid; FC: furthest from the centroid; CMD: mean distance from the centroid; CMeD: median distance from the centroid; H. I.: highly interact; S. I.: sporadically interact; R. I.: rarely interact.

For the analysis of the transcribed answers from the interviews (its results are in Section 4.2), the steps were followed according to Bardin [39]. It was divided into three main steps: (i) categorization of speech excerpts inductively through codes; (ii) quantitative review and unification of similar codes; (iii) analyzing related categories through word similarity indicators. Finally, the Pearson correlation coefficient was used [46] to assess possible causal and associative relationships between the codified categories to provide an understanding of the difficulties and interaction strategies of students from the hierarchical grouping.

4. Results

Analyzing the quantitative data from the interaction of students in the virtual environment allowed us to group students by interaction levels. It also allowed delimiting a sample set of the experimental population to be interviewed. From the interviews, evidence was collected that qualified the interactions in the context of remote education. The results of these analyses are in the subsequent sections.

4.1. Grouping of Students by the Similarity of Interaction Patterns

Section 4.1.1 presents the clustering results from the analysis of values collected for variables related to 504 elementary school students, and Section 4.1.2, the 459 high school students. In Section 4.1.3, we present the results of the patterns identified by unifying the results obtained between the levels of interaction of students in elementary and high school.

4.1.1. Interaction Levels of K-9 Students

Four clusters were formed for K-9 (elementary school students). In an unsupervised way, the clustering algorithm distributed the students as follows: 5 (1%) students in cluster 1, 164 (32.5%) students in cluster 2, 298 (59.1%) students in cluster 3, and 37 (7.3%) of the students in cluster 4. Figure 2 shows the box plots of each variable (VAR01 to VAR10), with normalized values (scale from 0 to 1), for each cluster.

It is possible to see from the graphs (Figure 2) that the dispersion of values in the dataset for students grouped in clusters 1 and 4 has a higher interquartile range than those in clusters 2 and 3. To understand this situation, Table 4 presents the mean and percentage values of the variables for each cluster. It is possible to verify that in cluster 1, the overall number of messages sent by the students (VAR04) has an average of 524 (91.4%), messages sent student–student (VAR05) have an average of 516.6 (94.8%), and these are the highest values relating to the other variables observed. The other groups have similar behaviors.

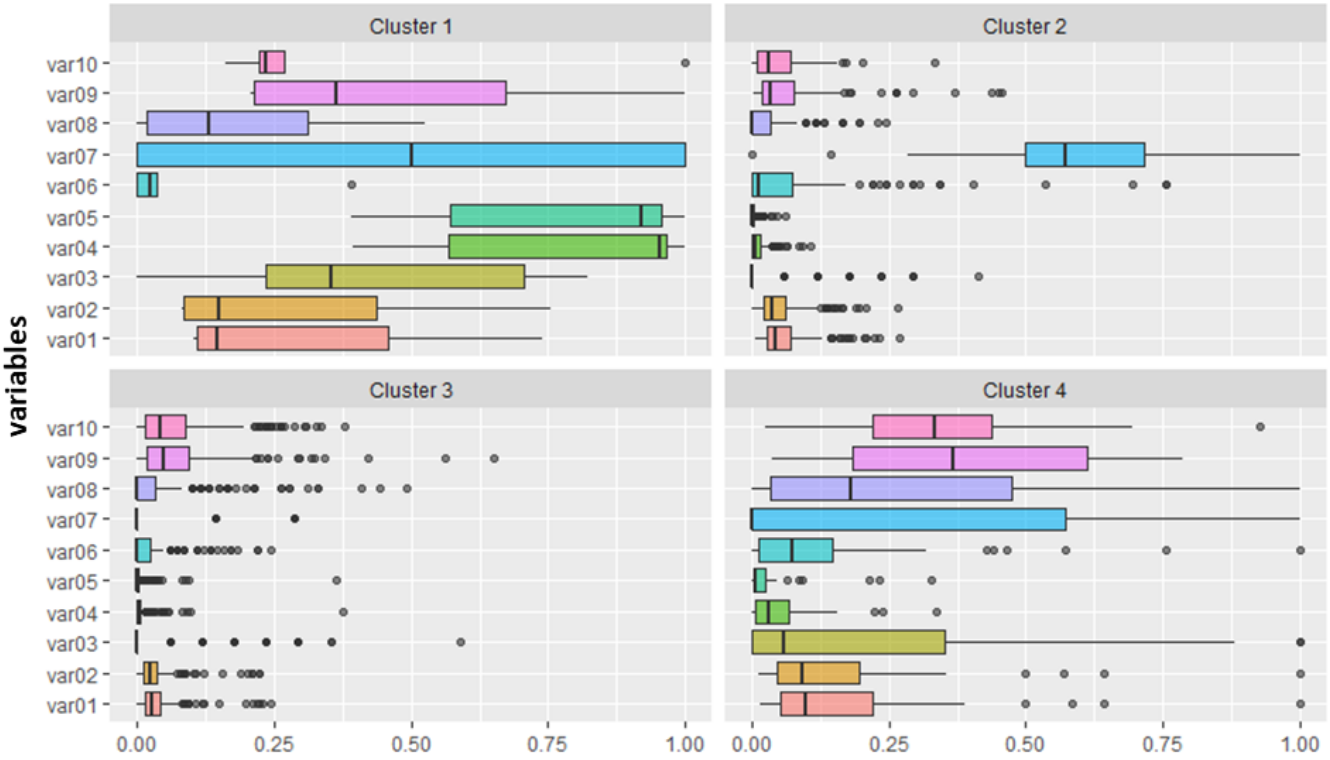

Figure 2. Frequency of occurrence of variables for K-9 clusters (clusters 1 and 4 higher interactions, and clusters 2 and 3 lower, visually perceived from the analysis of the box plot graphs).

Table 4. Average of the variables for each group of K-9 students.

Variables	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Average of Variables
VAR01	195.4 (53.2%)	36.40 (9.9%)	21.31 (5.8%)	113.86 (31.0%)	91.74
VAR02	162.8 (54.7%)	27.29 (9.2%)	16.24 (5.5%)	91.54 (30.7%)	74.47
VAR03	7.2 (60.2%)	0.52 (4.3%)	0.47 (3.9%)	3.78 (31.6%)	2.99
VAR04	524 (91.4%)	7.66 (1.3%)	4.28 (0.7%)	37.43 (6.5%)	143.34
VAR05	516.6 (94.8%)	2.04 (0.4%)	2.74 (0.5%)	23.73 (4.4%)	136.28
VAR06	7.4 (27.2%)	5.46 (20.1%)	1.49 (5.5%)	12.86 (47.3%)	6.80
VAR07	0.6 (11.3%)	3.28 (61.9%)	0.07 (1.3%)	1.35 (25.5%)	1.33
VAR08	12 (37.0%)	1.48 (4.6%)	2.12 (6.5%)	16.81 (51.9%)	8.10
VAR09	284.4 (48.9%)	38.69 (6.6%)	39.58 (6.8%)	219.24 (37.7%)	145.48
VAR10	81.8 (45.2%)	10.10 (5.6%)	13.89 (7.7%)	75.03 (41.5%)	45.20
Cluster Average	179.22 (52.4%)	13.29 (12.4%)	10.22 (4.4%)	59.56 (30.8%)	65.57

In cluster 2, only the number of exercises performed by the students (VAR07) had an average of 3.28 (61.9%), with the 2nd quartile (median) above 0.50. All variables in cluster 3 had an interquartile range below 0.25 and median of 10.22, representing 4.4% of the interaction level. In cluster 4, the number of comments made by students (VAR09) and the general number of responses received by the students on the posts made (VAR10) have a higher 2nd quartile (median) for the group.

Correlations were calculated considering the variables VAR01 to VAR10 using equal weight to define the levels of student interactions. Figure 3 presents the resulting correlation matrices. Strong negative correlations occur, for example, in cluster 1, between the overall numbers of messages sent (VAR04), the number of messages sent student–student (VAR05) correlated with the number of help requests (VAR08), and comments made by the students (VAR09). That is, for students in this cluster when posting their help requests (VAR08) or making comments (VAR09) directly in the virtual environment, they send fewer direct messages (VAR04 and VAR05). Equivalent correlations also occur in clusters 2 and 4. By concentrating on the exercises (VAR07), students seem to send

fewer comments (VAR09). Among the interactions of students in cluster 3, there is no correlation between the overall number of messages sent by the students (VAR04) and student–student messages sent (VAR05) with help requests (VAR08). This also occurs in cluster 4 when correlating the number of different colleagues to whom the student sent messages (VAR03) with the student–teacher messages (VAR06), and the overall number of messages sent by the students (VAR04) with the responses obtained on the posts in the virtual environment (VAR10).

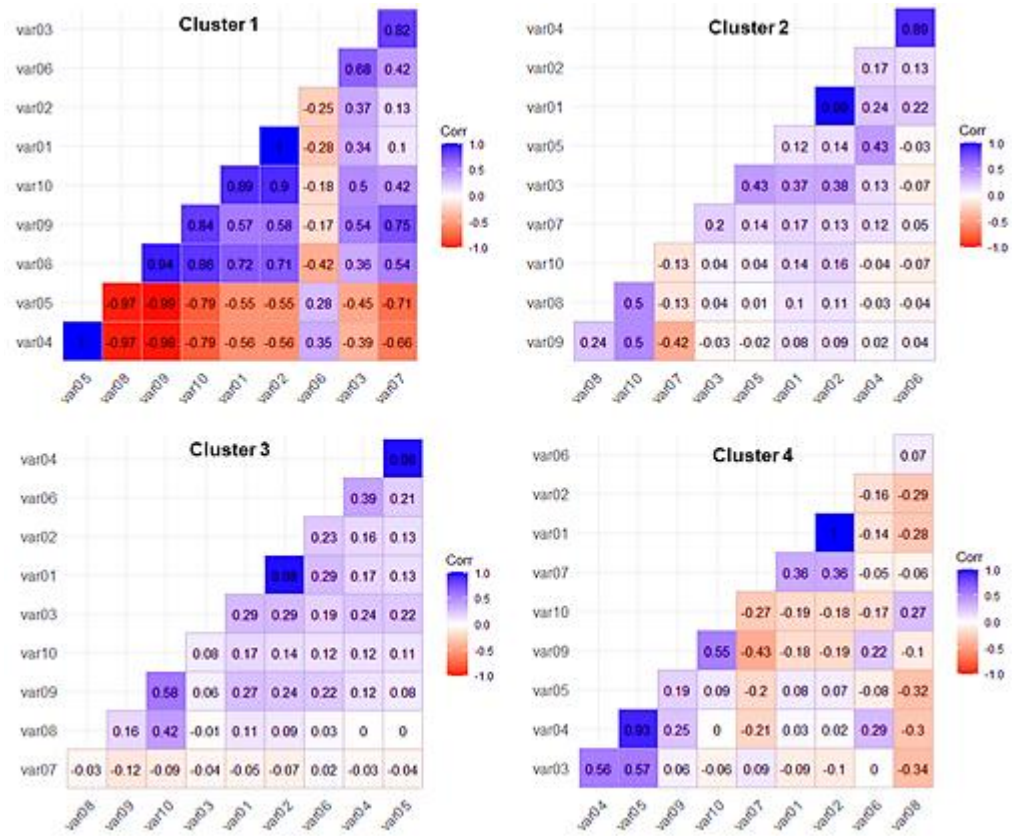

Figure 3. Correlation matrices for K-9 clusters (clusters 1 and 4 have more negative correlations between the observed variables, and clusters 2 and 3 have more positive correlations).

On the other hand, it is possible to see a strong positive correlation in the four clusters when the number of student friends (VAR01) is correlated to the number of student friends who are students (VAR02), as in clusters 1, 3, and 4 when relating the overall number of messages sent by the students (VAR04) with the number of messages among students (VAR05). For students in cluster 1, the more they request help (VAR08), the more comments are made (VAR09). The greater the number of friends in the virtual environment (VAR02), the more responses they receive on their posts (VAR10). For students in cluster 2, the more they send direct messages (VAR04), the more the frequency of sending student–teacher messages (VAR06) increases.

4.1.2. Interaction Levels of K-12 Students

Four clusters were formed for K-12 (high school students). Cluster 1 has 11 (2.4%) students, cluster 2 is represented by 20 (4.4%) students, cluster 3 has 194 (42.3%) students, and cluster 4 is formed by 234 (51%) students. Figure 4 shows the box plots of the normalized values (scale from 0 to 1) for the variables (VAR01 to VAR10) of the four formed clusters.

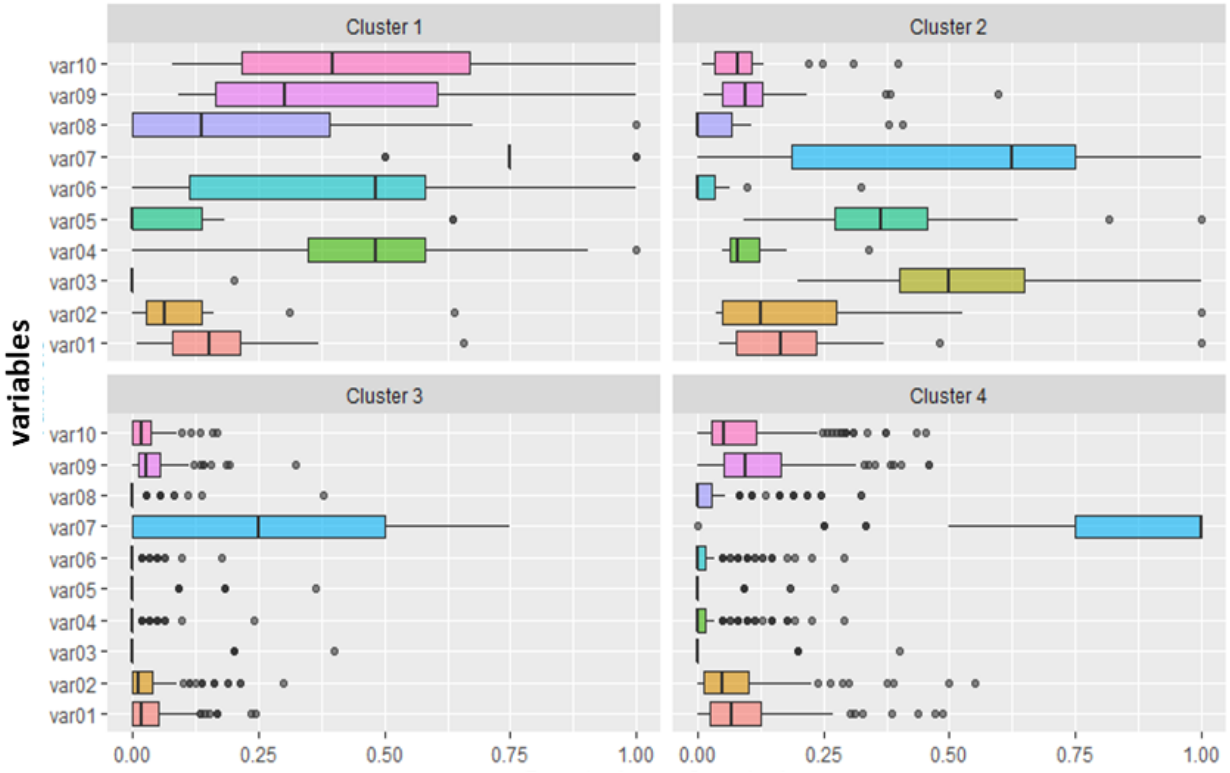

Figure 4. Frequency of occurrence of variables for K-12 clusters (clusters 1 and 2 higher interactions, and clusters 3 and 4 lower, visually perceived from the analysis of the box plot graphs).

It can be seen from the graphs (Figure 4) that the values of extremes and quartiles of variables present in clusters 1 and 2 are higher compared to the same variables in clusters 3 and 4.

Complementing this, Table 5 presents the means of the values of the variables. Clusters 1 and 2, respectively, have a cluster average of 23.13 (49.8%) and 9.91 (34.9%), being, therefore, the clusters that possess students with higher levels of interaction. On the other hand, clusters 3 and 4 have averages of 1.85 (4.1%) and 5.41 (11.1%), respectively, which reveal that students in these clusters have lower levels of interaction in the virtual environment from observed variables.

Table 5. Average of the variables for each group of K-12 students.

Variables	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Average of Variables
VAR01	23 (36.2%)	25.4 (40.0%)	4.43 (7.0%)	10.63 (16.8%)	15.87
VAR02	10.45 (30.0%)	16.4 (47.0%)	2.39 (6.9%)	5.62 (16.1%)	8.72
VAR03	0.09 (3.0%)	2.8 (92.7%)	0.08 (2.6%)	0.05 (1.7%)	0.76
VAR04	29.73 (77.9%)	6.7 (17.6%)	0.43 (101%)	1.28 (3.4%)	9.54
VAR05	1.55 (25.4%)	4.35 (71.2%)	0.12 (2.0%)	0.09 (1.5%)	1.52
VAR06	26.18 (88.7%)	2.0 (6.8%)	0.27 (0.9%)	1.08 (3.7%)	7.38
VAR07	2.91 (37.7%)	1.7 (22.0%)	0.74 (9.6%)	2.36 (30.6%)	1.93
VAR08	9.73 (73.7%)	2.2 (16.7%)	0.25 (1.9%)	1.02 (7.7%)	3.30
VAR09	77.55 (58.5%)	25.65 (79.5%)	7.14 (5.4%)	22.18 (16.7%)	33.13
VAR10	50.09 (67.3%)	11.85 (15.9%)	2.64 (3.5%)	9.81 (13.2%)	18.60
Cluster Average	23.13 (49.8%)	9.91 (34.9%)	1.85 (4.1%)	5.41 (11.1%)	10.07

The correlation matrices between the variables in the four clusters (Figure 5) reveal which variables are strongly negatively correlated, lack correlation, or are strongly positively correlated. Strong negative correlations are denoted in cluster 1 between the overall number of messages sent by students (VAR04) and the number of student–teacher messages (VAR06) correlated with the number of responses obtained on posts in the virtual

environment (VAR10). This reveals that the students in this cluster, when sending direct messages to teachers, reduce the need to receive responses to posts, requests for help and comments in the virtual environment. Something similar can be noticed in cluster 2 when correlating the number of student–student messages (VAR05) and the sending of student–professor messages (VAR06). This shows that sending more messages directed to students reduces the messages to teachers and vice versa. There is no correlation between the number of different colleagues to whom the students sent messages (VAR03), and the number of student friends (VAR01) in cluster 2; the number of student–teacher messages sent (VAR06) in cluster 3; and the overall number of messages sent (VAR04) in cluster 4. Something similar occurs in cluster 3 between the overall number of messages sent (VAR04) and student help requests (VAR08). It suggests that sending messages does not interfere with student help requests for students in cluster 3.

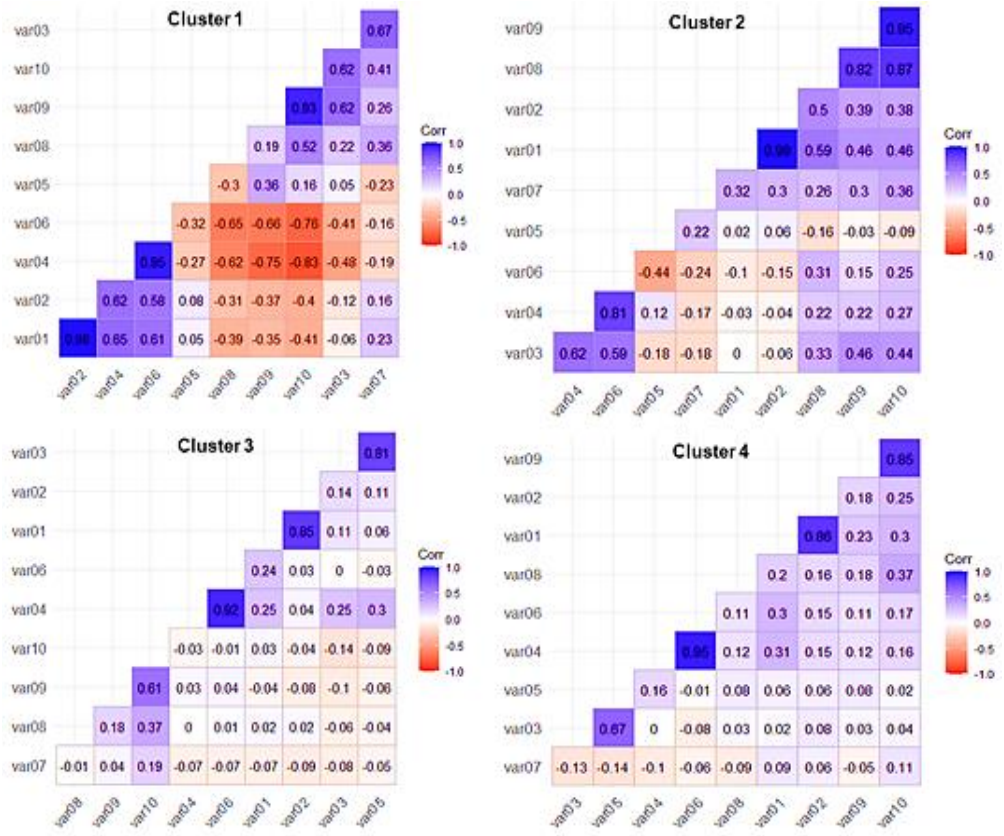

Figure 5. Correlation matrices for K-12 clusters (clusters 1 and 2 have more negative correlations between the observed variables, and clusters 3 and 4 have more positive correlations).

For students in the four clusters, the overall number of friends (VAR01) and the number of friends who are students (VAR02) correlate positively. This allows inferring that these variables are complementary. As someone has more friends, the overall number of friends increases proportionately. Similar correlations are present in clusters 1, 3, and 4 concerning the number of messages sent (VAR04) and the student–teacher messages (VAR06). Additionally, the more comments that are posted (VAR09), the more responses the posts receive (VAR10) in clusters 1, 2, and 4. In cluster 2, the more students request help (VAR08), the greater the number of responses to their posts in the virtual environment (VAR10). In cluster 3, the more messages sent student–student (VAR05), the more different colleagues to whom the students sent a message (VAR03).

4.1.3. Characterization of Interactions of K-12 Elementary and High School Students

From the analysis of the interactions of K-12 (elementary school—ES and high school—HS) students in the virtual environment, interactions between students were characterized into three levels: (i) highly interact (represented by clusters 1 and 4 of ES and clusters 1 and 2 of HS), (ii) sporadically interact (by cluster 2 of ES, and cluster 4 of HS), and (iii) rarely interact (by cluster 3 of ES and cluster 3 of HS). Table 6 shows the characterization, the total number of students and representative percentage for elementary and high school, and a description of the students present in each characterization.

Table 6. Interaction patterns of elementary and high school students.

Characterization of Interactions	Educational Clusters		Description of Student Profiles
	Elementary School	High School	
Highly interact	Clusters 1 and 4 42 (8.3%)	Clusters 1 and 2 31 (6.8%)	The students present in this group were the ones who interacted the most among the others. They have a higher number of friends in the virtual environment, send more messages to colleagues and teachers, and sent few messages have more interactions via forums when asking for help and making comments. They receive more responses to posts made. This group has more interactive students in the virtual environment, representing a percentage of 83.2% of the interactions that took place among elementary school students and 84.7% in high school. However, the percentage of students represented in this group is low, 8.3% in elementary school and 6.8% in high school.
Sporadically interact	Cluster 2 113 (32.5%)	Cluster 4 234 (51.0%)	Students in this group have the characteristics of being in occasional interactions mediated by the virtual environment. From the correlations of the variables observed, few messages were sent to colleagues and teachers. However, they are reduced to carrying out exercises. However, performing the exercises. The group has percentages of interactions of 12.4% for elementary school students and 11.1% for high school students. The number of students in this group is quite representative, 32.5% in elementary school and 51% in high school.
Rarely interact	Cluster 3 298 (59.1%)	Cluster 3 194 (42.3%)	This group was considered to have the worst level of interaction among the others, given that the students present in this group have few friends, send few messages, and have low values for the variables observed. They have lower interaction levels: 4.4% in elementary school and 4.1% in high school. However, the group represents 59.1% of elementary school students and 42.3% of high school students, which is quite representative.

From the characterization (highly interact, sporadically interact, rarely interact), the frequency of the interactions for elementary and high school was identified. Figure 6 shows the box plots resulting from this analysis. It is possible to confirm that: students who interact the most have higher values in the observed variables; those who interact sporadically have the exercise performance as the main highlight (VAR07); and students who interact rarely have lower values for the observed variables. It seems that students who interact sporadically do so only to perform exercises and those who rarely interact even do some exercises.

Correlations between all variables (VAR01 to VAR10) were analyzed. Figure 7 presents the resulting correlation matrices for each characterization. In them, it is possible to notice that the overall numbers of friends (VAR01) and, among these, the friends who are students (VAR02), are positively correlated at the three levels (high interaction with corr = 0.99 of correlation; sporadic interaction with corr = 0.89; and rare interaction with corr = 0.91 of correlation).

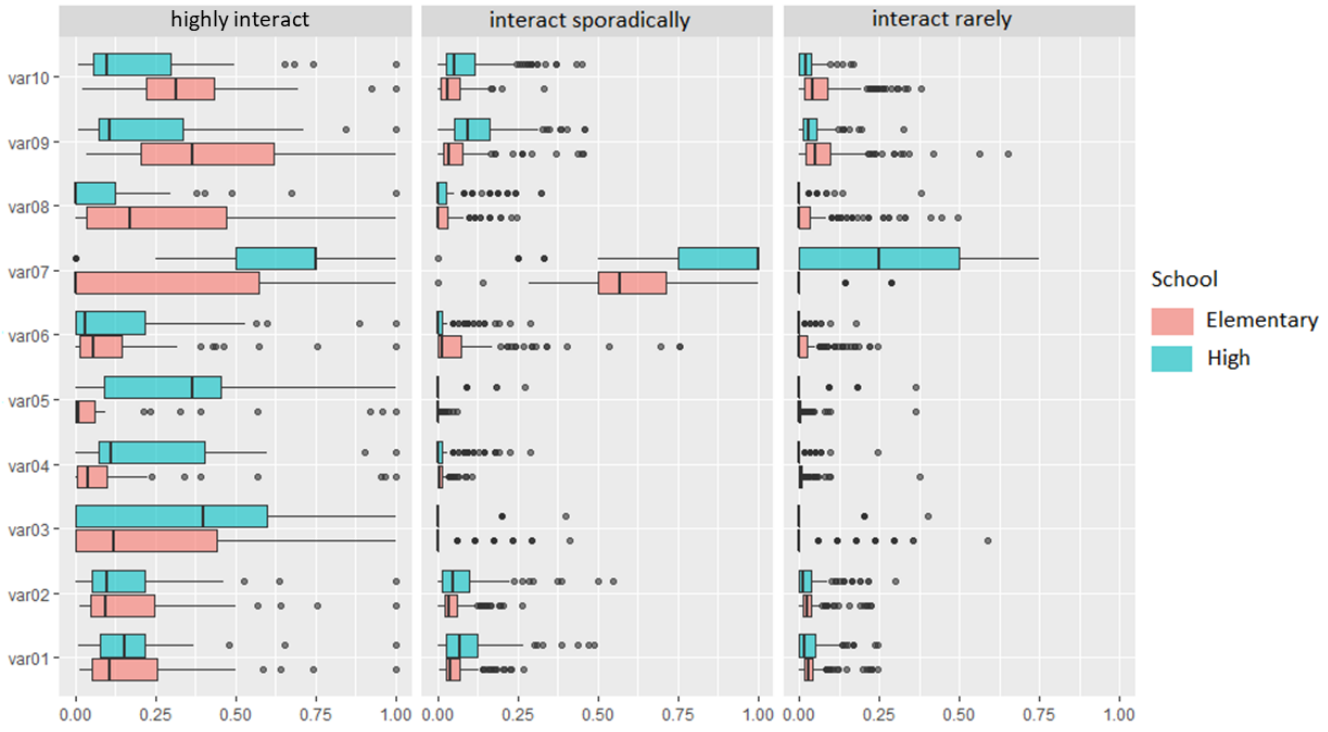

Figure 6. Occurrence frequency of the variables to characterize the levels of interaction (highly interact, interact sporadically, and interact rarely) of groups of K-12 students.

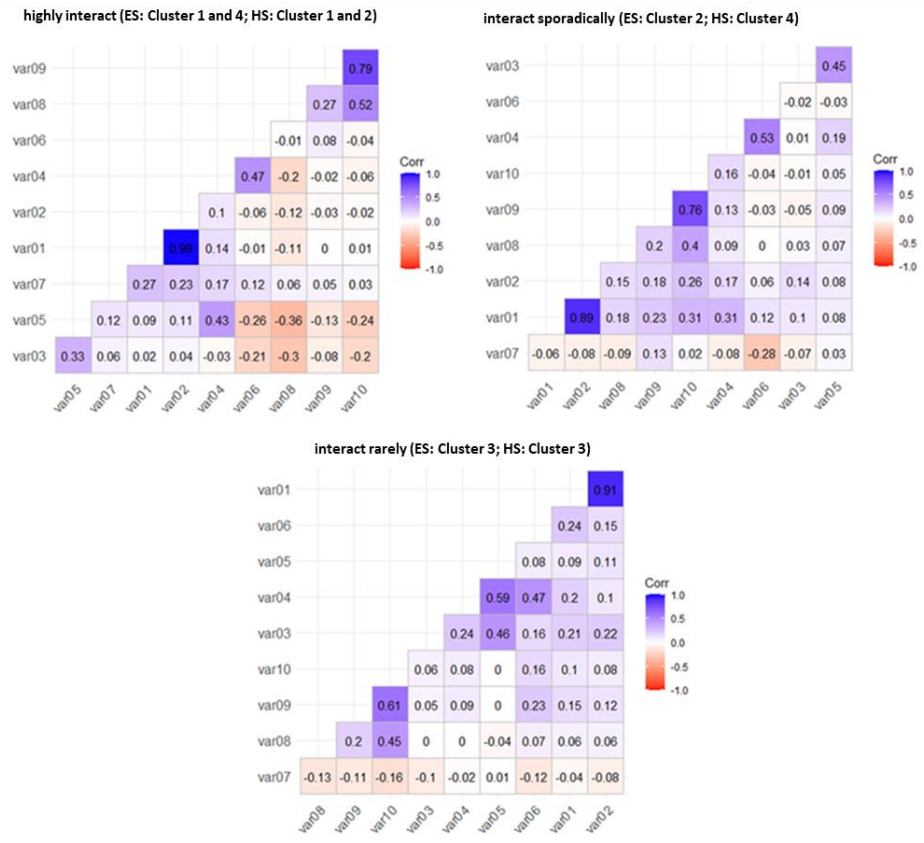

Figure 7. Correlation of variables to characterize the levels of interaction (highly interact, interact sporadically, and interact rarely) in K-12.

Positive correlations are also noted between the number of different colleagues to whom the students sent messages (VAR03) and the number of exchanged student–student messages (VAR05). Likewise, there is a positive correlation between the number of help requests (VAR08). The number of comments made (VAR09) correlates with the number of responses to posts received by the students (VAR10). These results allow seeing that these correlated variables show little variability in their correlation values between different levels of interaction.

For students who interact sporadically, the sending of messages (VAR04) is more strongly correlated with the number of student–teacher messages (VAR06). This is unlike what happens for students who highly or rarely interact, since, at this level, message sending (VAR04) increases proportionally both relating to the number of messages sent student–student (VAR05) and student–professor (VAR06). It reveals that among students who interact sporadically, as they send messages, they seek more contact with teachers than with colleagues. On the other hand, for students who interact the most, the number of help requests (VAR08) is negatively correlated with the number of different colleagues to whom the students sent messages (VAR03) and with the number of student–student messages sent (VAR05). This allows understanding that the more students who interact more publicly ask for help in the virtual environment (VAR08), the less they send direct messages via chats to colleagues and professors. This consequently reduces the overall number of messages sent. The opposite process also occurs in this case, as with increasing the number of direct messages sent to colleagues or professors, the students reduce or dispense with collaborative interactions promoted collectively between students enrolled in the same course.

In addition, for students who highly interact, the number of messages sent student–student (VAR05) has a negative correlation with the number of messages sent student–teacher (VAR06). This allows confirming that students at this level of interaction are faced with doubt. When they send more messages to their colleagues, they send fewer messages to their teachers and vice versa. For students who sporadically interact, when the number of messages sent to the teacher increases (VAR06), the number of exercises performed by the student decreases (VAR07). By understanding that the reverse process can also be possible, not performing the exercises leads to a higher number of messages directed at teachers. However, these analyses are not clarifying and do not allow inferring the reasons for this inversely proportional correlation. The flexibility of online-mediated interactions allows students to expand the possibilities to acquire new skills and keep strengthening their knowledge, regardless of the physical–spatial distance factor. Even though the interaction levels were identified and characterized, inferring at which level to operate to promote learning is not easy, as the purpose is not to have more interactions—it is to have better interactions in K-12. Interaction levels are an option for teachers to interpret the engagement in remote learning. However, knowing only these levels is insufficient to reveal whether there are formative intentions in the interactions. Therefore, understanding how to improve experiences by transforming virtual moments into developmental interactions becomes essential. It can be assumed that students interact more as they are more engaged and feel more comfortable collaborating with the teaching–learning process. However, the main reasons may be linked to problems, need for help, difficulties, justifications, or extension of deadlines in carrying out activities, among others. These aspects and the dimensions of interactions between elementary and high school students can be revealed by qualitative analysis. Section 4.2 presents these results.

4.2. Qualification of Interactions and Identification of Difficulties

After identifying the interaction levels and the characteristics of the students in each group of elementary and high school, it was sought to understand the situations of interactions that go beyond the use of the virtual environment Redu. By analyzing the interviews, it was possible to categorize which interaction situations were being mediated through the interfaces of the virtual environment Redu, the improvisations performed outside the

virtual environment, and the difficulties imposed on the interactions. From an inductive analysis of the interview responses, it was possible to understand the dimensions of the students' strategies regarding what they did in the virtual environment Redu, what they could not do in the virtual environment Redu using external resources, and the difficulties faced in using the platform. Table 7 presents the categorized dimensions and strategies, followed by a description of what was collected in the interviews.

Table 7. Interaction strategies and student difficulties.

Dimension	Strategies	Description of Data Collected in the Category
In the virtual environment Redu	Access to educational resources	Access to digital classroom materials posted in the virtual environment regarding the possibility of viewing, retaining, and sharing.
	Following the posts	Descriptions of reciprocal interaction in which teachers post and students follow their posts, view comments, and ask for help.
	Absence of colleagues	Situations in which they want the presence of other students in the environment.
	Absence of teacher	Situations in which they want the presence of teachers in the environment.
	Immediate contact	Interactions or circumstantial interactional needs to receive urgent responses.
	Help request and response	Reciprocal interaction in case of doubts and questions.
	Use of environment	A result of mediation and use of resources made available in the virtual environment Redu.
External to the virtual environment Redu	Search for content	Acts inherent to the need to complement studies with digital educational resources or not.
	Contacting colleagues	Description of moments of reciprocal interaction between a student and one or more colleagues in a bidirectional way.
	Contacting teacher	Bidirectional reciprocal student–teacher interaction.
	Formation of groups	The reciprocal interaction between three or more members to communicate with each other.
	Video conference	Reciprocal interaction situations mediated by multimedia resources (video, audio, among others) in real time, which occurred through platforms other than the virtual environment of this study.
Difficulties	Access to technological resources	Impossibility of access to computers, cell phones, internet.
	Self-regulation	Strategic situations to manage resources in the teaching–learning process.
	School performance	Indicative of how the teaching–learning process is going.
	Time management	Procedures for organization, management, and planning of studies.
	Interaction and communication	Unmet needs regarding dynamism and proximity in interactional and communication needs.
	Technology handling	Evidence of problems in understanding and using technological resources and educational technology.
	Teaching–learning practice	Circumstances of adaptation to methods and methodologies adopted by teachers in the teaching–learning context, because, in some, teachers continue to use classroom teaching practices, and these are not appropriate for the teaching modality mediated by technologies.

Cluster analysis by word similarity was performed using Pearson's correlation coefficient in NVivo® 12 [46]. In the categorized strategies, the relationships between the interactions mediated by the virtual environment, what they could not do and were looking for in resources external to the virtual environment, and the difficulties faced were explored (Figure 8).

The dendrogram is the result of analyzing the number of common words. Strategies with similar contents (for example, "absence of the teacher" and "immediate contact") are presented close together. Less related strategies are presented further apart ("teaching–learning practice" and "technology handling"; "time management" and "self-regulation"). Figure 8 shows some strategies of different dimensions. It indicates that, in the face of difficulties that were not possible to resolve from interactions mediated by the virtual environment, students resorted to strategies external to the virtual environment. In Figure 9, it is possible to see the relationships between the strategies and perceive those that are most correlated by the straight lines inside the circle. From the analysis of the relationships between the categorized strategies, it is possible to see that "immediate contact" seems to be a strategy that has a close relationship with "teacher absence" to enable "help request and answer".

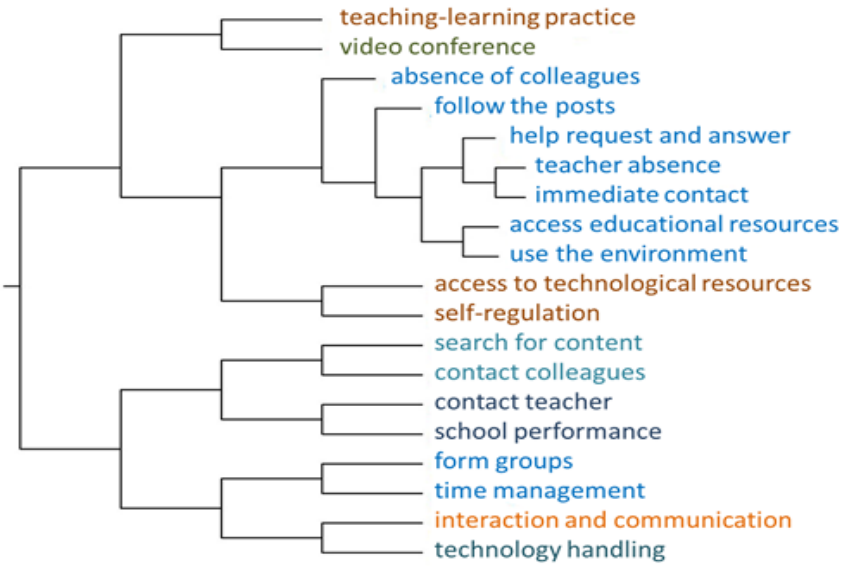

Figure 8. Cluster analysis of student strategies identified from content analysis.

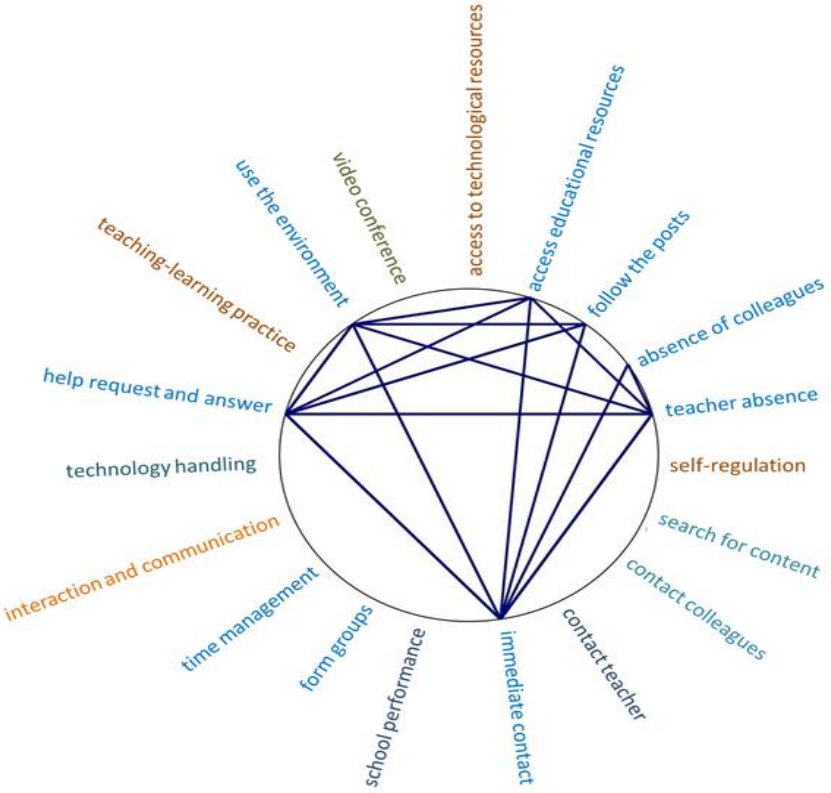

Figure 9. Analysis of correlations between students' strategies identified from content analysis.

The intersections between the categorized strategies induced the understanding that "immediate contact" is an essential strategy for intermediate interaction in the virtual environment Redu. The matrix coding query allowed observing the coding intersections between the categorizations of the strategies performed in the virtual environment Redu by the interviewed students (Figure 10). From the radar chart (Figure 10) that compares the categorized strategies, it is possible to see that "immediate contact" and "help request and answer" are essential strategies in interactions mediated by the virtual environment.

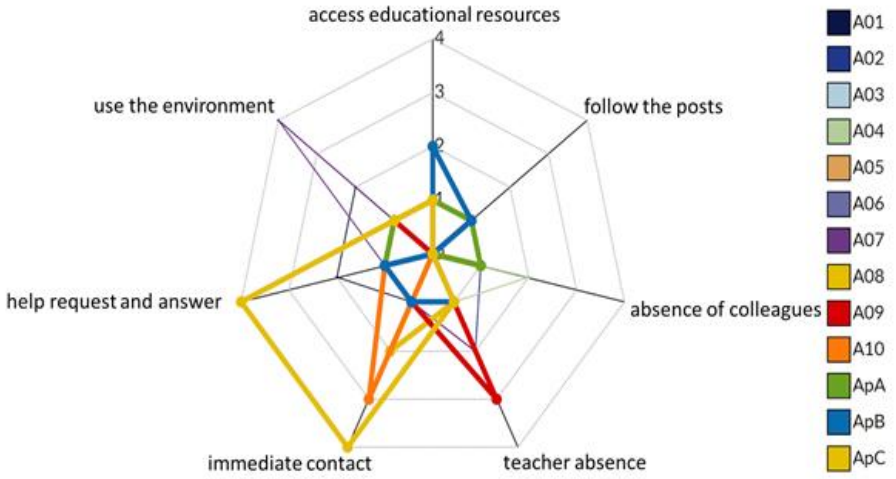

Figure 10. Comparison of strategies in the virtual environment intuitively categorized.

By analyzing the interviews, it was possible to inductively categorize which interaction situations were being mediated by the virtual environment and which occurred outside the virtual environment, and the difficulties inherent in the interactions.

Interactions in the Virtual Environment

In the virtual environment, students interact with available resources, sending and receiving messages. They have access to materials and can view them, participate in forums, and make requests for help. Some of these situations may occur as the student takes ownership of the virtual environment; others become an inherent need in the educational context.

Immediate contact is a situation in which the student perhaps seeks to approach the interactions that occur in face-to-face teaching, that is, interactions with speed or urgency. Sometimes, students report that the virtual environment Redu was the principal means to establish direct contact to resolve some queries related to materials, delivery of activities or exercises, and posting materials. When making comments or requests for help, one strategy was to send direct messages, via chat, to teachers in the virtual environment. However, some emphasize that they are not used to the interactions carried out in the virtual environment. ApC: "[. . .] *I did not particularly like the chat. The way the chat was built, it would be both with the teacher and with any other student*". A10: "[. . .] *the contact on the platform of the virtual environment for you to talk to someone was very complicated. I do not know if it was too complicated, or if we did not really try to find out what it was like, but to talk to you, I had to have a friend request or something [. . .] I could not talk directly to the person, I had I have to always be in the big chat, and I wish . . . sometimes there were huge questions, huge texts, numerous different links, many little things, and it was harder for you to find what the question was, what it was, where was it, where did the teacher respond it? But I think this direct communication in the virtual environment was pretty bad*".

In some situations, reports suggest times when students were unable to receive answers quickly. ApB: "*With the teachers, I believe it was the part that some take to answer. When, for example, I used to send [messages] most of the time through the virtual environment, some teachers took too long. There was a time, for example, when there was going to be a Philosophy live class, and it ended up not having it. Something canceled. I asked him about it in the virtual environment, and he did not answer me*". In some cases, they used multiple means and resources. ApC: "[. . .] *as I said, if I had a question and asked the teacher, the teacher took a while because he had to solve his things, clear the doubts of other students and even read my message, it could be that I had been able to resolve this doubt with a friend, or looking on the internet*". They searched even outside the virtual environment. A01: "*So, in the interaction with the teacher, my hugest difficulty was the response time. The teacher takes too long on the platform. On the platform, it was one day, three days that the teacher took to respond when he was faster. And when it took longer, he did not respond at all. The way to ask was to seek the teachers' WhatsApp®, they*

responded faster". This indicates a need to study mechanisms that can reduce the waiting time for responses and so streamline the interaction process so that other users can answer questions when students wait for answers for a long time. In other words, the problem is not necessarily attributed to teachers alone. Therefore, the mechanism would allow redirecting or invite other users to respond to requests for help. This opens the door to jobs such as recommendation systems and intelligent tutoring, among others.

In the category of access to educational resources, episodes of non-reciprocal interaction of contact and use of classroom materials provided by teachers in the virtual environment were organized in formats that could be viewed and shared between platforms and students. In some cases, reports suggest evidence of what specific types of resources helped to resolve doubts. Some reported the video classes, for example, helped to understand the contents and activities, or resolve doubts. ApB: "[. . .] *the teachers' video lessons. They made available the slides they had, which they used in the video classes, and I saw the slides and started watching their videos, and it helped a lot because it is as if we had them in the classroom, they explain. I was taking notes, and it did not bother me a bit. It helped a lot. And like I said, if I had a question about the class, or I didn't understand anything, I will ask them. In the virtual environment or by email. So the video lessons helped me a lot*". Others mentioned not liking video lessons, but they still helped. ApC: "*I do not like video lessons, but it helps me a lot. Mainly those who had a maximum of 30 min. The video lessons, the live classes they made and kept on YouTube®*".

Students report difficulties when using materials when accessing, viewing, and trying to share across platforms and peers. From their point of view, the virtual environment works as a mechanism to access external materials, and posts are just links to materials deposited on other platforms. ApA: "*For me, the virtual environment was another messaging channel about the activities. And they put it there. I usually put a link in the virtual environment for us to do activities on Google Forms or some other platform. But, the 'second-year' group also did a lot of this, putting the message like—Look at this activity here is due to that day, here is the link too. The 'second-year' group helped, it kind of took a lot of that part that would be kind of, the virtual environment part of doing*". They report that materials were made available in formats that did not allow for direct sharing. ApB: "[. . .] *another thing is the preview of materials, PDF. Teachers sometimes just put the image there, and the quality is sometimes a little bad*". They report about changing platforms, such as from the virtual environment to storage on personal devices, and thus, regardless of the environment, it is easy to view, organize, and consult later. ApB: "*And even having to save it on the computer, the quality is very poor. You cannot understand anything. We have to call the teachers on WhatsApp® or in the email asking them to send it to us*". A10: "[. . .] *one thing that bothered me a lot was when the teachers placed the sheets or slides as an image in the virtual environment, and I could not download it, to be able to look, sometimes they had to put another link. Anyway, I could not get it, easy files are much better, at least I think, to look at files outside the virtual environment, which you can go through easier, go back and forth, look at more than one page, otherwise we do not understand*".

Students report a voluminous number of posts, comments, and materials for each course, discipline, and module to follow in the virtual environment. A09: "[. . .] *sometimes there are so many messages on the wall and on the individual that the teachers receive that, I really believe it is very difficult for the teacher to see everything, sometimes you even end up getting an answer to another question, for example, the same question you had the teacher did not answer you, but he answered someone else. These are the ways I found of asking something or needing to resolve a note or something like that, it was through message, virtual environment wall, and by email*". They report that the way to find the posts made it difficult to keep track of materials. ApA: "*I accessed it a few times a week and had to go see all the tabs if there was something new. I had to go to all the subjects. It took a long time, sometimes, I was unwilling to do it, and also, sometimes, I did not see anything new that went unnoticed. There was a time I even missed a literature activity*".

The absence of the teacher and colleagues leads to a feeling of loneliness and solitary study. Contact with teachers or peers can allow interaction for more meaningful learning. The reports highlight the feeling of the absence of colleagues in the context of teaching

mediated by the virtual environment. It was a feeling of being alone, unlike what they experienced in face-to-face classes. A02: "[. . .] *The first change is the online classes themselves in face-to-face teaching, you are in a classroom with your colleagues and teacher, and virtually you are not feeling their presence. That add-on. There is the teacher, and you have your colleagues, but it is a little different because you are not seeing them, so that is a more striking difference*". A08: "[. . .] *the main difference I was able to notice, even seeing the group commenting that sometimes—Ah! The teacher did not answer my question. I believe that was the main change I noticed*".

Therefore, they are not able to know who is in the environment and what to study. A10: "[. . .] *they did not see what other students were asking during classes, most of the people were silent, so there really was not much, few people went to class, few participated in online classes. When you were in the face-to-face classes, you heard someone commenting on the subject, someone asking a different question, and in the online class, especially if it was recorded, you really only listened to the content. I believe that this multilateral exchange was what we lost most in this exchange for remote learning*". If in face-to-face teaching setting, students are in an environment of face-to-face interaction, where the dialogue processes occur intensely due to the proximity with colleagues and the teacher, and this became difficult in remote education. A04: "*To talk to the teacher is more difficult because you have to send something in the virtual environment or an email. They only respond after a while, sometimes they do not*". A05: "*The lack of teachers because everything was remote. As I said, they could not answer at the time, you asked something, and maybe a day or two later they would answer, but you did not always see it*".

Online-mediated interactions are limited to the available resources that students can use, and there may be a different interaction routine. A07: "*I only practically studied the day before the test, and I could not keep up with the study routine, because of the lack of contact with the teacher, with the other students, to see that others are engaged, studying. So, that is the biggest difference I have seen*". The presence of the teacher was a requirement at the time they were studying. A06: "*My hugest difficulty was the issue of time, I was supposed to study from nine and midnight. And the teachers only responded the other day* [. . .]". A08: "[. . .] *with the teachers, in general, it would be the conflict of schedules. Because sometimes, when I was available to ask my question, to solve my doubt, the teacher was not. This break, one time he can answer, another he cannot, and when he can answer, it is when I am not online either, we cannot discuss to me understand a question better* [. . .]". Reports suggest that, in some cases, students kept in contact only with colleagues who were already close. A07: "[. . .] *a lot of people practically do not talk to me. Only about four remained in contact. But I believe that good friendships continued. It was very sad this year*". A10: "[. . .] *The people who were closest to me, I kept in touch, but whoever was a classmate that I saw or asked something during the class, really, I ended up losing contact with several people, it is so much that now at the end of the year, I believe everyone feels it, I am not sure who was in my classroom*".

A request for help and response can be made with the mechanism present in the virtual environment, which the student can use, in a public and directional way, through comments on each material posted by the teacher. They are public posts and can be viewed and answered by all users enrolled in the same course. However, in some cases, students highlighted that there were situations of shyness or that they did not want to ask publicly. ApC: "*Mostly I would talk to my friends. Did you understand?—Hey, look, can you explain this to me? So, who were close friends that I was not ashamed to ask* [. . .]". Theirs strategies were to use other resources (email, WhatsApp®), external to the virtual environment. ApC: "*And once in a while, I asked the teacher, and it was by email* [. . .]".

In other situations, the reports describe that when requesting help through the virtual environment, it takes a long time to receive answers. A04: "*To talk to the teacher is more difficult as you have to send something in the virtual environment. They only respond after a while, sometimes they do not*". The answers take time. A02: "*In the virtual environment, I believe that there was a great difficulty in the response time. I would send a question to the teacher he could take a day or two to answer, it was nothing very fast*". It was to the point that students sought other means, such as contact with colleagues. A03: "*It was the delay, that they usually had a lot of*

students with doubts and a lot of classes, when, generally, they could not respond quickly because of that, I even started to consult my friends more than teachers, in case of doubt". They searched on the internet, asked parents for help, contacted friends or teachers by other means outside the virtual environment. A09: "*Look, when the teachers did not answer, I could not wait too long because after all, I would need the answer soon to do some activity, some test, even studying, I had to ask my parents for help, internet, friends, other means*".

Students describe situations in which they studied at different times. A06: "[. . .] *the issue of time, I was supposed to study from nine to midnight. And the teachers only responded the other day* [. . .]". As this was not a time when interactions in the classroom and teaching usually took place, this may have increased the time for teachers to answer questions. These difficulties suggest the necessity to consider developing solutions that allow students to establish momentary interactions, for example, with peers learning, around questions and requests for help.

The student uses a set of resources from the virtual environment (chats, forums, multimedia files, digital materials, friend requests). Some reports propose that the outline of topics in the virtual environment helped them understand the organization of courses and the layout of the available classroom materials. A07: "*Well, teaching remained very good in the virtual environment, for example, it was wonderful. I really liked the way the subjects were divided, how it was organized, how the teachers used it, it just practically changed my study routine, which I could not follow [. . .] It was very stressful. I did not like staying at home studying, I wanted to be at school. But, as I said, the virtual environment helped a lot to continue, well organized. The teacher's classes also helped a lot. But I believe I will not be able to take much from this year to the next*".

The resources available in the virtual environment were not enough for the interactions. To their detriment, students used resources outside the virtual environment because to search for class materials, to know which of these had already been consulted, and which were new posts, they would have to go through all the modules of the courses individually. This did not become an easy task, as it would have to be performed routinely. ApC: "*The teachers posted, there were the modules for the classes. And there were classes. It was too much, I got lost easily, I could not find it. It took a long time to find what I wanted there. And it ended up disturbing me, even making me too lazy to study in the virtual environment* [. . .]". From their perception, the need for improvements regarding the resources available in the virtual environment is evidenced, since the results show that students seek interactions outside the virtual environment. Section 5 discusses the results of these interactions.

4.3. Interaction Alternatives beyond the Virtual Environment

After identifying the interaction levels and the characteristics of the students present in the groups formed for elementary and high school, an attempt was made to understand the situations of interactions carried out that go beyond the use of the virtual environment Redu. Outside the virtual environment, students search for alternatives to unmet interactions. These were mainly for searching for content, contacting colleagues and teachers, forming groups, and videoconferences.

Students search for content [47,48] in available media and channels. Upon identifying that the materials or content posted by teachers in the virtual environment was not enough to understand gaps in the subjects, students resorted to the internet and content available on YouTube® channels to search for other materials that would allow them to better understand the subject studied. ApA: "*I took the keywords, went to the internet and researched how it was done. Or else I would go to my friend, and we would ask the questions together, solve the doubts together*". ApB: "*I first went to a friend of mine who studied earlier than me. So, she could have already solved the doubt. So, I turned to this friend of mine. If it took a long time, I could sometimes, not always, but I would send a message to the teacher* via *email or WhatsApp®. Depending on the teacher and expecting to answer, I would go to YouTube® or the internet*". A03: "*I often went to YouTube® and researched classes on the subject to gather more information*".

The reports suggest that even when searching the internet or asking the teachers, if the students did not receive answers related to what was being discussed in the context of the classes, they also resorted to their colleagues. A06: "*I sent a message to the teacher through the virtual environment and also contacted my friend to see if he could explain the subject better so that I could understand*". They resorted to learning groups or even to the teacher in an attempt to resolve a doubt or better understand the content addressed. A10: "*When I had any doubts, I would try to see with some of these groups of content that we had, if anyone knew if someone took notes somewhere, or else, I would really look at the teachers, or even look on the internet. As I was never really sure, really, if I would be able to talk to the teachers, if they would see, anyway. I ended up looking it up on the internet before, if I really could not find it or did not understand, I would contact the teachers*".

Contact with peers [49–51] was one of the main strategies for students to interact, clarify doubts and understand some content, or simply communicate during the restrictions of social distancing. ApC: "*I did not have much difficulty with colleagues because I communicated mainly through WhatsApp®, at least with colleagues. We were there all the time—Hey, I am not able to do the exercise the teacher gave us, so we could practice, I do not know what. —Hey, I do not understand this part of the content. Can you explain it to me? These things happened a lot. I had some friends who could explain it to me. When, for example, teachers passed some review exercises before a test or simply an exercise to practice that subject. When we could not, I went there and asked*". Some report that it is essential, even concerning internet searches, to contact colleagues to ask questions. In some cases, these interactions occurred through WhatsApp® messages, which allowed contact with other multimodal elements relating to interactions. A10: "*With colleagues, I believe I was really not talking to almost anyone, if I was going to talk to someone it had to be through WhatsApp®, it had to be my number, a more direct contact with people* [. . .]". Students reported a need for immediacy in the teacher's responses and collections, and as they were slow to respond through the virtual environment, WhatsApp® replaced some of the interactions that could occur in the virtual environment. In some cases, they used this tool because it allowed interaction directed to a single colleague or a group.

Contact with teachers [51–54] took place during videoconferences via a virtual environment, and when they were slow to respond, students resorted to their emails or WhatsApp®. ApB: "*I did not ask a lot in live classes, why? For shame. So, let me ask in an email. It was always* via *email or WhatsApp®, as I said*". As some report, contacting teachers through emails became a recurrent approach. A04: "[. . .] *sent an email. Sometimes I would ask a very basic question in the virtual environment, but only* via *email occurred my interaction*". On WhatsApp®, only a few teachers made their contact available. This led the students to resort to interaction alternatives. A03: "[. . .] *with the teacher, I did not ask a question much, usually, I just emailed them when when I needed to know about a pending issue or more about the grades, assignments, and exams. I kind of, If I had a doubt, I would consult my friends, and we would do something about it*".

Forming groups [55,56] was one of the principal mechanisms used by students to interact and collaborate to understand subjects or contents addressed by teachers in the classes. A06: "[. . .] *there was a group that had some people who were administrators, they put it every day. They went there and put the activities we had to deliver, the exams. So, it ended up helping a lot*". The reports suggest situations in which the students helped each other, asked questions about some specific issues, and posted these doubts in the groups to receive help. ApA: "[. . .] *the 'second-year' group once, or someone else sent there that had some new things in the virtual environment for us to do, some activity, task. I did that too sometimes, I sent to the 'second-year' group. It was just a group that we created*".

Their doubts were related to the dates of activities and new posts in the virtual environment. For example, when a material or activity was posted in the virtual environment, it was replicated or informed through some group members. ApB: "*It was more the deadline for the activities, and from time to time, some students would ask to explain something they did not understand. Since teachers were sometimes slow to respond*". ApC: "*It was a group that we were asking questions from each other at times [. . .]. Whenever we had a doubt, we went there. And*

these groups were also mainly to do work necessary for us to create a group there to get everything done right".

The formation of these groups occurred mainly through WhatsApp®. One of the main factors reported for choosing WhatsApp® is that it was considered, by students, an instrument in which interactions occurred immediately with colleagues and, in some situations, teachers. The teachers themselves built groups for classes, replacing interaction situations that could happen in the virtual environment.

Videoconferences [36,57,58] were one of the main activities carried out during remote classes. Previously scheduled and synchronous moments of interactions were planned. Students mention videoconferences as one of the mechanisms that came closest to the context experienced in face-to-face classes. Therefore, it was a moment of interaction that the students enjoyed, as the real-time involvement allowed them to establish interactions that are closer to face-to-face interactions. ApC: "*They did YouTube® lives. Classes were on Google Meet. They held classes from time to time through Google Meet, it also helped me a lot because at the time the teacher took some questions and I could write it down as if it were a face-to-face class [. . .] Lives through YouTube®, classes through Google Meet or Zoom, and video lessons. It was these strategies that the teachers used that I liked the most*". However, some students pointed out that many videoconferences were taking place daily, and it became difficult to keep up. In some cases, in a synchronous interaction process, if there were questions via message, it was a habit of some teachers to pause the explanation to respond immediately, and it resulted in discontinuity of the dialogue in these interactions. A01: "*I liked the video lessons better, I dislike the live lessons because the teacher watches the questions, he stops explaining what he was explaining to see the questions. It made me lost and 'shake' me, I would give up and leave* [. . .]".

Alternative strategies that resulted from interactions external to the virtual environment were analyzed using a matrix coding query. Figure 11 presents the situations categorized from the students' reports.

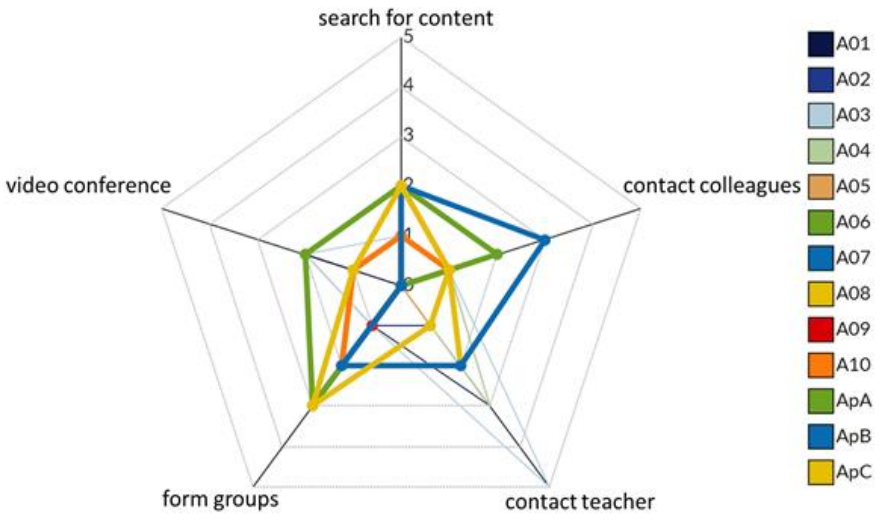

Figure 11. Comparison of interaction strategies external to the students' virtual environment.

It is possible to see, from the perspectives of the interviewed students, that "contact colleagues", "contact teacher", and "form groups" are identified in the most widely developed codifications.

4.4. Student Difficulties

The matrix coding query, shown in Figure 12, allows observing that, among the difficulties categorized for the interviewed students, "teaching–learning practices", "interaction and communication", and "self-regulation" are situations of well-remarked difficulties.

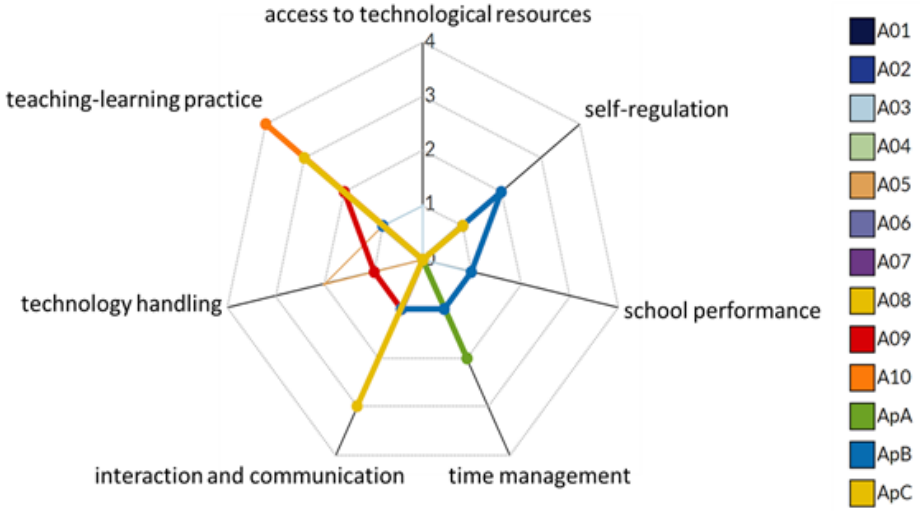

Figure 12. Comparison of students' difficulties intuitively categorized.

The practice of teaching–learning [59] in the remote modality requires approaches not previously experienced in face-to-face teaching. Reports indicate that students faced difficulties in adapting. ApC: "[. . .] *one thing that, I thought, was really cool, but it also ended up complicating it, was about of the personalized study that we did the way we wanted, in our time, but it was complicated after a while due to the organization because at the beginning we thought it would only be two weeks. [. . .] for me, a remote class would be setting a time like here, for example, on Google Meet and talking to the teacher at that time, after another time it is another teacher. But, it is not that. I ended up 'waddling' because I prefer precisely this question of conversation. Not slides, something like that, that is there. I am not a big fan of video lessons either, so it was really hard for me, that part*".

Some teaching–learning practices applied were factors of difficulties for the students. As they are faced with a mnemonic process of posting materials, studying materials, and carrying out activities in a repetitive routine, this process becomes tedious. A09: "*I also had difficulties in the way of teaching, as it was more theory despite having been a recorded class, it was reading, memorizing and going to the test*". A10: "*When we went online, it became a very robotic thing, we asked, and the teacher answered, although this process is smooth, there were no others* [. . .]".

Some examples, such as video classes and videoconferences, have been very useful for students. A04: "*The practices that helped me the most were the videoconferences and recorded classes too. This helped me a lot*". However, due to the moment of an abrupt transition of modality, a broader period of adaptation by students to remote learning may be necessary.

In interaction and communication [60,61], difficulties are situations that, in some cases, students highlight when faced with a context of remote education that is different from what was experienced in face-to-face teaching. ApB: "*I believe that it was mainly the part of communication with the teachers, that in the classroom we talked better with the teachers, it was possible to clear up more doubts. I did not take much off in the middle of classes, but I always waited until the end of the class to talk to them and had my question answered kind of on the spot, depending on what I wanted to know. And in remote classes, you have to send a message to the teacher. And, depending on the time and depending on the teacher, it takes a little longer*".

In face-to-face teaching, interactions flowed from the dynamics of proximity with teachers and colleagues. A10: "*I believe that this interaction in face-to-face classes had a much greater exchange between the teacher and the student, and the students among themselves as well*". In remote learning, the interaction is usually by sending messages. A09: "*What I missed was this kind of participation because I sometimes sent a message to the teacher. He is slow to respond. We end up leaving it aside, going to another subject. It happened a lot, it happened to me, leaving some things aside, some doubts, and go on to another subject so as not to be late*".

In this process, the waiting time to carry out the communication is one of the main factors reported that made interactions difficult. ApC: "*The interaction was usually the most*

difficult part, because, for example, to debate with a teacher, we could not do it due to the time difference. Because the teacher had to see several things, several messages and it ends up being as difficult for him as it is for us, because we wanted to clear the doubt right away, and in the future, it could be that we ended up solving this doubt, and the teacher would only answer after that".

Self-regulation [62] defines situations described by students as activities to organize their hours and forms of study, which led to them experiencing difficulties. ApB: "[. . .] *in face-to-face classes, I was a little more committed because I tried harder in classes since I had more pressure, and in remote classes, I ended up procrastinating a little more to study. Sometimes I studied in advance for the tests, which troubled me a little*". A01: "*And in online classes, you chose what time you did things, you sometimes watched the class eating something, not bothering with the teacher telling you to save your breakfast, that is more . . . It is more the freedom we had that unfortunately hindered our studies a little*". The materials were being posted in the virtual environment on a routine basis, and the students had the autonomy to customize how to follow up and carry out the activities. However, some confirm that they did not have the autonomy to do it themselves. ApA: "*I did not organize myself very well, and I showed up in the group—Look, the class on that subject started. I went there, clicked on the link, and went to class*".

Difficulties regarding time management, school performance, use of technologies, and access to technological resources, although less emphasized by students, are also essential to be discussed.

Time management [63,64] is supposed to be strongly linked to self-regulation, by being responsible for study schedules. ApA: "[. . .] *before we had our schedule ready. It was the school that dictated what to do in the morning and the afternoon. We were left to ourselves, which was just doing homework or studying a little. But, now I am totally responsible for my workload, for my schedule. It was difficult to continue doing this in the morning [. . .]. I could not follow the classes well, and at first, I thought that the pandemic would only last for a couple of weeks. It was an illusion, I had not done anything. Then I realized it would last a lot longer. I started to accumulate, I could not fulfill everything I had to do. I kept accumulating, and I got stressed, it was not very good*".

Some improvised to organize the study schedule. A03: "*I did not organize myself by a table or anything like that, I just looked and tried to mentally organize myself at least. I got the majority because sometimes there were different times, but it did not happen frequently, there were few*". This led to situations of oscillation in school performance. A07: "*I managed to do well this year. But I was studying the day before, I could go well like this, I could not follow anything for a while. In this case, in recent months. At first, until I managed to continue with my studies. But then I did not get used to it*".

School performance [64–66] has been affected in the face of difficult situations, for example, access to and use of technological and educational resources, difficulty in managing and organizing schedules, and that students were experiencing a teaching context not experienced before. ApB: "*And after a while, as I said, I ended up procrastinating a little longer, so my performance dropped a lot. And I believe it was more at the beginning that I liked it*". A03: "*My performance dropped a lot overnight, I usually got above-average grades, like eight and so on*".

The use of technologies [67,68] was a difficulty for students, in some cases because they did not previously deal with technological resources. A05: "*Well, of course in remote learning you have to do everything online. Works, some teachers gave the option of writing either in the notebook, or in PDF, or Word. As I did not know, I did not get the computer right, so I did not know. I had to research to learn, my father also taught me some things, and for me, that was the most significant difference because I did not know how to use practically anything on the computer*". The resources adopted in technology-mediated teaching demanded time for the adaptation process. A05: "*As I said, in the beginning, it was very difficult because I let it accumulate, and I also did not know how to use the computer, I did not know anything, so it was very difficult to practice these things [. . .] in the beginning it was very difficult to attach the link without fall to the connection because the internet was a little weak, oh sometimes, fall out of nowhere. Apart from that, the second quarter onwards was easier*". They had to learn to deal with different situations of teaching mediated by technologies. A09: "*I found it a bit difficult, after all, I never studied like*

that, although it has been a long time to adapt because I really never studied like that, and it was weird mainly, for example, when there was a problem in the sending or when without wanting to be erased, that kind of thing gets in the way a lot. When you think you saved a file and left it, and the page did not save or had technical errors either, it gets in the way a lot. I think this made it a little difficult. But we have to look for the solution, do it again [. . .]".

Access to technological resources [56,69,70] is also a difficulty linked to the context of remote education. A03: "*There were some difficulties because I do not have many ways to study at a distance. I only have my cell phone, and it is not such a good cell phone for studies, and I felt a bit of complication, especially in live classes because teachers generally could not answer many questions*". The availability of devices and infrastructure to carry out virtual activities, of course, may not be evenly distributed in the familiar environments of students.

5. Conclusions

This study aimed to gather evidence on the effectiveness of emergency remote learning mediated by educational technology relating to the interaction levels of elementary and high school students at a public institution that adopted emergency remote learning mediated by a virtual environment of a social network for education.

The adoption of remote learning represented an opportunity to investigate the behavior of large groups of users using virtual learning environments. Without this modality, it would not have been possible to analyze how elementary and high school students were involved in the teaching–learning process when the only interaction between students and teachers was at a distance.

The students were grouped according to interaction levels from the data on the use of the virtual environment Redu. It is concluded that the students who interact the most look for ways that approximate their experiences with a degree of closeness between colleagues and teachers. Those who interact spontaneously focus their interactions on the purpose of carrying out the activities and exercises. On the other hand, students with a low level of interaction present behaviors difficult to understand.

The interviews allowed dimensioning the strategies used by the students through or outside the virtual environment and identifying their difficulties. Students value interactions, centering mainly on immediate contact with peers and professors and asking for help with questions. Data on interactions show a wide range of alternative improvisations that took place outside the virtual environment. These external interactions are related to situations not supplied by the virtual environment, which indicated that it does not have enough functionality to meet some demands observed. It led students and professors to structure ways to interact by sending access links to external resources and complementary platforms. In these, students seek content, contact colleagues and teachers to obtain more immediate responses, form groups, and hold videoconferences searching for interactions that resemble those experienced in face-to-face teaching.

The results obtained in this study expand the knowledge about the remote teaching and learning experience. This evidence makes it possible to lead the evolution of the virtual environment, given that the possibilities of online-mediated interaction are currently insufficient to meet the needs of the participants. It also guides improvements in teaching practices in remote learning and potentially in an alternative necessary hybrid educational context, flexible to face-to-face teaching.

Limitations and Future Research Opportunities

However, more anthropological studies are needed to complement the protocol for identifying levels of interaction. More in-depth monitoring of interactions is also needed to achieve higher uniformity among the investigated subjects, especially in qualitative analyses and confirming the identified patterns. More digital ethnography studies are also necessary to understand how the meaning of the digital occurs and is projected to improve the findings of this research regarding the students' interactions in an atypical context that resembles the reality observed in this study. In addition, it is necessary to include teachers

to understand these interactions and causes of difficulties that involve the two subjects (students and teachers). Not being able to identify data to conclude on the relationship between quality of interactions and student performance was also a limiting factor of this study. It highlights a need to rethink the architecture of the virtual environment and the distribution of data to expand the possibilities of understanding the relationship between these two aspects (better interactions and student performance).

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