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"The influence of technological designs on teachers' and students' meaning-making: Semiotic chains configuring teaching and learning activities"

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ABSTRACT

The relationships between digital technologies and the realization of teaching and learning activities have received increased attention in interdisciplinary research. Knowledge of the connections between technological designs and users' meaning making in semiotic chains is, however, still partial. Teachers' and students' remediation of technological designs through cognitive processing was studied in this paper to gain insights into semiotic chain configurations. Data consisting of video recordings, interviews, and observations were processed with quantitative content analysis and learning analytics strategies. The findings suggest that the technological design's visualized functions greatly affect the semiotic chain configuration when integrated with their users' meaning making in lower-level actions. Technological designs seem to buttonize meaning making, and teaching and learning activities become technologized. Scaled cognitive processes can provide insights into differentiated meaning making according to the technologies, and perspectives on paralanguage are proposed.

1. Introduction

The rapid implementation of technologies in classrooms challenges our understanding of technology and meaning makers' interactions [1]. As various multimodal technologies are adopted and shift in learning environments, teachers and students must pay attention to the multimodal representations that are generated to realize their meaning making in the shared classroom activities [2–4]. Research has emphasized the mediation of technologies' meaning potentials for users' intentions [5]. Simultaneously, researchers also contend that the technology dimension remains underrepresented and that more interdisciplinary and holistic approaches are necessary to embrace the technological impact on meaning making and social practice [6,7].

Recently, researchers have begun to consider the joint implications of hardware and software for multimodal representations [3,8]. The various configurations of hardware and software technologies contest what and how meanings are represented [9]. Moreover, as each of the hardware and software solutions complexly interact in meaning making activities, it is important to continue studying them at various levels and with various approaches [10].

All multimodal representational presences in the classroom are important but can be sifted by the meaning makers' attention in various ways [11]. Understanding what representations specific technological compositions mediate is therefore vital to appreciate what meaning making outcomes are influenced [8,10,12,13]. It requires a sensitivity to the connection between the mediation of technological designs and the meaning makers' cognitive processes of remediation [14].

Semiotic technology researchers have studied the connection between certain technologies' design features and the meanings they create in use. For example, drawing on social semiotic multimodal approaches, Poulsen [15] found that technological designs affect social practices by providing or reinforcing specific meanings, which is in line with the findings of scholars such as Djonov and van Leeuwen [16], Jewitt and Henriksen [17], and Kvåle [18]. Research has shown that functions seem to inspire actions in meaning making activities [19,20]. Other research has demonstrated that sign-making is an outcome when a meaning maker engages with various parts of the technological design [8,21]. However, more research is necessary to explore the mediated *meanings* and their links to the remediated *meanings* to understand technology-meditated meaning making outcomes [14] and cf. [6,22,23]. This can be done by highlighting the many representational relationships between the technological design and the meaning making outcomes involving the meaning makers' cognitive processes. These multimodal relations can be considered forming into semiotic chains

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[13], revealing the tendencies that shape digital social practices. However, semiotic chains are multifaceted and include many elusive processes. Research on them is complicated and has been rather sparse.

This study is intended to provide fine-grained perspectives on semiotic chains that include several layers of multimodal relations. A multimodal layer (ML) framework [24,25] is used in this study to explore the representational connections between the meanings mediated by technologies and their remediation by teachers and students into multimodal meaning making outcomes involving various cognitive processes. A fine-grained perspective on representational diversities can reveal what meaning making outcomes are technology-mediated and to what extent and contribute to a more holistic understanding of the tendencies that underlie today's teaching and learning activities and, thus, multimodality in semiotic chains [13]. To explore the layers of multimodal relations, this study relies on a quantitative approach operationalized with learning analytics tools. The following research questions were addressed:

RQ1: What technological (hardware, software) configurations do teachers and students frequently use in teaching and learning activities?
RQ2: What technological designs' meanings are most frequently mediated, and what cognitive processes can be observed in teachers' and students' remediation?
RQ3: What meaning making outcomes result from teachers' and students' remediation processes?

2. Theoretical framework: the multimodal layers

Technologies and meaning makers perform through representations [3,26,27], whose multimodal relations must be studied in research on meanings' causes and effects [28].

Multimodality is often defined as the representation of meanings through multiple semiotic modes for meaning making and re-presentation in social situations [27,29]. This definition emphasizes the numerous representational and re-presentational connections seized in the notion of semiotic chains [13]. Representations are defined in this paper as *sign systems* – i.e., "signs combined through formal/social rules [that become] meaningful in certain combinations" ([30], p. 257). Sign systems are the most common and significant representations of social and cultural meanings engendered by people in various contexts and activities. They inhere and are used in almost all of our dominions and partake in realizing technology-mediated practices [3,4,29].

These "systems of signs" are regarded as cohering in meaningful units (e.g., an icon or speech) or a combination of units (e.g., into multimodal modes of representation or an activity) and need to be studied *together*. For that, a multimodal lens is required, and the sign systems can then explicate the multiple relations underlying the real-life events they represent [17,28,29].

Technological and meaning making meanings can be represented quite diversely by sign systems, which can complicate an understanding of what caused a certain outcome and is why they need to be framed to be studied [28,29]. Sign systems are applied in this study to appreciate the multimodal meanings mediated by the technologies and their remediation by meaning makers such as teachers and students into multimodal meaning making outcomes that involve various cognitive processes. Sign systems are encapsulated by and connected via the ML framework's five components: 1) *technologies* (combined hardware/software), 2–3) *technologies' functional* and *semiotic properties* (the technological design as mediators that become remediated through the meaning makers' various cognitive processes), 4) *modes of representation* (MoR), and 5) *activities* (the meaning making outcomes). Theories addressing these technological and cognitive components are combined in the ML framework in addition to the social dimensions already highlighted in semiotic technology research, detailed in the upcoming sections [24,25].

2.1. Technologies

The layer "technologies" combines the hardware (the equipment) and the software (knowledge, skills, and experiences organized into data, [31]) into what is here called *composite interfaces* (CIs, [24]). The CIs mediate in meaning making with a setup of multimodal sign systems [32,33], thus partaking in the semiotic chain formations in praxis [13].

Technologies serve as an important conceptual layer of semiotic chain analysis. Defined theoretically, a CI has multimodal implications because it configures unique combinations of sign systems. Fig. 1 shows that a certain CI configuration's (CI 1–3) switch (horizontal orientation) affects the other four MLs (vertical orientation).

2.2. Technologies' functional and semiotic properties

The layers *technologies' functional* and *semiotic properties* (Sections 2.2.1 and 2.2.2) address the connections between the mediated sign systems in technological designs and their remediation through meaning makers' various cognitive processes.

Sign systems are understood along Vygotsky's [34] idea of symbolic cultural artifacts' or psychological tools' roles in human development. They are combined with Wartofsky's [35] notions of cognitive artifacts or represented models of cognitive praxis in socio-historical contexts. Sign systems affect meaning makers' internal and external cognitive processes because they *mediate* countless meanings [21,29] into what Cole [22] and others call *remediation* of new meanings. The remediation is transacted by the intrapersonal [34] means of the meaning makers' representations [35], which means that the meaning makers' interpretation is influenced by their previous socially and culturally impregnated experiences with sign systems [29]. When the newly produced meaning making outcomes are externalized into sign systems, they coordinate in the interpersonal [21,34].

The cognitive acquisition of meanings by meaning makers in their remediation of the numerous meanings mediated via sign systems is not monotonous. Vygotsky [34] asserted that the "unity of perception, speech, and action, which ultimately produces internalization of the visual field, constitutes the central subject matter for any analysis of the origin of uniquely human forms of behavior" (p. 26). This statement pinpoints the cognitive intake of the multimodal sign systems via the meaning makers' perception of visuals vis-à-vis the technological designs (see [36]). When sign systems are mediating symbolic multimodal representations of social and cultural meanings shaped by meaning makers' cognitive praxis [35] or cognitive processes of actions and speech [34], similar cognitive processes are evoked in the meaning makers interpreting them. These cognitive processes then reverberate in their meaning making externalizations [21,29]. Hence, the internal and external cognitive processes share a common genesis while being functional with psychological tools such as sign systems [34,37]. Vygotsky [34] avowed that the complexity of cognitive actions is no different from the complexity of externalized motor actions. These dialectical relations can help us understand what manifested meanings were mediated and taken up and what cognitive processes were activated when meaning

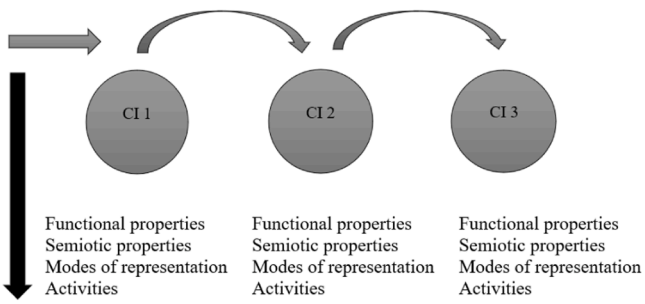

Fig. 1. CIs' relation to the other four MLs.

makers reshape them into new meanings [21,29]. When the cognitive processes externalize, these relations become discernable to various extents [29]. New meanings become represented and spark a new spiral of representational re-production [38].

Vygotsky [34] also claimed that practical intelligence and actions were predecessors to the use and production of signs (cf. the speech, here sign-making, [29]), thus interconnecting and early on promoting the idea of scaled cognitive processes in meaning making with sign systems. Particularly, "higher psychological function or higher behavior as referring to the combination of tool and sign in psychological activity" is required when the "internalization of culturally produced sign systems brings about behavioural transformations and forms the bridge between early and later forms of individual development" ([34], p. 7).

To conclude, actions (early, practical intelligence) and speech (later, sign-making) are internally activated when meaning makers engage with sign systems mediated as a combination of tool (e.g., functions) and sign (e.g., abstractions) meanings [39]. Higher psychological functioning underlies these processes in the meaning makers' interpretation, even if their sign system remediation results in externalized actions with the tool alone. Wartofsky [35] viewed the modes of cognitive praxis (actions) as scaled, which deepens the idea of cognitive processes' levels and illuminates possible multimodal inclinations of action representations. The idea of action scales is used in the MLs to understand how meaning makers' lower to higher cognitive processes are activated and interconnected in sign system remediation. The higher-level actions are connected to sign-making, and together, they underlie multimodal meaning-making outcomes, encapsulated by the ML framework.

2.2.1. Technologies' functional properties

Functional properties (FPs) are the sign systems in the technological design formed as squares, lines, text, or spaces into buttons, icons, etcetera, with meanings of functions (see e.g., [15,19]). FPs mediate actions and influence meaning makers' cognitive processes of actions [24] when they remediate the FPs' featured meanings through means of their representation [35].

2.2.1.1. FPs and scaled actions. In the ML framework, Wartofsky's (1979) primary, secondary, and tertiary artifact levels illustrate the relations among sign systems in CIs mediating FP meanings and meaning makers' remediation into scaled actions, and how these meaning making externalizations come to realize different activities.

According to Wartofsky [35], the primary level of action mediation and remediation occurs when representations (here, FPs) are interpreted by meaning makers as meanings for conveying work and inspire them to convey similar types of lower-level performances. A lower form of cognition, the practical intelligence, supports direct externalized actions [34], such as pushing a physical (e.g., on a keyboard) or virtual button in technology use. The primary level is related to the intermediate, secondary level of action mediation and remediation [14,35,39]. It occurs when representations, such as FPs, are interpreted by meaning makers as meanings for *organizing the work* and inspires them to arrange the substance for production [14,22]. According to Wartofsky, the primary and secondary levels are online. These online feedback loops are linked to the tertiary level: the offline loop [14,35]. The tertiary level is used in the ML framework to describe when FPs are remediated by meaning makers in higher-level actions, inspiring them to exploit the sign systems with more abstract meanings related to that function, the semiotic properties in their sign-making.

2.2.2. Technologies' semiotic properties

The layer technologies' semiotic properties entails the sign systems attached to a function used at a tertiary action level that mediate coherent abstract meanings (colors, images, templates, etc.) and therefore require the meaning makers' higher forms of cognitive processing, such as sign-making in the remediation [24,25].

The semiotic properties, together with the FPs at the tertiary level, connect the actions and sign-making processes when a meaning maker engages with a CI's designs. When actions and sign-making processes are remediated jointly, technology-mediated multimodal MoR compose the meaning making outcomes in the social space.

2.3. Modes of representation

The MoR layer identifies what cognitive processes of actions and sign-making are active in the signification process [40] when the meaning makers remediate the technological design into new sign system outcomes. These meaning making outcomes incited in the social space by each technology user influence other meaning makers. The MoR thus integrate semiotic chains with technologies' properties into various teaching and learning activities [13,41].

Under optimal circumstances, actions and sign-making processes are interrelated when meaning makers remediate the technological design that help shape the most apt signifiers of meanings represented into multimodal MoR [4,8,29] but not always. When the technological design is limiting [11], the meaning making can be affected, resulting in lower-level actions [24,25]. Such actions can be associated with tapping or pressing a computer screen and are sometimes viewed as gestures and communication (e.g., semovergent paralanguage, [42]). However, gestures are understood in the ML framework as part of the multimodal sign-making. The actions and sign-making interconnections are important to avoid sidelining the actions as meaning making forms in their own right and their scales' refinement in cognitive processing and relations to the sign-making, and thereby, an understanding of how meaning making compounds multimodally via technologies in semiotic chains. Moreover, if these meaning making forms are undifferentiated, it is not easy to understand the level of technology mediation in the meaning making.

The term paralanguage in this paper incorporates the actions and sign-making scales when the design of CIs are remediated by meaning makers to determine what technological designs and cognitive processes compose technology-mediated meaning making outcomes and to what extent. This description of paralanguage adds to its more common definition as language expressions cohering in modes of communication not necessarily tied to technologies (e.g., accompanying speech, such as intonation, facial expressions, and gestures; [43]). By doing so, the technology-mediated quality of interpersonal exchanges in the social space can also be recognized [44], as well as the extent to which semiotic chains are configured multimodally.

2.4. Activities

The layer activities, and as Fig. 2 shows, encompasses the other four layers. *Activities* are therefore the result of the other four layers' momentary configurations, incorporated into the idea of semiotic chains in this paper (cf. [13]). When employing the activity layer, one can observe the other MLs to gain insights into technology-mediated teaching and learning advancements.

This study uses the five MLs to map and analyze multimodal sign system relations in semiotic chains, which will be the focus of the next section.

[1] The elements in Fig. 2 are not intended to demonstrate a hierarchical ordering of the five MLs, but rather how the MLs are qualitatively distinguished: The circles demonstrate how they interrelate. For instance, the "activities" layer is the product of the other four layers. "Technologies" is a layer encompassing technological design (properties) mediating meaning making (cognitive) processes into different modes of representation.

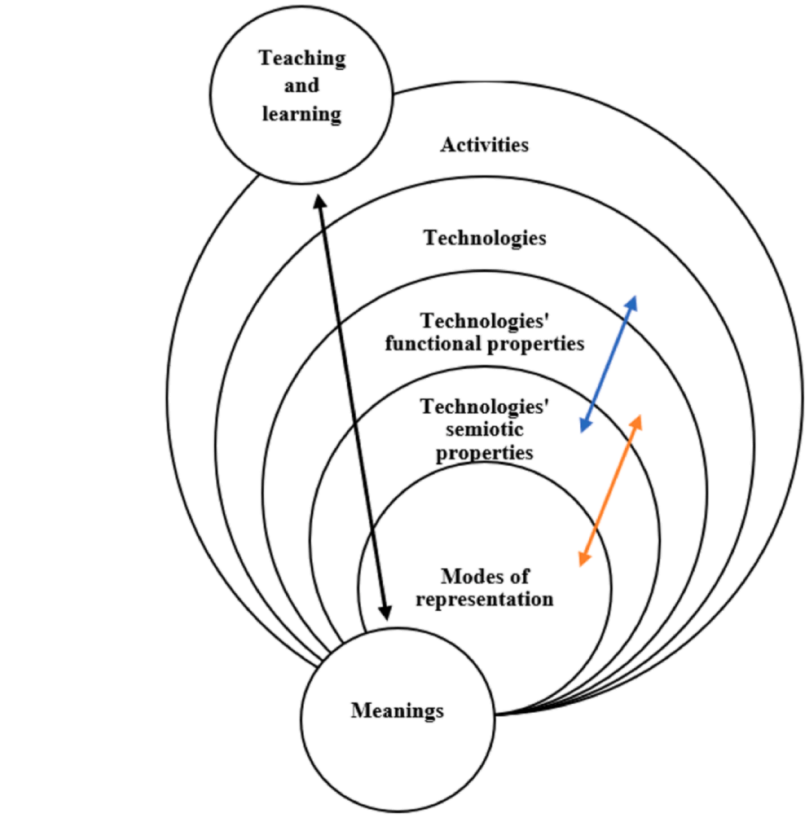

Fig. 2. Five layers of multimodality and their connections.[1]

3. Method

In this study, what technological designs were most frequently mediated by certain hardware and software configurations and what cognitive processes the teachers and students thereby remediated into meaning making outcomes were explored by attending to the sign system frequencies in and between the MLs. The sign system frequencies were congregated and connected in the ML mapping because they can represent the teachers' and students' technology-mediated meaning making and thereby illuminate its tendencies.

When multimodal relations are mined, the sign systems shift with the MLs. The sign systems become plentiful and require qualitative and quantitative approaches to be identified in the data, analyzed, and represented.

Multimodal data on meaning makers' technology interactions and the technological design were essential to enable studying the sign systems between the MLs in this paper. These situated occurrences were best captured by VRs, observations, and VEIs [45]. Quantitative content analysis (QCA) strategies were applied in data processing to identify the data's many sign systems. QCA is often used to create contextual narratives because it provides strategies for identifying and combining quantitative elements in data [46]. The numerous sign systems were defined and combined through iterative QCA processes during the data collection and review, of which a theoretical grounding, here through the MLs, is vital [46].

For instance, the sign systems emerged in the data by foregrounding strategies of the MLs [47,48]. Some sign systems became more salient for the researcher's interpretation of the VRs or during observations when a certain setup of technologies' designs was noted. Sign systems were also foregrounded through the meaning makers' attention in their technology interaction (e.g., through the direction of their gaze and body towards certain design features). Paying attention, as internal mental activities, became visible for interpretation by the researcher when combined with the meaning makers' actions and sign-making externalizations (into, e.g., speech, texts, and gestures) with certain parts of the CIs [21,29]. The foregrounding strategy was later used by the researcher to categorize the respective MLs into subcategories by defining the data's sign systems through keywords (representing a sign system unit or a combination of units) when transducted into texts. Manual identification of the many sign system keywords in the data per ML category was deemed impossible, given their extensiveness (see [49]). QCA was, in that instance, operated via learning analytics – the quantitative ethnography (QE) tools – affording a reliable sign system embracement.

Later, QE tools were also used to connect and visually contrast the MLs into network models in an analysis program to enable analyzing and representing the data in a comprehensible manner (see [46,49,50]). Constructing a comparative hypothesis was the first step in that attempt, i.e., that teachers' and students' meaning making via technology use is dissimilar. This hypothesis later facilitated the systematic operation of the ML categories by their sign system (keyword) frequencies into various connections to compare the real-life occurrences they represent and to identify their tendencies.

3.1. Sampling procedures and participants

The ML data on teachers' and students' meaning making via technology use were collected in the autumn of 2020 in Swedish schools. A

purposive sampling method of school classes was applied [51]. Primary school settings commonly include teachers' and students' collaborative learning activities and was the first inclusion criterion. Second, school classes were selected in which the most common mobile hardware devices (laptops, smartphones, and tablets) were used for learning purposes daily. Third, it was important to sample digitally confident students and grade-five was considered to fit this target participant criterion [52]. These criteria rendered three primary school classes from three differently sized schools located in separate regions. One teacher from each school participated in the study, and each teacher chose one participating student in their class. Information on various technologies, subjects, pedagogical strategies, assignments, etcetera was part of the data collected from at least two lessons per participant (Table 1).

3.2. Data collection

A combination of VRs, observations, and interviews were used to gather the ML data. VR was the primary data collection method to obtain visual and auditory sign system information, as well as data on how sign systems were used and connected in practice [45,28]. Two cameras were used during the recording of each lesson: one focused on the sign system mediation and remediation, and the other on the technology-mediated classroom activities. The six participants were recorded for approximately 840 min (14 h).

The author took structured observation notes on a schedule (Appendix A) during the VRs to strengthen the interpretations in the subsequent data analysis.

Video elicitation interviews (VEIs) were conducted with the research participants after the completion of the VRs. The VEIs were based on a question guide (Appendix B) categorized by the MLs and complemented with video examples of significant events. The sign system were sometimes difficult for the participants to understand. The video examples aided a dialog between the researcher and the participants as they illustrated real-life examples of the participants' technology use. The participants' recalls then erected vivid narratives [45]. The VEIs were conducted individually with the participants in their respective school environments, lasting approximately 417 min (7 h).

3.2.1. Annotation and transcription

Transcription and annotations turned the data into a single mode – text, necessary for conducting the manual and machine-operated QCA procedures on all data [46]. VRs were annotated into texts using Transana software, while the interview data were transcribed verbatim in word-processing software. The observation notes were transferred into plain text. Translation of the transcripts from Swedish into English before their compilation into a single document (divided by participant) facilitated data cleaning of missing or incorrect information, important to operate the data in the analysis tools.

Table 1
Participants' demographics.

Participant	Gender	Hardware technology	School setting	# of students in class	Subjects
Teacher 1	Female	Laptop	Rural area, <500	21 students	Science, Mathematics
Teacher 2	Female	Tablet	City area, >500	28 students	Social Science
Teacher 3	Female	Smartphone	Rural area, <200	25 students	Mathematics
Student 1	Girl	Laptop	Rural area, <500	21 students	Swedish, Social science
Student 2	Boy	Tablet	City area, >500	28 students	Swedish
Student 3	Girl	Smartphone	Rural area, <200	25 students	Science, Mathematics

3.2.2. Segmentation

Three types of segmentation of the text data were carried out as a first part of the manual QCA [46] to sift the sign systems per ML in preparation for the analysis.

The first segmentation entailed separating the text data into individual lines ($N = 1622$ data lines; Table 2; Appendix C), based on how sentences addressed the MLs by framing the sign systems.

The second and third segmentation were source- and delimiter-based [53]. The source-based segmentation involved adding metadata (numbering the data lines) when the text data was transferred to a spreadsheet according to each data type (the VR, VEI, and observations) to address the temporal contexts of the sign systems as participants addressed them more frequently and in different ways over time (referred to as utterances). The delimiter-based segmentation entailed adding spatial information based on the activities (subjects/individual/collaborative) to the spreadsheet, because each ML's sign systems varied with these contexts. All three segmentation types created a contextual basis for connecting the MLs in the data analysis program as they facilitated various settings (Section 3.4, Table 4).

3.3. Code construction and coding

QCA facilitated manually defining the MLs as codes through the iterative read-throughs of the text data. ML subcategories were constructed to establish code variables and were manually attached with sign system values by the foregrounding of information strategies of the keywords in the teacher and student data.

The program nCoder,[2] designed to work on big data (sample size/data entities) accumulated in texts, was used to encompass all sign systems occurring in the data lines (N = 1622) by an automated coding procedure of the MLs' keywords. First, text classifiers (N = 49, Table 3) of the MLs enclosed with unique keywords were constructed in nCoder. nCoder automatically coded all data lines by searching for the MLs' keywords while testing the coding procedures' reliability; Cohen's kappa, > 0.9 (level of agreement between raters) with a rho (alpha level)

Table 2
The first segmentation.

Hardware	Technology users	# unique datasets	# data lines	# coded lines ($N = 1622$)
Laptop	Teacher 1	Video	75	696
		Interview	290	
		Observation	72	
	Student 1	Video	77	
		Interview	104	
		Observation	78	
Tablet	Teacher 2	Video	46	377
		Interview	116	
		Observation	11	
	Student 2	Video	86	
		Interview	97	
		Observation	21	
Smartphone	Teacher 3	Video	122	549
		Interview	185	
		Observation	25	
	Student 3	Video	120	
		Interview	65	
		Observation	32	

[2] https://www.n-coder.org/

Table 3
Number of codes for each ML.

MLs	# of codes Teachers	Students
Technologies (software)	5	5
Technologies' functional properties (incl. action scales)	11	10
Technologies' semiotic properties	1	1
MoR	4	4
=	4	4
TN=	49	

less than 0.05. The coding first involved a human rater (H1, Codebook, Appendix D) that determined the individual ML's theoretical saturation on a fixed number of lines (N = 100) by validating each code's keywords against an automated classifier (AC). A second coding step included a second rater (H2), whose code estimations were measured against H1's. In the third stage, nCoder matched the H2 with the AC. Hence, nCoder's rating of the keyword quantity (1 – yes [keyword occurrence] and 0 – no [no keyword occurrence] of each of the 1622 lines) later served the analysis program's visualizations of the ML frequencies and connections into network models that illustrated the ML tendencies forming the semiotic chains. The level of agreement between the raters was assessed on all codes with a kappa of > 0.09 (Codebook, Appendix D).

3.4. Epistemic network analysis

The program for analysis – epistemic network analysis (ENA) – is a QE tool used in the final step of the QCA. ENA operates on coded text data (0/1) and identifies the many structures of connections residing among quantitative elements (here keywords/sign systems) when refined into categories (the codes/MLs). Comparisons are possible between units (here, the teachers and students and their use of the respective hardware devices) because the strength of the codes' associations is measured via summary statistics and visualized into networks per contrasted unit (Table 1). These QE rationales thus facilitated making the ML connections and enabled the creation of an epistemic frame of semiotic chain configurations [49,54].

The coded data were exported from nCoder to ENA Web Tool v1.7.0.[3] A range of settings (the conversations and stanza windows) were applied to facilitate a contextual tie between the keywords in the data interconnecting the codes. These settings were based on qualitative judgments of the sign systems' contexts (the segmentation) relevant for linking the MLs. Accordingly, ENA computed connections among the ML keywords frequenting the lines (first segmentation) based on the conversation setting (second and third segmentations) within an activity for the respective data type for the two units of analysis (Table 4; for details, see [50,53]).

A stanza window defines how connections among codes are computed within conversations by determining their number of lines. Since the ML keywords occurred frequently, a moving stanza window of size 4 allowed the ENA program to construct networks by connecting the MLs across all the data occurring within the context of four lines, where each line was associated with the previous three (see [53]).

Mathematical matrixes of the ML connections were created in ENA, underlying the network graph distributions. In the network visualizations, *nodes* represent the MLs (codes), and the lines between nodes represent the co-occurrence of the MLs for the contrasted units (red – teacher; blue – student). Moreover, the nodes vary in size depending on the keyword frequency for the respective ML in the dataset, and the line thickness indicates the frequency of co-occurring MLs.

The differences between the teachers and students are displayed in the following sections based on the structure of connections arranged by a specific selection of MLs, in which their positioning in the x and y projection space describe their content (for computational rationales, see [55] and [56]).

The ML connections were modeled using the same selected codes for teachers and students. Their node names are displayed in Table 5, and data on the MLs are presented in Figs. 3–6.

4. Results and analysis

This study intended to explore the semiotic chains configured by teachers' and students' technology-mediated meaning making that realize the teaching and learning activities. The results from this exploration are detailed in this section.

4.1. Technological configurations used in teaching and learning activities

The first research question related to what technological (hardware–software) configurations teachers and students frequently use and how they mediate in teaching and learning activities.

Descriptive statistics from the coded spreadsheet (see Appendix C) of the code frequencies (in percent) for the CIs and activities can be found in Tables 6-9. Tables 6–7 indicate what sign systems are most frequently mediated and remediated in teachers' and students' use of CIs (excluding the hardware's sign systems). The activities that the CIs mediate in are presented in Tables 8-9.

The software was identified in this study as diversely incorporated into the teaching and learning activities, which is why this technology's sign systems vary most in meaning potentials (presented in the column labels in Tables 6 and 7). Table 6 shows that multimodal and linguistic sign systems[5] were mostly mediated and remediated by the teachers' use of the software in the differently configured CIs (22.5% and 21.6%, respectively), together with diverse online (Software: Other, 34.2%) solutions (see Codebook, Appendix D) to display learning content to the students.

In Table 7, the same tendency (a linguistic emphasis; 36.7%) despite the different CIs evinces that the multimodal sign systems mediated were impacting the students' remediation into mostly language-based activities (producing text, reading).

These findings indicate that the software transcended teachers' and students' technology use despite the CIs' capacities for shifting sign systems into diverse multimodal compositions. The software integrated mostly linguistically organized teaching and learning processes regardless of type. The somewhat low software percentages in Tables 6 and 7 suggest that the CIs were backgrounded in mediating multimodal activities for the teachers and students – the software assignation across all three hardware devices and users never exceeded 50%. This finding is reinforced by the observation that the CIs mediated in the teachers' and students' individual production and consumption activities, such as presenting orally, listening, reading, and writing (Tables 8 and 9).

When the technological solutions did not wholly accommodate the teachers' and students' joint interests and needs, an engagement with few sign systems in individual technology use appeared to be the

[3] https://app.epistemicnetwork.org/

[4] Based on the data in Table 2.

[5] In this paper, technologies are regarded as inherently multimodal [8], but a technology does not become multimodal per se. Data showed that the CIs' multiple sign systems did not always reverberate in the teaching and learning activities. Technologies become meaningful and multimodal by the meaning makers' remediation of their sign systems, i.e., their properties. The software's ***most frequent*** sign system remediation determined their categorizations. For example, various software properties were remediated mostly in reading and writing activities. These technologies were then denoted as linguistic (e.g., word processing software). When various software properties were equally remediated to support the activities, the software was labeled multimodal (e.g., communication apps used for messaging pictures, text, and emojis).

Table 4
ENA settings operationalizing the ML connections.[4]

The stanza window constructing the connections across the segmented data		The conversation in epistemic network analysis			
Unit	The first segmentation	The second source-based segmentation		The third delimiter-based segmentation	
Student 1 (laptop)	Raw data lines	Metadata (numbering the data lines)	Data type	Subjects	Individual/ Collaborative
(Rows numbered 1–77)	And only then would there have been a movie on studi.se, it is also an app you can watch movies and do quizzes.	1	Video recording	Social Science	Individual

Table 5
ENA network elements.

Network elements	MLs modeled in networks displayed in Fig. 3-4	MLs modeled in networks displayed in Fig. 5-6
MLs	Functional properties Levels of actions	MoR Semiotic properties Tertiary level of action
Node (code) name	FP.+ name of manifestation [physical/virtual] + name of function Level.of.Action.Primary Level.of.Action.Secondary Level.of.Action.Tertiary	MoR.+ name of sign-systems Semiotic.Properties Level.of.Action.Tertiary

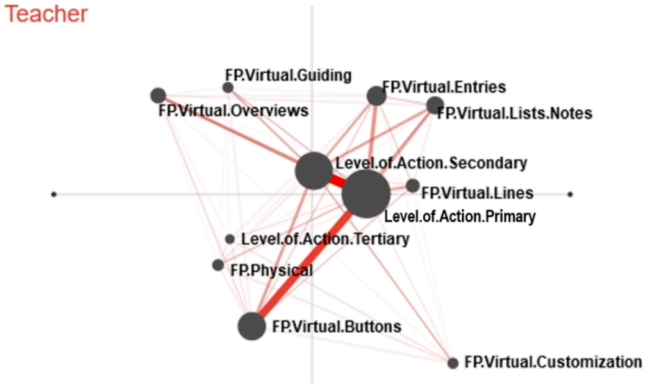

Fig. 3. Teachers' remediation of actions with FPs.

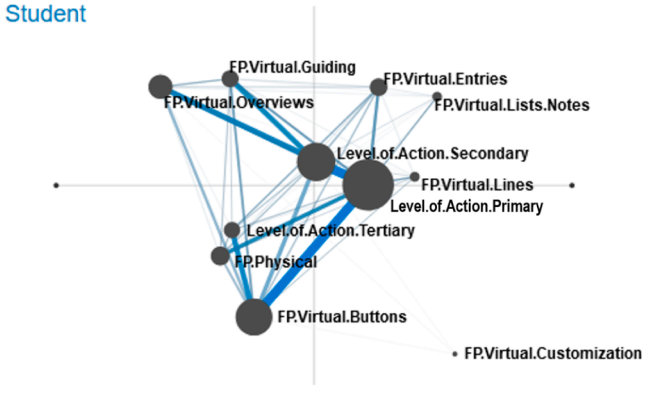

Fig. 4. Students' remediation of actions with FPs.

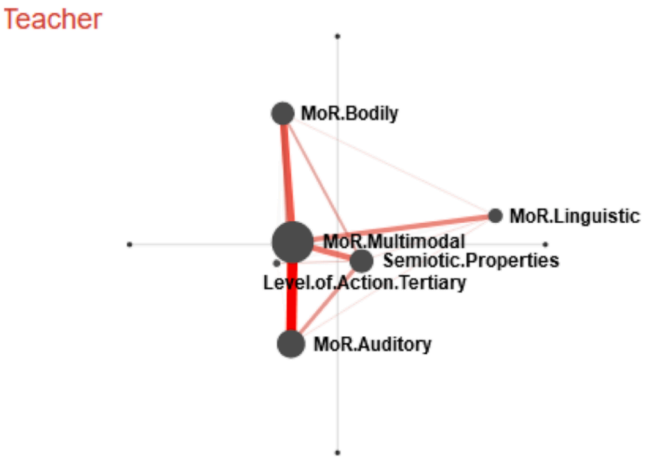

Fig. 5. Teachers' meaning making outcomes.

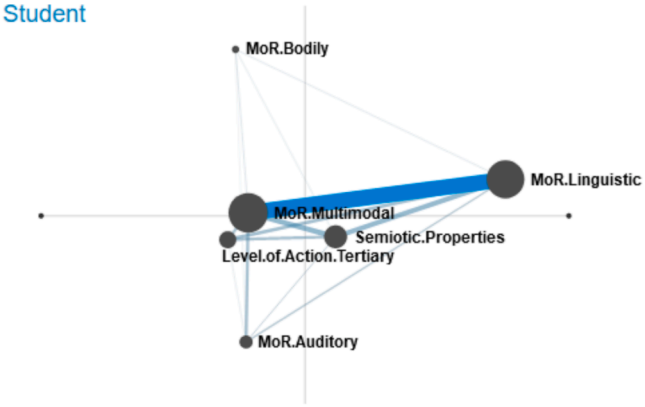

Fig. 6. The students' meaning making outcomes.

Table 6
CIs' mediation of sign systems in the teachers' use.

Software Hardware	Linguistic	Multimodal	Visual	Other	Repository
Laptop	5%	9%	2%	11%	2%
Tablet	18%	3%	2%	21%	9%
Smartphone	1%	13%	8%	6%	1%
Part of use:	21.6%	22.5%	10.8%	34.2%	10.8%

Table 7
CIs' mediation of sign systems in the students' use.

Software Hardware	Linguistic	Multimodal	Visual	Other	Repository
Laptop	7%	4%	11%	4%	6%
Tablet	18%	1%	1%	6%	6%
Smartphone	11%	13%	8%	1%	1%
Part of use:	36.7%	18.4%	20.4%	11.2%	13.3%

Table 8
CIs' initiation of teachers' technology-mediated activities.

Activities Hardware	Individual	Collaborative	Production	Consumption
Laptop	8%	4%	22%	24%
Tablet	15%	3%	28%	39%
Smartphone	6%	2%	22%	17%
Part of engagement:	15.2%	4.7%	37.9%	42.1%

Table 9
CIs' initiation of students' technology-mediating activities.

Activities Hardware	Individual	Collaborative	Production	Consumption
Laptop	11%	10%	30%	24%
Tablet	10%	1%	36%	14%
Smartphone	14%	12%	31%	18%
Part of engagement:	16.6%	10.9%	46%	26.5%

consequence. Because individuality tends to reinforce and sustain individual activities, the limited technology-mediated reflexivity that arose might affect the social space. This, perhaps unintended, technological impact will then also affect the multimodal configurations of the semiotic chains. Teachers and students talked about such consequences during the interviews when they had to adapt their meaning making to the technological conditions, thus impinging on their joint teaching and learning activities.

Table 10
The FP and action nodes' labels.

Node labels	Examples
	FPs featuring virtually manifested sign systems in software such as:
FP.Virtual.Buttons	rectangular shapes and shades composing 3D effects of buttons for pressing.
FP.Virtual.Lines	framed spaces for typing or sorting text in software.
FP.Virtual.Guiding	variously represented indicators, e.g., an hourglass or a clock administering the users' actions.
FP.Virtual.Entries	texts or icons, e.g., messages, links, or toolbars mediating digital progressions.
FP.Virutal.List.Notes	a virtual list presented as, e.g., menus, result lists, and notifications suggesting actions for the users.
FP.Virtual.Overviews	a framed space assembling various functions, e.g., badges and activity centers directing the users' actions.
FP.Virtual. Customization	a digital assignation shifting when the users adjust, e.g., the hardware.
FP.Physical	FPs featuring physically manifested sign systems in hardware such as the size of the screen, home buttons, or keyboards.
Level.of.Action. Primary	Lowest level of actions remediated into operative work externalizations.
Level.of.Action. Secondary	Intermediate level of action remediated into externalizations to organize the work.
Level.of.Action. Tertiary	Highest level of action with FPs linked to the sign-making with the semiotic properties.

4.2. The mediation of technological designs and their remediation in teachers' and students' cognitive processing

The second research question, concerning what meanings are most frequently mediated via technological designs and their impact on the teachers' and students' cognitive processes in remediation, is addressed in the following section.

4.2.1. The FPs and cognitive processes of actions

FPs were frequently represented in the analyzed technologies' design and enabled identifying what design features were mostly considered and remediated by the teachers and students in their cognitive processing and became visible in their meaning making externalizations. The FPs displayed in Table 10 were used most recurrently and are categorized as per their purpose for the teachers' and students' actions (Table 10).

The FP–action connections in the networks in Figs. 3 and 4 have a strong goodness-of-fit (Pearson/Spearman 0.99) with the hypothetical ML model. This implies that the modeled FPs' relations to the scaled actions can depicture the teachers' and students' real-life remediation activities with this part of the technological design. A Mann–Whitney U test revealed non-significant differences between teachers' and students' use of FPs (x axis $p = .2$ and y axis $p = .8$).

Fig. 3 proposes that FPs featuring sign systems formed as buttons (strong ties to the node *FP.Virtual.Buttons*) are mainly mediated and impact the teachers' remediation of lower-level actions - the strong ties to the nodes *Level.of.Action.Primary* and *Level.of.Action.Secondary*.

This finding has two important implications. First, when the technological design seem to preference FPs appearing as buttons, the teachers' remediation of lower-level primary actions are encouraged observed in their meaning making externalizations, such as "tapping," "projecting, and pushing." Second, the many FPs available in the technological design then appear unfrequented (weak connections to the various FPs probably also caused by the software's low attainment, Table 6).

These technological design features seemed to "operate in the background" while meditating in the teachers' meaning making, resulting in a management of the teaching activity with the technologies. For instance, Teacher 3 addressed tapping and termination actions with buttons in one of the interviews: "When I have to get out of there, I either tap this button in the middle, which is the home button, or I tap the three lines so that I can terminate them at once. I usually vary." Teacher 1 also addressed the buttons used in projecting instructions effectively; "On occasion, you put something up [project it], and I have to choose again to delimit what they are going to see." To conclude, the teachers' meaning making resided in lower-level actions when FPs mostly formed as buttons were mediated. Then, the technological design might affect the social space unproductively by inferring technology-mediated meaning making outcomes that are individually conveyed (Table 8) and might be low in multimodality.

Similar to the teachers' technology use, the students' cognitive processes, remediated through the technological design's FPs featuring buttons (ties to *FP.Virtual.Buttons*, Fig. 4), were externalized as lower-level actions observed by the researcher as "clicking," "pressing," or "adjusting" (ties to the nodes *Level.of.Action.Primary* and *Level.of.Action. Secondary*). The students addressed that using buttons for clicking overrode the other technological design features and yielded somewhat monotonous meaning making outcomes. For instance, Student 1 claimed, "Your technology use is about you clicking on different things… a button that you press to submit, and then you cannot adjust what you have submitted." Student 3 gave the same indication; "And when you access, there is one [button] that you can click to see if it is right or wrong."

When the technological design mediates mostly action paradigms through buttons, it becomes evident that students are compelled to use technologies to advance their individual task priorities through the

systems via actions (Table 9). In turn, these meaning making externalizations might reinforce this behavior when transacted into the social space as meaning makers' undertakings interact and can result in relatively one-dimensional semiotic chains.

Despite this initial analysis, the students seemed to remediate various FPs more vividly. For instance, FPs featuring buttons were used on the tertiary level of action (ties to the nodes *Level.of.Action.Tertiary* and *FP.Virtual.Buttons* in Fig. 4). In addition, the students integrated also physically manifested FPs such as keyboards, screens, accessories, and mousepads (strong ties to *FP.Physical* reinforced by the weak software attainment in Table 8) in their primary actions. Overviews and guiding functions (ties to *FP.Virtual.Overview/FP.Virtual.Guiding nodes*) were also part of the students' action remediation on a secondary level. Meaning making grows more technology-mediated as the technological sign systems are explored, multimodally feeding the social space.

4.3. Technological designs' impact on meaning making outcomes

The third research question was posed to investigate the teachers' and students' meaning making outcomes (the MoR) of the remediation of the technological design (Table 11).

Like the networks previously demonstrated, the graphs in Figs. 5–6 have a high goodness-of-fit with the theoretical ML model (Pearson/Spearman 0.9). This means that the modeled MLs can represent the real-life connections between higher-level tertiary actions remediated via FPs and the sign-making remediated via the semiotic properties underlying the MoR. The differences between teachers' and students' meaning making were non-significant (Mann–Whitney U test, x-axis $p = 0.2$ and y-axis $p = 0.8$).

Fig. 5 demonstrates that the FPs limitedly mediated in the teachers' higher-level action aspirations in their meaning making (weak tie to *Level.of.Action.Tertiary* node). The semiotic properties were then downplayed (weak tie between *Level.of.Action.Tertiary* and *Semiotic.Properties*). The ties between the nodes *MoR.Multimodal*, *MoR.Auditory*, and *MoR.Bodily* and the larger node *Semiotic.Properties* indicate that the CIs' design with more abstract meanings mediated in the teachers' demonstration of learning content multimodally, for instance, when they talked, deictically gestured, and moved around in the classroom simultaneously. Teacher 1 emphasized this performance as being integrated with their teaching mission with the technologies: "But I have to point out what they will do with many gestures. I think many students disconnect from what I say."

When the technological design's many meaning potentials partially mediated in the teachers' meaning-making (into lower-level actions), and the teaching ran parallel to rather than through the technological design as demonstrated, the multimodal MoR that were communicated by the teachers to the students were not necessarily technology-mediated. Teacher 2 expressed the technology's role as a projector of the learning content (rather than as means for their meaning making) via images, stating, "If I had written a lot and the students had to copy it, I would have lost their attention." This is perhaps a natural consequence of teachers' purpose in classrooms when they bespeak learning content. However, limitedly technology-mediated MoR impact the formation of a multimodal social space as the technologies' multimodal affordances are backgrounded.

The students' meaning making in this study is thus a result of the task requirements posed by the teachers' instructions, encouraged by the CIs' functions mediating their individual work into lower-level actions. However, the students also remediated the technological properties' meanings more extensively as previously mentioned (Fig. 6). For instance, the tie between the nodes *Level.of.Action.Tertiary* and *Semiotic.Properties* suggest that the students remediated the various meanings of the technological design through higher-level actions including also the sign-making. These endeavors rendered various meaning making outcomes, reflected by the ties to the node *MoR.Multimodal,* that sometimes tended to be more linguistic (i.e., ties to the node *MoR.Linguistic*). This is possibly a result of word processing applications (the emphasis on linguistic software, Table 7), whose well-known toolbar FPs encouraged the students to go beyond their immediate visualizations to use the semiotic properties in their sign-making. This finding can be obtained when studying technologies' properties for cognitive processing.

An example of this meaning making was observed when the students were writing and discussing a text. Semiotic properties such as spaces, colors, or font size were mediating in the students' sign-making when they were activating the toolbar FPs through tertiary actions of pressing. Student 3 articulated: "Pressing the enter button brings you down a notch so that you break down the text in sections so that it does not become so long. Then, it usually makes it easier to do it by categories using different bullets instead." This student also described how these multimodal MoR fed into the social space: "And then there was group work, and then you have to discuss in your group to get a good text together." These two quotes demonstrate how the technological design's properties that were mediated became remediated by the students' and resulted in cognitive processes externalized as texts and discussions. They also reflect how multimodal meaning making outcomes then reverberate in the social space through technology-mediated MoR.

Table 11
MoR.[6]

Node labels:	Examples:
Level.of.Action.Tertiary	Highest level of action with the FPs linked to the semiotic properties and the sign-making.
Semiotic.Properties	Abstractions available in the technological design via FPs such as font, font size, colors, templates, and bullets.
MoR.Bodily	Sign system units in the meaning making outcomes such as: walking, gaze or gestures.
MoR.Linguisic	writing, texts.
MoR. Auditory	talking.
MoR.Multimodal	Combined sign system units.

[6] The MoR are categorized according to their most frequent sign system units or combination of units saturating the participants' meaning making outcomes as a consequence of the mediated and remediated sign systems via the technologies. Sign systems are inherently multimodal [30], e.g., texts consist of letters, signs, and font. However, these examples are viewed as the sign systems within a unit (e.g., a linguistic mode) in this paper. When sign systems units such as linguistic, auditory, or visual are combined, they emerge multimodal MoR.

5. Discussion

This section discusses the tendencies in sign system mediation and remediation that form into semiotic chains and fluence how teaching and learning activities realize, identified when studying how teachers and students engage cognitively with certain CIs and their designs in meaning making. In this investigation, the question of *what* became important to identify the multimodal sign systems numerically residing between teachers, students, and technologies.

A first indication when contrasting teachers' and students' meaning making via technology use – and thus, their impacts on the semiotic chain formations – is that the technological design seemed to pattern the semiotic chains uniformly across the studied classrooms. This finding is surprising, as teachers and students have various prerequisites, knowledge, skills, and quite different missions in the classroom; one could reasonably assume these variations would entail some differences. The various technological configurations, subjects, and activities studied would also influence this outcome. Hence, the sign systems in the technological design appear to have quite strong effects on the teachers'

and students' meaning making, and, therefore, on the realization of teaching and learning activities. These findings are discussed in the following sections.

5.1. Technologies and technological designs' impact on cognitive processing

As stated at the beginning of this paper, teachers and students frequently use various technologies to enhance their learning. Teachers choose technologies to convey learning content, and this analysis indicates that sign systems featuring FPs influenced their remediation externalized into lower-level actions. The same tendency was found among students. This finding has four implications for understanding the semiotic chain configurations in this study.

First, technological designs seem to technologize classroom practices. Technologization occurs when technological (e.g., functions) and social forces (e.g., lower-level actions) cohere and become patterned, as described in this paper. This is due to the "hegemonic semiotic regimes" in the technological design that control how individuals make meaning ([12], p. 603) and how semiotic chains then form. Hence, when the meaning making is externalized similarly into "effective operations" and individual task prioritizations by teachers and students as an effect of the technological design [57,58], an unreflexive learning environment is an outcome that again may perpetuate low sign system incitements either by the technologies or by the meaning makers into the social space. This reciprocity pattern in the semiotic chains might form instructional design models [59]. The semiotic chains are balanced and co-designed one-dimensionally. If seeking co-design, a term often adapted to describe collaborative technology-mediated environments between teachers and students [4], it is important to understand when design patterns are reversed in this way.

Second, as main mediators in technological designs, FPs appear to stand separately from the sign systems representing the learning content, sometimes overriding it and driving the user to proceed in a program effectively [60]. The FPs encourage meaning makers to externalize certain meaning making outcomes (lower-level actions) that appear to offset other sequences associated with, for instance, subject content, which is part of meaning makers' teaching and learning obligations. This finding possibly complements existing research on software content for meaning making by providing insight into differences in designs' influence on cognitive processes and, thus, how teaching and learning activities then realize via them.

Third, these findings call for a better understanding of sign system relations and meanings (properties and content) in digital learning materials, especially when certain meanings (formed into FPs) are common in technological designs and reverberate into similar remediation processes regardless of who the users are, what technologies mediate them, or which activities they include or are supposed to enhance.

Fourth, an FP sometimes becomes a semiotic property with the cognitive processes' progressions and sometimes not. Hence, there seems to be a difference between what Vygotsky [34] denoted as higher psychological functioning and other higher-level cognitive processes (e.g., sign-making), requiring further investigation. Higher psychological functioning is required to interpret and sift a complex setup of sign systems [34] in technological designs, regardless of what meanings are subsequently remediated. This higher-level cognitive capacity seems separate or parallel to sign-making because this process is only sometimes evoked. Moreover, technological properties' representational appearances (the designs' features) are unreliable for understanding their implications on meaning making.

To conclude, technological properties' meanings can profoundly influence meaning makers' remediation and their meaning making externalizations. More research is needed to understand the levels of cognitive processing in sign system remediation. It would also be useful to study how sign systems in technological designs can be formed with intuitive or easily detainable appearances for higher-level sign-making performances - the semiotic properties – and gain more knowledge on how different properties and learning content cohere in mediation to realize more multimodal teaching and learning activities.

5.2. Technological designs' impact on meaning making outcomes

This study shows that technologies partially mediated in the teachers' and students' classroom undertakings and can result from technological solutions' initiation of behavioristic or cognitive epistemologies. Such teaching machines or intelligent tutoring systems are designed to teach in solitude, apart from the context's and the "recipients'" prerequisites. Meanings are mediated via the technological design that encourage meaning makers to remediate their meaning making individually and effectively via operations [61]. Opposite to such ideas is associated with computer-supported collaborative learning (CSCL), in which technologies are regarded as accommodating social learning aspirations and can impel meaning makers' joint cognitive processing [62]. The technologies, their properties, and the meaning making outcomes then become highly reflexive in the semiotic chains, with a multimodal impact on teaching and learning activities [13]. Hence, what or to what extent technologies mediate in teaching and learning activites are important to attend when seeking multimodal relations in classroom practice, in which the technological configurations and designs are key ([13,26]).

The level of technology-mediation was highlighted by the findings of the teachers' technology use. The teachers' demonstrations of different learning content with the software's semiotic properties included gestures as a part of the multimodal MoR. This sign-making, externalized as gestures, supported oral, interpersonal communication as an effect of the teaching mission, which seemed partially remediated via the technological design. The teachers' meaning making actions were technology-mediated (via the FPs) but diminutive in the social space's multimodal formation when other properties and the sign-making were minimized. These occurrences can irradiate to what extent technologies mediate in teaching and learning activities, especially when certain meanings (FPs) seem to exceed other meanings (the semiotic properties and subject content) when mediating in the meaning making (partially) but appear inconsequential if not.

Elaborating on this finding is not intended to separate meaning making from other forms of communicated meanings but rather to illustrate the interpersonal effects of differences in cognitive processing (internal/external) conditional to the CIs and their designs. To do that, paralanguage or semovergent paralanguage, as well known concepts in semiotic research [42,43], are adapted to understand the scales in actions and their relation to sign-making activities when technological designs mediate in meaning making. In other words, the actualization of teaching and learning activities by the technological design and meaning makers' remediation processes into lower- to higher-level actions (e.g., bodily movements appearing as gestures) combined with sign-making, such as gestures is more multimodal than if the technological design influence meaning makers partially in remediation of actions or sign-making that alone realize these activities. Building on He and van Leeuwen's [42] research on the different interactions elicited by a user engaging with a hardware-software configuration, the level of technology mediation and nuances in cognitive processing can only be understood in relation to the CIs' (physical/virtual) properties. The result of the students' technology use in this study reinforces this idea. Because these thoughts are still quite immature, more research is needed on paralanguage.

5.3. Limitations and implications

It is vital to frame the central design features and their uses residing in technology-mediated practices to understand multimodal meaning relations [28,26]. Through the MLs, several important variables were

identified, and others were left out. VR, VEI, and observation data were collected on individuals, and situated and multimodal insights into the MLs' connections in semiotic chains were gained. This was accomplished when matching the MLs via the sign systems as a common denominator. Numerous sign systems were required to fine-grained depicture the many interrelated meanings between the CIs' configurations, the technological design, and the meaning making outcomes they represent. The sign systems' multimodal relations could be compared, with various tendencies discovered. The cognitive processes constituted an important, perhaps new, study element in this context. However, it could also be argued that meanings' causes and effects arising in situated practices are difficult to study because they are plentiful and elusive. To gain more fine-grained insights into the MLs, teachers and students were studied and compared individually to differentiate their various use of the CIs more precisely.

Large sample sizes were excluded when the MLs were studied as they require multimodal data on a range of technology and meaning making aspects that were best gained by VRs, observations, and VEIs [45]. Contextual descriptions were obtained. The sign system quantities withdrawn from the MLs then complicated considerations of other semiotic interconnections, such as research participants' prerequisites, skills, genders, and socioeconomic factors. Hence, small sample sizes, delimited study objects, and context-sensitive events make this study's findings un-generalizable. Nevertheless, judging from the results that sign systems seem to exceed other rationales, some of the findings could be transferred to other contexts (e.g., common design features across today's technologies; functions' relations to actions).

Quantitative tools are often used to generalize findings on large-scale sample sizes, which can detach the findings from their context [63]. When originating "crude measurements" of social phenomena [4], situated storying is disabled. As such tools were used in this study, they may be perceived as contradicting the purpose of the qualitative and small-scale data and the sign systems' representations of contextual events. Besides, one could claim that it is impossible to study tendencies in situated and small-scale data. However, insights into multimodal relations through sign systems were only obtainable with quantitative data processing strategies and tools, as a limitation of the human mind [49]. Because sign systems together can represent contextual meanings, their frequencies obtained via the QCA and QE procedures of the MLs could depicture the many interrelated events generated by the data. The QE tools are relatively new and constantly improving and sometimes require many data tryouts, which is a reliability issue. For instance, the ENA generated the same results after several tryouts with various conversation and stanza settings. Therefore, ENA outputs must be validated with different datasets.

Adding to the theory-RQ-method perplexity are the sign system transitions from the VR, observation, and VEI data into keywords. In this case, a theory is important [46], but the analysis is still a manual, subjective process dependent on the researcher's delineation skills and interpretation of (here the MLs in) the data. Besides, the VEI procedure must be viewed from a reliability standpoint, as the researcher forced certain concepts and reasonings through the video sequences (hence the sign systems later detained in the keyword modeling).

Each sign system represents meanings that could be conceptualized [46]. However, the transitions between sign system meanings and keywords were ambiguous when keyword synonyms had to be used to distinguish the respective ML's sign systems in the QE analysis. Because some keywords overlapped between the MLs, coding became complex and cumbersome, possibly diminishing the codes' explanatory power in the ENA modeling. Moreover, issues in the code construction concerned MLs that were difficult to attach sign systems/keywords to. For instance, the ML activities (e.g., reading), hardware technologies (e.g., computer), and CIs were for that reason not included in the network modeling. A significant shortcoming of this study is the difficulty of observing the hardware's impact on sign systems and the CIs' role in the meaning making.

The central finding made in this study that mediated meanings appear to match remediated meanings has implications for research and practice. Overall, a richness in sign systems can be challenging to deal with, but with more balanced qualities, sign systems can progress cognitive processes that serve learning, advance multimodality, and increase the interaction in the classroom.

It is essential to match sign systems with meaning makers' aspirations and not the other way around. Matching meanings can be done by analyzing sign system and how they pattern meaning making processes. These matches can stabilize understandings of meaning relations, often difficult to obtain in sprawling teaching and learning settings where everything can be an effect of everything. Such understandings can yield insights for teachers on technologies' potentials to serve learning and boost students' metacognition and self-efficacy regarding what technologies work in learning and why. These understandings might also enhance critical awareness of complications. Sign system matches are not clear-cut but can offset impressionism accusations of semiotic research [26] and support technology acceptance. Hence, there is a need for more studies examining how to evaluate the use of technological configurations and their designs for various purposes and on many decision levels, as better strategies can enhance the quality of technology integration and use in schools. This study offers concrete suggestions (e.g., sign system meanings' relation to cognitive processing and learning content).

Thus, this study can encourage future examinations of sign systems' impacts on meaning making. However, when cognitive processes are viewed as residing inside an individual's mind, they are often regarded as indefinable by an outsider. From a representational perspective, cognitive processes are represented in meanings such as sign systems, mediate (e.g., in technologies), and are externalized via the meaning makers' remediation. These mediators and remediating connections leave traces in the social space and can progress multimodal learning opportunities if tools and strategies for inferring them are supplied.

Separating sign systems generated by meaning makers via technologies from those linked to meaning making outcomes in which the technologies were not mediating, is difficult. In addition, it is complicated to discriminate which mediators have a direct bearing on the cognitive processes remediated. Especially since the remediated activities may result from impressions taken up by the meaning makers from other occurrences, a fine-grained lens is required to examine these relations, which is why sign systems were emphasized in this study. It is imperative to understand what and to what extent technologies mediate in the meaning making of today's classroom. How data on these relationships can be reliably and validly obtained requires further examination.

In future quantitative studies on sign systems, generating data with eye-tracking or LA data-mining techniques such as natural language processing might be more feasible. Chiefly, such tools can quantitatively attach numerous sign systems to many variables directly while eliminating detours via manual procedures, and qualitatively collected and small-scale data [64]. Regarding eye tracking, controlled studies of technology use can add information on CIs' designs and their roles for the meaning makers' cognitive processes, as these relations were difficult to distinguish from the VRs, observations, and VEIs in this study in favor of the interactions.

6. Conclusion

On paper, the demands of digital schooling are being fulfilled as many technologies integrate and encourage multimodal meanings in today's classrooms. Simultaneously, when one sees this in detail, a "buttonization" of meaning making recurs when the technological design indorses mostly functions, and other properties go incognito. The semiotic chains technologize when teaching and learning homogenize through lower-level actions. In an extended sense, paralanguage can afford insights into differentiated meaning making according to the

technologies. This idea of paralanguage can make us understand how and when rewarding technologization processes arise by integrating other - often viewed differently - technology-mediated meaning-making forms into the research conversations. Paralanguage can then also help identify higher levels of interpersonal multimodality in the social space. This study's results show how semiotic chains, as an important field of inquiry in semiotic technology research, are complex to unravel, as they vary with the sign systems available in the technological design and the social space that determine the cognitive processes and the meaning making outcomes, and therefore, the extent to which teaching and learning activities can be technology-mediated and multimodal. If the various properties of the CIs promote differentiated meanings more successfully, more technology-mediated multimodality will seize the day.

Notes

Data collection and administration were preceded by a formal ethical review stating no objections to the research project.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.caeo.2023.100136.

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