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Semiotic Engineering Theory for Human-Computer Integration: An Applicability and Usefulness Evaluation

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Abstract.
The relationship between users and autonomous technologies is evolving towards integration (in the sense of partnership), transcending the stimulus-response interaction between these two agents. To follow this evolution, Human-Computer Interaction (HCI) researchers have defined and characterized a new interaction paradigm, Human-Computer Integration (HInt), which extends the focus of the HCI area to cover this new relationship of partnership between humans and autonomous technologies. As HInt is an emerging paradigm, the concepts and ontology of Semiotic Engineering Theory have been extended to address HInt as an extension of the traditional HCI interaction. Thus, this paper aims to evaluate and discuss the applicability and usefulness of the extension of Semiotic Engineering to define, explore, and explain the phenomena involved in HInt. Our findings provide useful insights and reflections on the benefits and limits of Semiotic Engineering for HInt to support the study, design, and evaluation of the partnership between humans and autonomous technologies.

Keywords: Human-Computer Integration, HInt, Semiotic Engineering, Ontology, Evaluation.

1 Introduction

The rise of autonomous technological solutions is changing the relationship between humans and technologies so that the interaction era is extending to the integration era [Farooq and Grudin, 2016]. In this new era, humans and autonomous technologies integrate physically and/or conceptually and become codependent partners with the autonomy to cooperate and collaborate to achieve common goals. To follow this evolution, Human-Computer Interaction (HCI) researchers have defined and characterized a new paradigm, Human-Computer Integration (HInt), which extends the focus of the HCI area to cover this new relationship of partnership between humans and technologies [Farooq and Grudin, 2016; Mueller *et al.*, 2020]. In other words, HInt is an emerging paradigm (i.e., model) that aims to define, characterize, and explain the relationship between humans and autonomous technologies as a partnership that transcends the traditional HCI interaction (stimulus-response). Thus, technological solutions that follow this paradigm are called **HInt Technologies**, **Partner Technologies** or **HInt Solutions** [Barbosa *et al.*, 2023; Farooq and Grudin, 2016; Mueller *et al.*, 2020].

HInt offers new opportunities and challenges for the HCI field, including demands for revising and proposing theories and methods so that the design and evaluation of HInt focus on both interaction and the partnership between humans and technologies [Barbosa *et al.*, 2021a, 2023; Barbosa and Prates, 2022; Farooq and Grudin, 2016; Mueller *et al.*, 2020; Zaina *et al.*, 2024]. As HInt is an emerging paradigm, the demands for theoretical approaches that extend HCI to HInt can be explored from different perspectives, including within the Semiotic Engineering scope [Barbosa *et al.*, 2021a, 2023; Barbosa and Prates, 2022; Zaina *et al.*, 2024].

Semiotic Engineering is an HCI theory that provides an ontology, epistemology, and methodology for exploring, understanding, and explaining HCI phenomena [de Souza, 2005]. From the perspective of this theory, interaction is a special case of communication from the designer to its users, called *metacommunication*, and the quality of this metacommunication is defined by its *communicability*. The Semiotic Engineering theoretical framework (i.e., concepts and ontology) allows us to structure explanations for the phenomena involved in the design, use, and evaluation of interactive technologies. From this theoretical basis, we can derive frameworks and models of particular aspects of HCI, independently of the interaction context and/or the type of technology [de Souza, 2005].

In a previous work, Barbosa and Prates [2022] extended the concepts and ontology of Semiotic Engineering to address HInt as a particular case of HCI. As future work, the authors have indicated the need and importance of conducting other studies to explore and evaluate the benefits and limits of Semiotic Engineering extended to HInt. According to Barbosa and Prates [2022], this demand can be explored from different perspectives. For instance, it is important to investigate whether the proposed approach is applicable and useful for: (a) supporting professors and researchers in the expansion of knowledge, teaching, and research in HCI with a focus on HInt; (b) supporting students in the learning, study, design, and evaluation of HInt in the academic context; and/or (c) guiding the development of partner technologies in industry. Initiatives like these can contribute to the consolidation and evolution of the Semiotic Engineering theoretical framework for HInt [Barbosa and Prates, 2022].

Given this context, our paper aims to investigate and discuss the applicability and usefulness of the extension of Semiotic Engineering to support the definition, explanation, and exploration of HInt as a new HCI paradigm. To achieve our goal, we conducted two types of evaluation: (a) a proof of concept, in which we applied the Semiotic Engineering extension to existing examples; (b) two case studies, in which in the context of a workshop and undergraduate course, we collected other people's perspective about Semiotic Engineering for HInt.

It is important to highlight that this paper is a revision and extension of the study published and presented by Barbosa and Prates [2024b] at the *"XXIII Brazilian Symposium on Human Factors in Computing Systems" (IHC 2024)*. In the previous paper, we explored the applicability of the Semiotic Engineering theoretical framework for HInt from the perspective of undergraduate students [Barbosa and Prates, 2024b]. In this new paper, we present and discuss the evaluation of the extension of Semiotic Engineering to HInt through a more holistic approach. That is because, in addition to considering student perceptions, we include: (a) a proof-of-concept analysis conducted by the researchers who proposed the extension and (b) an analysis of the experiences and perceptions of other HCI researchers and professionals regarding the applicability and usefulness of Semiotic Engineering extended to HInt. These additional perspectives complement and contrast with the students' point of view (reported in the previous paper), enriching the analysis presented here and allowing for a deeper and more refined understanding of the advantages and limitations of addressing HInt in the light of Semiotic Engineering.

Thus, our results provide useful insights and reflections that contribute to expanding knowledge about the existence, benefits, and limitations of Semiotic Engineering extended to conceptualize, explore, and explain the phenomena involved in the design, use, and evaluation of HInt. In addition, our results stimulate new initiatives and contributions grounded in Semiotic Engineering theory (e.g., methods and tools) to address the new partnership relationship between humans and autonomous technologies.

This paper is organized into nine sections. Section 2 and Section 3 present the HInt paradigm and the extension of Semiotic Engineering to this new paradigm, respectively. Section 4 summarizes the related work. Next, Section 5 describes the methodology adopted to evaluate Semiotic Engineering extended to HInt from different perspectives. Section 6, Section 7, and Section 8 present and discuss the main results of this research. Finally, Section 9 presents the final considerations.

2 HInt Paradigm Overview

Human-Computer Integration (HInt) is an emerging paradigm that extends the HCI field, which aims to define and characterize the new relationship between humans and autonomous technologies as a partnership that transcends the traditional HCI interaction (stimulus-response) [Farooq and Grudin, 2016; Mueller *et al.*, 2020]. From the perspective of this paradigm, users and technologies are codependent partners with some autonomy to collaborate towards their goals [Barbosa *et al.*, 2021a, 2023; Mueller *et al.*, 2020]. In literature, solutions that follow this paradigm are called ***HInt Technologies***, ***Partner Technologies*** or ***HInt Solutions*** [Barbosa *et al.*, 2021a, 2023; Mueller *et al.*, 2020]. Some examples of these solutions are: smart alarms; semi-autonomous cars; exoskeletons; smart robots; pills with ingestible sensors; smart assistants for smart TV; smart bands; and smart eBike [Andres *et al.*, 2020; Farooq and Grudin, 2016; Niess and Woźniak, 2020; Mueller *et al.*, 2019, 2020; Stephanidis *et al.*, 2019].

As the integration and partnership between humans and technologies can occur in many ways, HInt can be characterized regarding the following aspects: (1) **Agency**; (2) **Scale**; (3) **HInt Type**; and (4) **Physical Coupling Type** [Mueller *et al.*, 2019, 2020]. The **Agency** characterizes the level of autonomy (i.e., control) that humans and technologies have in the partnership during integration. This control ranges from: (a) *controlled mainly by humans*; (b) *equally shared control between humans and technology*; to (c) *controlled mainly by technology* [Mueller *et al.*, 2019, 2020]. It is important to highlight that to describe the integration between humans and technologies as a kind of partnership, both agents need to control the integration at some level, even if only minimally [Barbosa *et al.*, 2021a; Mueller *et al.*, 2020]. In turn, **Scale** characterizes the level at which integration occurs. The integration can occur at: (a) *Social/Collective Level*, in which whole cultures or user groups are integrated with the technology; (b) *Individual Level*, in which a single individual and technology are integrated, or (c) *Organ Level*, in which the human and technology are integrated via a part of the human organism and integration occurs at a micro-level [Barbosa *et al.*, 2023; Mueller *et al.*, 2020].

The dimension **HInt Type** indicates the forms of partnership between users and technologies. The **HInt Types** are: (a) *Integration by Fusion* and/or (b) *Integration by Symbiosis*, and they **are not** mutually exclusive. In **Integration by Fusion**, the technology – physically coupled to the human body (internally or externally) – supports and extends the individual's bodily abilities and experiences. Usually, fusion occurs on an individual level (e.g., a human limb or sense), and the integration is controlled mainly by humans or mainly by technology . Examples of technologies that promote Integration by Fusion include: electronic piercings for monitoring body temperature and human augmentation technologies (e.g., exoskeletons and intelligent prostheses) [Barbosa *et al.*, 2023; Mueller *et al.*, 2020].

In turn, in **Integration by Symbiosis**, humans and technologies conceptually work together toward common or complementary goals. In this type of HInt, control is usually equally shared, and integration may occur at both the individual and the social level Mueller *et al.* [2020]. Examples of technologies that promote Integration by Symbiosis include: semi-autonomous vehicles, smart alarms, health and well-being monitoring technologies, as well as autonomous recommendation services (e.g., YouTube video recommendations) [Barbosa *et al.*, 2023; Mueller *et al.*, 2020].

Finally, HInt must be classified with regard to the **Type of Physical Coupling** between the technology and the human body. HInt solutions can be classified as: (a) *In-Body*, which are integrated within the human body (e.g., ingestible sensors); (b) *On-Body*, which are integrated on the surface of the body or externally connected to the body (e.g., smart watches), and *Off-Body*, which are situated in the environment and not physically connected to the body (e.g. intelligent virtual assistants) [Barbosa *et al*., 2023; Mueller *et al*., 2020].

Taken together, the *Agency*; *Scale*; *HInt Type*; and *Physical Coupling Type* are the attributes that describe and map the **Nature of Partnership** - i.e., they define how humans and autonomous technologies can relate as partners in integration. According to the HInt definition, these four attributes apply to all solutions that follow this paradigm (i.e., they are mandatory requirements of a partner technology) [Barbosa *et al*., 2021a, 2023; Mueller *et al*., 2020]. In addition to these attributes, HInt technologies can also be classified in relation to **Intelligence** and their **Composition** [Barbosa and Prates, 2022, 2023].

Concerning **Artificial Intelligence**, HInt technologies may or may not be able to learn and act based on the user's demands and preferences to promote human-computer integration (i.e., they may or may not have intelligence). Although *autonomy* and *intelligence* may be related, there are autonomous HInt technologies that are not intelligent. For instance, smart bands have the autonomy to monitor and report the user's performance during physical activity. However, despite their name, these partner technologies do not possess the intelligence to anticipate and suggest alternative solutions to the user's demands. Therefore, although the *Level of Autonomy* is a mandatory attribute to characterize a technology as an HInt solution, being an *Intelligent Agent* is an optional characteristic of this type of solution [Barbosa and Prates, 2022, 2023].

In turn, the **Composition** classifies the partner technology regarding: (1) its *Components* and (2) *Interactive components (i.e., interactive interfaces)*. The **Components** refer to the number of physical devices and digital systems that the user has to deal with (at interaction time) and which together compose the partner technology as a whole. On the other hand, **Interactive components** refers to the number of different interfaces of the HInt solution with which the user can or needs to interact directly during the partnership. For each one of these attributes, the HInt solution can be classified as: (a) *single* or (b) *multiple* components [Barbosa and Prates, 2022, 2023]. Note that the characteristics: (a) *be an intelligent agent* (in addition to being autonomous), and (b) *be composed of multiple components* are optional requirements of the partner technologies [Barbosa and Prates, 2022, 2023].

Figure 1 shows five examples of partner technologies classified according to the attributes and characteristics that define a HInt solution. It is important to highlight that the classification regarding the nature of partnership, intelligence, and composition of the HInt technology depend on the design decisions of each solution. Therefore, the examples in **Figure 1** were classified according to the descriptions presented by Andres *et al*. [2020], Farooq and Grudin [2016], Mueller *et al*. [2020] and Stephanidis *et al*. [2019].

Considering the above and as shown in **Figure 1**, when compared with technologies that do not follow the HInt paradigm, partner technologies have particularities (e.g., their purpose, nature of partnership, intelligence, and composition) that may influence the design, use and evaluation of this kind of solution. For this reason, the HInt paradigm and partner technologies offer challenges to the HCI Community, including demands for reviewing and/or proposing empirical and theoretical HCI approaches to support the study, design, and evaluation of the partnership between humans and technologies, taking into account the HInt particularities [Barbosa *et al*., 2021a, 2023; Cornelio *et al*., 2022; Farooq and Grudin, 2016; Mueller *et al*., 2020, 2021, 2022; Zaina *et al*., 2024]. The lack of HCI theories focusing on HInt, as well as the possibility of exploring this demand from different theoretical perspectives, motivated the review and expansion of the Semiotic Engineering theoretical framework to define, explore and explain HInt as an extension of traditional HCI interaction (stimulus-response) [Barbosa and Prates, 2022, 2023, 2024a].

3 Semiotic Engineering for HInt

This section presents the theoretical framework of Semiotic Engineering extended to HInt. To better understand this extension, initially, we present an overview of this theory and its main concepts. Next, we present the concepts and ontology of Semiotic Engineering for HInt.

3.1 Overview of Semiotic Engineering Theory

Semiotic Engineering is an explanatory and reflective (i.e., non-predictive) theory of HCI that provides an ontology, methodology, and epistemology for exploring and understanding the phenomena involved in HCI [Barbosa *et al*., 2021c; Prates and Barbosa, 2007; de Souza, 2005; de Souza and Leitão, 2009]. From the perspective of this theory, the interaction between humans and technologies is a special kind of communication (i.e., communicative process) from the designer to its users, mediated by interactive technology. Through the interface, the designer (i.e., the design team) conveys to the users their understanding and decisions regarding: (a) who the users of the technology are, and what their demands are; (b) what problems technology can solve; and (c) how to interact with the technology. The users perceive and interpret the message as they interact with the interface [de Souza, 2005].

Thus, Semiotic Engineering understands that the designer-user communication (unidirectional) takes place through the user-system communication (bidirectional). For this reason, the designer-user communication is known as **Metacommunication**, and the message (i.e., content) transmitted by the interface is known as **Metamessage** [de Souza, 2005]. The metamessage content can be paraphrased as follows (i.e., the **metamessage template** is): *"Here is my understanding of who you are, what I've learned you want or need to do, in which preferred ways, and why. This is the system that I have therefore designed for you, and this is the way you can or should use it in order to fulfill a range of purposes that fall within this vision"*.

During the interaction, the communication is successful if users can generate interpretations compatible with the intentions and meanings encoded by the designer in the interface [de Souza, 2005]. Therefore, *designer-user metacommuni-*

HINT TECHNOLOGY EXAMPLE	NATURE OF HINT				INTELLIGENCE	COMPOSITION	
	Agency	Scale	HInt Type	Physical Coupling Type	Intelligent Agent	Number of Components Composing	Number of Interactive Components
Exoskeleton	CMH	Ind.	F	On	No	SC	SC_UI-Mono
Intelligent Robot	CMH or ESC	Ind. or Soc.	S	Off	Yes	MC	MC_UI-Mult
Pill with ingestible sensor	CMT	Org. or Ind.	F	In	No	SC	SC_UI-Mono
Smart Assistant for Smart TV	ESC	Ind.	S	Off	Yes	MC	MC_UI-Mult
Smart Band	ESC	Ind.	F&S	On and Off	No	MC	MC_UI-Mult
Smart eBike	ESC	Ind.	F&S	On	Yes	MC	MC_UI-Mono

LEGEND:

1) Agency (i.e., Autonomy Level):
CMH = Controlled mainly by humans
ESC = Equally shared control
CMT = Controlled mainly by technology
2) Scale (i.e., HInt Level):
Org. = Organ; **Ind.** = Individual or **Soc.** = Societal
3) HInt Types:
F = Fusion; **S** = Symbiosis; or **F&S** = Fusion and Symbiosis
4) Physical Coupling Type:
In = In-Body; **On** = On-Body or **Off** = Off-Body

1) Is HInt technology an intelligent agent?
Yes = In addition to being autonomous, the HInt technology is intelligent
No = HInt technology is not an intelligent agent

1) Number of Components Composing:
SC = Single Component
MC = Multiple Components
2) Number of Interactive Components:
SC_UI-Mono = Single Component with User-Monocomponent Interaction
MC_UI-Mono = Multiple Components with User-Monocomponent Interaction
MC_UI-Mult = Multiple Components with User-Multicomponent Interaction

Figure 1. Classification of partner technology examples (*Translated from Barbosa and Prates [2022, 2024b]).*

cation quality affects the quality of the user's interaction (communication) with the technology [de Souza, 2005]. For this reason, the **communicability** [de Souza, 2005; de Souza and Leitão, 2009; Prates *et al.*, 2000] is the property (i.e., quality attribute) that qualifies this particular case of communication between designers and users mediated by technology. **Communicability** is the distinctive quality of interactive technologies that communicate to their users - in an organized and clear way (efficiently) - the intentions and principles that guided their design; in addition, this communication achieves the desired result (effectively) [de Souza, 2005; de Souza and Leitão, 2009]. Thus, Semiotic Engineering Theory focuses on *communication-centered design* and the evaluation of communicability [Barbosa *et al.*, 2021c; Prates and Barbosa, 2007; de Souza and Leitão, 2009].

Semiotic Engineering provides concepts and an ontology (i.e., theoretical framework) to assist HCI professionals and researchers in exploring, understanding, and explaining the phenomena involved in the design use and evaluation of interactive technologies [de Souza, 2005]. From this theoretical framework, we can derive structures and models for particular cases of HCI, independently of the type of technology. As HInt is an extension of the traditional HCI, the concepts and ontology of Semiotic Engineering have been extended to address this new paradigm [Barbosa and Prates, 2022, 2023, 2024a]

3.2 Theoretical Framework of Semiotic Engineering for HInt

The original ontology of Semiotic Engineering Theory defines the categories and elements that conceptualize and characterize interaction as a communicative process. This ontology comprises four categories: (1) **Interlocutors**; (2) **Design Space**; (3) **Communication Processes** and (4) **Signification Processes** [de Souza, 2005]. To define and characterize HInt as an extension of the HCI communicative process, Barbosa and Prates [2022] have extended: (a) 3 out of 4 categories of the ontology; (b) the metamessage template; and (c) the Semiotic Engineering definition of communicability [Barbosa and Prates, 2022, 2023, 2024a].

Originally, the **Interlocutors** category characterizes the agents involved in the communicative process that takes place during interaction. The agents of interaction are: *Designer* and *User* (human agents); and *System* (technological agent) [de Souza, 2005]. From the perspective of Semiotic Engineering, in addition to the user, the designer is an important interlocutor in the HCI process because he is responsible for creating the message conveyed to the user during metacommunication (i.e., during the interaction). The system is also considered an interlocutor because: (a) it corresponds to the designer's crystallized semiosis[1] (i.e., interpretation) regarding the designed solution and (b) it conveys this crystallized semiosis[2] to the user [de Souza, 2005]. To better characterize: (a) the kind of technological solution that works as an interlocutor in the HInt communication process and (b) the cases in which the multicomponent partner technology (exclusive or not) is designed by more than one design team, Barbosa and Prates [2022] have extended this category to comprise the following elements: ***Designer or Multiple Designers***; ***User*** and ***HInt Technology***. Thus, it is possible to define and describe the interlocutors involved in the communication mediated by the partner technology designed by either one team or multiple teams of designers [Barbosa and Prates, 2022, 2023, 2024a].

The **Design Space** category defines the elements that the designer must consider during the communication-centered

[1]Semiosis is the (potentially) unlimited process of production and interpretations of signs, which is triggered by the presence of signs representing any quantity or quality of elements [de Souza, 2005].

[2]Crystallized semiosis refers to the process by which designers intentionally encode their communicative intentions and decisions into technological artifacts. Thus, the interface becomes a "crystallized" representation of the designer's message, shaping how users interpret and interact with the technological solution [de Souza, 2005]

design of a technological solution. The elements are: **Sender**; **Receiver**; **Message**; **Code**; **Channel**; and **Context**. These elements define that, in a communicative process, a sender sends a message (i.e., metamessage) to a receiver to achieve certain effects. This message must be: (a) encoded using a code (i.e., interface signs) that the sender and receiver share, (b) transmitted and received through a channel (i.e., physical device on which the interface is accessed), and (c) related to a context. To better structure the HInt design space, this category has been extended to comprise the following elements: ***Sender or Multiple Senders***; ***Receiver***; ***Integrated Message (Integrated Metamessage)***; ***Code***; ***Channel or Multiple Channels*** and ***Context*** [Barbosa and Prates, 2022, 2023, 2024a].

In addition, the Integrated Metamessage template has been extended to better explain the design intentions and decisions regarding the intended HInt. Thus, by using the *integrated metamessage*, Barbosa and Prates [2022] have proposed that the designer answers the following questions to the user *[in **bold** the questions **included in the template extension**] [Barbosa and Prates, 2022, 2023, 2024a]*: *"(1) Who are you? (2) What have I understood that you want or need to do?* ***(3) What have I understood that you want that a partner technology does for you?*** *(4) This is the* ***HInt*** *Solution that I have created for you:* ***(4a) What is the partner technology and its components? (4b) What will the partner technology do autonomously for you? (4c) What is the nature of partnership that you both establish regarding: Agency (i.e., Autonomy Level)? Scale (i.e., HInt Level)? HInt Type? and How are you both physically coupled? (4d) To achieve the integration purposes, how many and with which components do you need to interact directly?; and finally, (4e) How can or should you and the partner technology interact and integrate for the partnership between you both to take place?***.

By extending the *Design Space* category, HInt can be explained as a process in which an integrated message (i.e., integrated metamessage) is sent from one or multiple senders to a receiver and it can be fragmented into multiple interfaces of the components of this solution. This integrated metamessage: (a) refers to the solution presented by the designer to its users via the proposed HInt technology, (b) refers to a partnership context, (c) must be encoded by a code shared between sender and receiver and (d) must be conveyed via one or multiple channels. Thus, it is possible to characterize the HInt design and communication processes, taking into account the particularities of this new paradigm [Barbosa and Prates, 2022, 2023, 2024a].

In turn, the **Communication Processes** category characterizes the types (i.e., levels) of communication that occur during traditional HCI. Originally, the elements of this category are: **Designer-User Metacommunication**; **User-System Communication**; and **Designer's Deputy** [de Souza, 2005]. This category describes that the designer-user (indirect and unidirectional) metacommunication occurs via the user-system (direct) communication. For this reason, the interface is the designer's deputy in the HCI communicative process (i.e., the interface tells the users what the designers mean). To better describe the communication processes that take place in HInt, this category has been extended to comprise the following elements: ***Designers-User Integrated Metacommunication***; ***User-System Communication*** and ***Designer's Deputy or Collective Deputy***.

The Designers-User Integrated Metacommunication (or Integrated Metacommunication) concept applies to any HInt technology (independently of the nature of partnership, intelligence, and composition); and it extends the original Semiotic Engineering definition of metacommunication to characterize better the special kind of communication that occurs in HInt. Integrated Metacommunication is a unidirectional and indirect communication from one or multiple designers to their users. Through the components' interfaces of the partner technology, the designers convey to the users - in an integrated and cohesive way - their understanding and decisions regarding: (a) the users' profile; (b) why and how this technology can work as a partner to the users; and (c) how the users and the designed technology can or should relate to work as partners to achieve the integration goals. The message conveyed in this particular kind of communication is known as *integrated metamessage*, and its content can be paraphrased according to the *integrated metamessage template* proposed by Barbosa and Prates [2022]. In turn, the Collective Deputy element is an extension of the *Designer's Deputy* element to represent cases in which the multiple interactive interfaces (i.e. multiple interactive components) of the HInt technology work together as a deputy to convey the *integrated metacommunication* of the HInt solution to the user. Thus, by extending this category, it is possible to describe the communicative processes that take place during HInt, independently of the composition of the partner technology and the number of teams involved in transmitting the integrated metamessage [Barbosa and Prates, 2022, 2023, 2024a].

The **Signification Processes** category defines that the **intention** (i.e., what you want to communicate), the **content** (i.e., what you are communicating), the **expression** (i.e., how you choose to communicate), the **signs** (i.e., expressive element that has meaning for someone [Peirce and Peirce, 1992]) and the **semiosis** (i.e. the process of interpreting the signs) are the elements that influence the perception and interpretation of what is being communicated during the interaction [de Souza, 2005]. Signification Processes were the only category in the original Semiotic Engineering ontology that did not need to be extended. That is because, these five elements also influence the signification processes that take place in HInt [Barbosa and Prates, 2022, 2023, 2024a].

Finally, the definition of **Integrated Communicability** has been proposed to qualify the integrated metacommunication that occurs during HInt. *Integrated Communicability* is the quality attribute of the partner technology that, through its single or multiple interfaces, communicates to the user - in a clear, organized, coherent, consistent and cohesive way - the intentions and decisions that guided its design, so that the user and the designed HInt solution can establish a beneficial partnership and achieve their integration purposes [Barbosa and Prates, 2022, 2024a]. Note that, based on this proposal, *Integrated Communicability* must be used to characterize the quality of the integrated metacommunication of a partner technology independently of the nature of partnership, intelligence, and composition (i.e. it applies to qualify any HInt solution). However, it is worth noting that when the partner technology is composed of multiple interfaces, the integrated metamessage is usually fragmented between them. Thus, the user needs to understand what each interface is communicating and how each part of the message relates to the others so that, together, they make sense as a whole. Therefore, the quality associated with the integrated metamessage whose parts are fragmented into different interactive components is also defined as *Integrated Communicability* [Barbosa and Prates, 2024a]. **Figure 2** summarizes how the new concepts and elements proposed relate to and extend the scope of Semiotic Engineering to conceptualize HInt.

From **Figure 2**, we can observe that Semiotic Engineering concepts and ontology have been extended to conceptualize and characterize HInt as a communication process between partners (i.e., an extension of traditional HCI), in which *designers*, *users*, and the *HInt technology* are the interlocutors. At design time and during the integration, *designers (one or multiple design teams)* act as the *message senders (one or multiple)*. In turn, users act as *receivers* of the message during the integration. The message is conveyed via *one or multiple channels*, and this quantity is defined by the number of physical components that compose the partner technology. The communication process occurs on two levels: (1) *User-HInt technology (direct) communication* and (2) *Designers-User (indirect) integrated metacommunication*. Although the HInt technology has autonomy and, in some cases, intelligence, the *integrated metacommunication* is the crystallization of the designers' *semiosis* regarding their understanding of the user's integration needs. The content (i.e., *integrated metamessage*) is encoded by *signs* that can be understood within *one or multiple signification systems*. Therefore, the integrated metacommunication must cohesively reveal the senders' (i.e., designers') *intentions* and decisions through its *content* and *expressions*. As the designers-user integrated metacommunication is mediated by the interface, the designed HInt technology is the *designer's deputy or collective deputy* in the HInt communicative process. In other words, the partner technology *"speaks"* (i.e., communicates the integrated message) for the designers. Thus, the designed HInt technology will satisfy the *integrated communicability* criterion if, during the integration, the users can generate interpretations and meanings (i.e., semiosis) compatible with the designers' intentions communicated in the partner technology interface [Barbosa and Prates, 2022, 2023, 2024a].

It is important to highlight that, as previously explained and shown in **Figure 2**, the definition of the elements: (a) *User* and *HInt Technology* of the HInt Interlocutors category; (b) *Receiver*, *Integrated Message*, *Code* and *Context* of the HInt Design Space category; (c) *Designers-User Integrated Metacommunication* and *User-System Communication* of the HInt Communication Processes category; (d) all elements of the HInt Signification Processes category; (e) as well as the concept of *Integrated Communicability* apply to any technological solution that follows the HInt paradigm. The *Type of Designer* of the HInt Interlocutors category and the *Type of Sender* of the HInt Design Space category are determined by the number of distinct teams responsible for the design of the partner technology. The definition of the *Type of Channel* of the HInt Design Space category is determined by the number of different physical devices that together work as transmission channels of the integrated metamessage. In turn, the *Type of Deputy* of the HInt Communication Processes category is determined by the number of different interfaces with which the user must deal during the partnership with the technology [Barbosa and Prates, 2022, 2023, 2024a].

According to Barbosa and Prates [2022, 2024a], the Semiotic Engineering theoretical framework extended to HInt provides a theoretical lens to support the study, design, and evaluation of HInt. However, it is necessary to conduct different application case studies to provide evidence regarding the benefits and limitations of the proposed extension [Barbosa and Prates, 2022, 2023, 2024a].

4 Related Work

The studies conducted by Barbosa and Prates [2022, 2024b] are the only initiatives identified in the literature that have extended and discussed the benefits of an HCI theory to address the HInt paradigm. However, to better understand how our paper contributes to the evolution and consolidation of this new paradigm and Semiotic Engineering Theory, this section presents: (1) some existing studies that have explored the challenges of HInt from different HCI perspectives and (2) other papers that have extended Semiotic Engineering to different contexts and discussed the applicability of the proposed extensions.

4.1 Exploring HInt Challenges

In general, the studies that are addressing the open challenges of HInt in the HCI context focus on: (a) exploring the challenges of design and evaluation of HInt by fusion [Andres *et al*., 2018, 2019, 2020, 2023; Danry *et al*., 2022; Gil *et al*., 2019, 2020; Mueller *et al*., 2021, 2022] and (b) investigating the effects of HInt on humans [Danry *et al*., 2022; Mueller *et al*., 2022]. For instance, the studies conducted by Gil *et al*. [2019, 2020] have explored the challenges of design and evaluation of HInt in the context of cyber-physical systems (CPSs), in which the control of interaction is equally shared between human and technological agents. Through a literature review and a case study involving the design and analysis of a semi-autonomous vehicle prototype, the authors have: (1) presented design considerations; and (2) discussed the challenges of specifying, designing, and evaluating cyber-physical systems that integrate physically or conceptually with the user, sharing responsibility for the interaction. As contributions, the studies present: (1) a conceptual framework to define and characterize the ways in which humans and cyber-physical systems can integrate and cooperate; and (2) a set of principles and a design process to guide HCI professionals and researchers in specifying, designing and evaluating this type of partner technology.

The initiatives conducted by Andres *et al*. [2018, 2019, 2020] have investigated the challenges of designing electric bikes (eBikes) that assist the user in the effort to control this type of partner technology. Based on the prototyping of three different Smart eBikes - *Ava* [Andres *et al*., 2018], *Ari* [Andres *et al*., 2019], and *Ena* [Andres *et al*., 2020] -, the authors discussed the implications (i.e., effects, benefits, and limita-

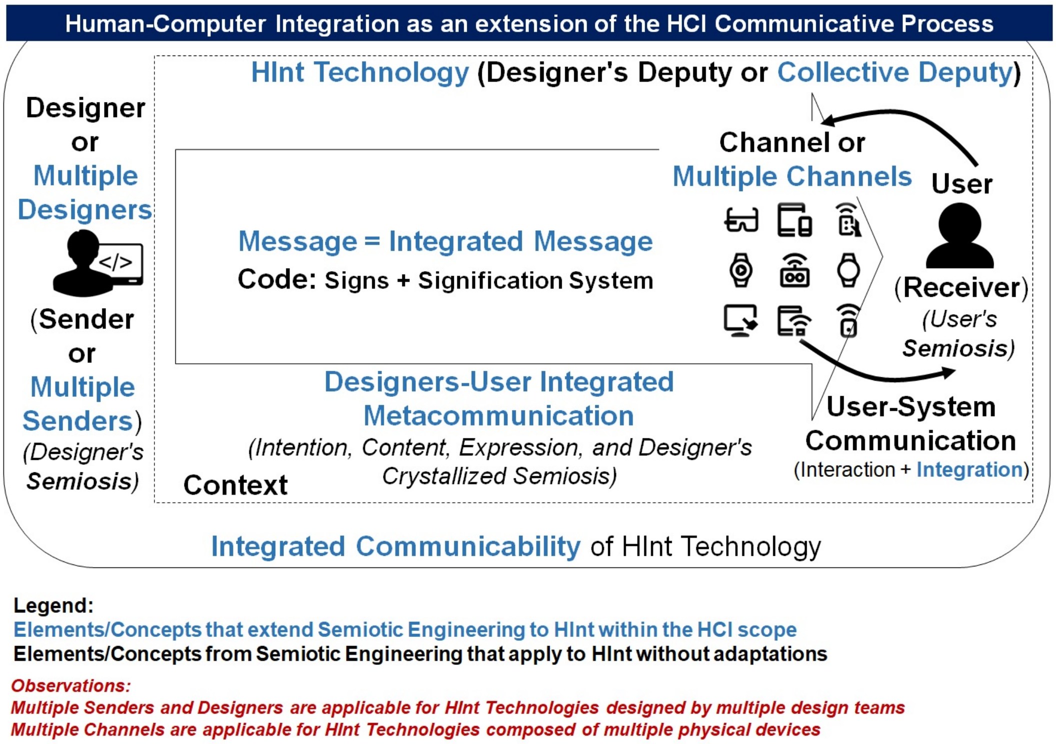

Figure 2. Extension of Semiotic Engineering theoretical framework to define and characterize HInt (*Source: Translated from Barbosa and Prates [2022]).*

tions) of designing solutions integrated with the human body (in-body and on-body) to share the responsibility of driving eBikes. As contributions, these works present insights and reflections to assist in the future design of technological solutions that work as partners of the user in the exertion context. Additionally, Andres *et al*. [2023] implemented the Smart eBikes prototyped in Andres *et al*. [2018, 2019, 2020] to: (1) explore different forms of in-body and on-body integration, and (2) analyze user experiences during the partnership with this type of HInt solution. Based on these new case studies, the paper presents the first conceptual framework to guide HCI professionals and researchers in understanding, designing, and evaluating HInt by fusion applied to the integrated exertion context.

In turn, the study conducted by Mueller *et al*. [2021] has explored the challenges of design and evaluation of HInt in the specific context of technologies that promote HInt by fusion. By analyzing examples of existing partner technologies that integrate with the user through body fusion, the authors identified and proposed two dimensions - *bodily agency* and *bodily ownership* - to better specify the ways in which the user and the HInt technology can control and negotiate in-body and on-body integration. Based on these new dimensions and previous knowledge regarding body integration, the authors: (1) defined and structured a design space that specifies which aspects HCI professionals and researchers should consider during the design and analysis of HInt by fusion; and (2) presented a set of strategies for the future design of partner technologies that physically integrate with the human body. Additionally, in a new study, Mueller *et al*. [2022] identified and organized a set of challenges specifically related to: (1) the next steps in the design and evaluation of HInt by fusion; and (2) the impacts of in-body and on-body integration on the individual and society. Thus, this paper guides future initiatives for the evolution of HInt physically coupled to the human body [Mueller *et al*., 2022].

Finally, Danry *et al*. [2022] have explored the challenges of: (1) the impacts of HInt on humans; and (2) the design of HInt in the light of phenomenology and cognitive science. The authors analyzed and discussed: (1) the potential effects of HInt on the sense of self of the individual integrated (physically or conceptually) with the partner technology; and (2) how the user's perception of their role in the integration can influence their experience during the partnership with the technology. In addition, the authors provide insights, reflections, and a framework to guide designers on: (1) how to explore the individual's sense of self in HInt; and (2) how to design partner technologies that enhance the user's sense of self during the human-computer integration.

The studies presented in this subsection have generated important contributions to HInt, especially in the context of integration by fusion. However, these initiatives have not explored the demands related to reviewing, proposing, and evaluating HCI theories to address HInt [Barbosa *et al*., 2021a, 2023; Barbosa and Prates, 2022; Farooq and Grudin, 2016; Mueller *et al*., 2020; Zaina *et al*., 2024]. Therefore, compared to previous initiatives, our work is different and relevant because we explore and discuss the applicability of extending an HCI theory to address HInt by fusion and/or symbiosis. Next, we present other studies that have also extended the Semiotic Engineering scope and discussed its benefits as a theoretical lens to address particular HCI cases.

4.2 Investigating Semiotic Engineering in Different Contexts

Except for the studies carried out by Barbosa and Prates [2022, 2024b], we have not identified any other initiatives that explore the applicability and usefulness of Semiotic Engineering extended to the HInt paradigm. However, some initiatives have extended the concepts and methods of Semiotic Engineering to: (1) different contexts/domains of use or (2) different types of technologies, and they have also investigated and discussed the applicability of these extensions [Barbosa *et al*., 2021b, 2024; Chagas *et al*., 2018, 2019; Chagas, 2020; de Souza, 2005; de Souza *et al*., 2010; Maués and Barbosa, 2013, 2014; Oliveira *et al*., 2008]. For instance, we have found initiatives that have extended the Metacommunication content and demonstrated the applicability of these extensions to include the particularities of the following systems: (1) Collaborative [de Souza, 2005; Prates and de Souza, 1998]; (2) Customizable [de Souza, 2005] and (3) Educational [Oliveira *et al*., 2008].

In turn, the study conducted by Maués and Barbosa [2014] presents the concept of *Cross-communicability*, a property that qualifies the metacommunication of a cross-platform system (i.e., the same system that can be accessed via different devices), considering: (a) all its versions and (b) the user's traversal between the different platforms. In addition, the authors: (1) proposed the *Cross-Platform Semiotic Inspection Method (CP-SIM)*, an extension of the Semiotic Inspection Method (SIM) to evaluate the Cross-Communicability [Maués and Barbosa, 2013] and (2) presented reflections on the usefulness of the proposed method [Maués and Barbosa, 2014].

Chagas *et al*. [2018] expand the scope of Semiotic Engineering to take into account the specificities of Internet of Things (IoT) technologies. The authors presented: (1) a semiotic description to characterize the process of incorporating IoT technologies into the environment and human practices and (2) the proposal of two quality attributes for IoT technologies: (a) *consistency between interfaces* and (b) *coherence between devices* [Chagas *et al*., 2018].

Finally, Barbosa *et al*. [2021b, 2024] extended the set of epistemic tools of Semiotic Engineering to support the design of morally responsible and ethically qualified digital technologies. The authors extended the template of metacommunication to explicitly address the ethical aspects involved in the proposed solution [Barbosa *et al*., 2021b]. Furthermore, Barbosa *et al*. [2024] investigated and discussed the usefulness of the proposed extension to assist in reflections on the ethical aspects that should be considered when developing machine learning solutions [Barbosa *et al*., 2024].

The studies presented in this section: (a) have extended the definitions and family of methods/tools of Semiotic Engineering to different particular cases of HCI, and (b) have provided evidence about the applicability and usefulness of these extensions. However, these studies have not explored the extension of Semiotic Engineering concepts and ontology to HInt proposed by Barbosa and Prates [2022] [Barbosa and Prates, 2022]. This kind of initiative is necessary to understand better and define the benefits and limits of Semiotic Engineering extended to HInt. Therefore, our study differs from and extends the contributions of previous work because we investigate and discuss whether the extension of the Semiotic Engineering ontology to HInt is applicable and useful as a theoretical basis for defining, exploring, and explaining the partnership between humans and technologies.

5 Methodology

To achieve our goal, we have investigated the following research question (RQ): *Can the extension of the Semiotic Engineering theoretical framework to HInt provide an applicable and useful theoretical lens for studying, designing, and evaluating HInt?* The methodology adopted to explore this question consisted of a qualitative approach [Leitão and Prates, 2017] divided into two phases: (I) Proof of concept from the perspective of the researchers who authored this paper and (II) Evaluation from the perspective of different interest groups. Next, we describe these phases and their respective steps.

5.1 Phase I: Proof of Concept

The goal of *Phase I* is to demonstrate - via proof of concept - the completeness and applicability of the Semiotic Engineering extension to conceptualize, structure, and characterize HInt as a special case of HCI. This phase was divided into two stages. Initially, we selected 10 examples of different partner technologies for the proof of concept. These examples correspond to HInt technologies mentioned and described in publications identified from a systematic review of the literature published in Barbosa *et al*. [2023].

Next, based on the descriptions of these ten examples, we characterized and described the analyzed partner technologies in the light of Semiotic Engineering extended to HInt. Through this proof of concept, we demonstrated that the extension of this theory to HInt includes all the particularities of this new paradigm and it can be used as a theoretical basis for defining, exploring, characterizing and understanding existing HInt. We conducted the evaluation via proof of concept in March 2023. The main results of the first phase of this research are presented in the *Section 6*. Next, we present the steps of the second phase of this research.

5.2 Phase II: Evaluation from the Third-Party Perspective

The goal of *Phase II* is to evaluate the extension of Semiotic Engineering to HInt from the perspective of different interest groups to better delineate the benefits and limits of this extended theory to HInt. We conducted this second phase through case studies in which the extension of the Semiotic Engineering theoretical framework to HInt was used to support the study, design, and evaluation of partner technologies. To perform the case studies, we offered a course for undergraduate students and a workshop for HCI researchers and professionals to: (1) disseminate knowledge about HInt; (2) provide a theoretical basis, grounded in Semiotic Engineering, so that participants can explore this new HCI paradigm; and (3) collect data for the proposed evaluation. Next, we

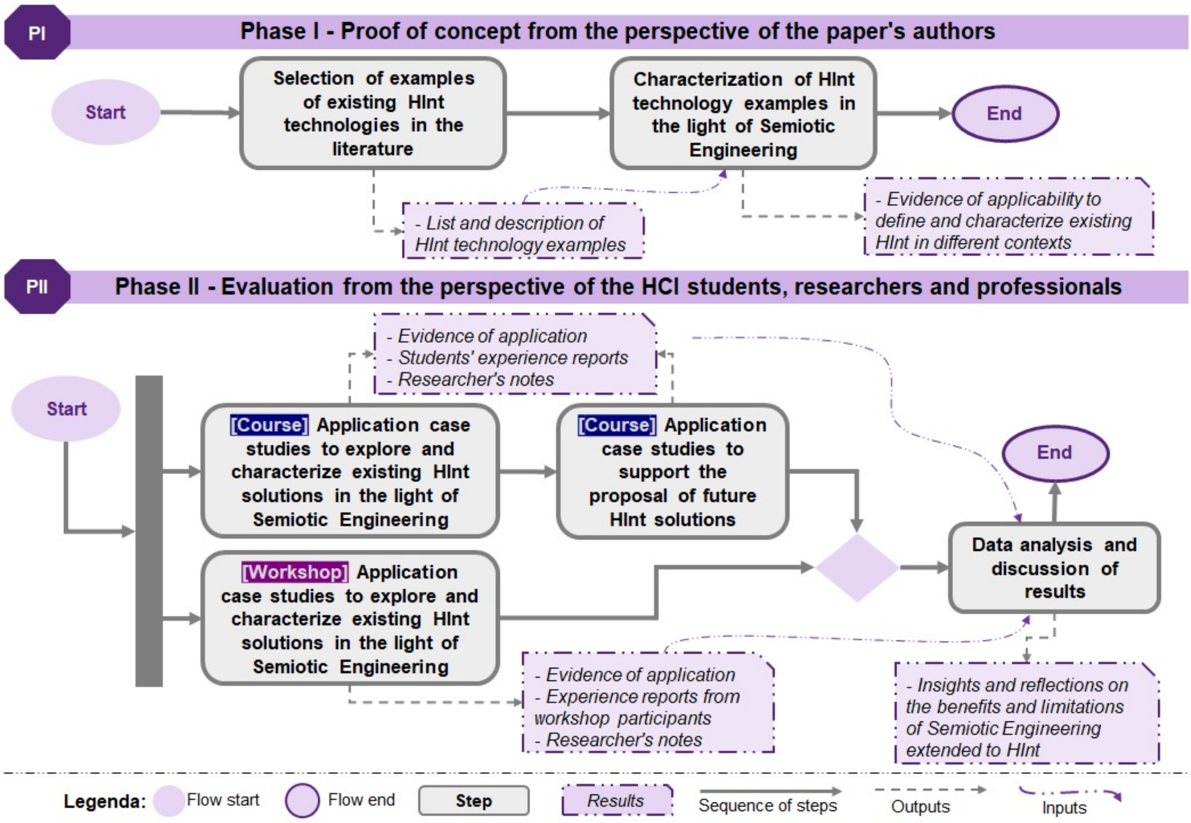

Figure 3. Overview of the evaluation methodology.

describe how the course and workshop were organized and conducted.

5.2.1 Data Collection via Course

To evaluate the extension of Semiotic Engineering to HInt from the perspective of higher education students, we offered an optional course (60 hours) to 25 undergraduate students from the Department of Computer Science (DCC) at the Federal University of Minas Gerais (UFMG) [3]. The course about HInt in the light of Semiotic Engineering was taught by the authors of this paper and offered in 2023-2.

Based on lectures and exercises relating to: the HInt paradigm; the Semiotic Engineering theoretical framework extended to HInt; and the future of HInt in the HCI context, the students worked in groups (3-4 people) to develop activities that involved applying the extension of Semiotic Engineering to HInt[4]. The proposed activities involved both analyzing and describing existing HInt technologies as well as proposing new and innovative HInt solutions. Additionally, we conducted discussion sessions [Leitão and Prates, 2017] with the students to address their experiences and perceptions after completing each case study. Each discussion session was guided by scripts prepared during the planning phase of this research, and it took place during a predetermined time (60 to 90 minutes) in the class period.

It is important to highlight that during the course, we faced the challenge of a shortage of HInt technologies available for students to interact with. We had identified this potential issue during the course preparation and, for this reason, we adopted two strategies for selecting examples of partner technologies for the application studies. Ideally, the students would select examples that they have access to for interaction. Otherwise, they could choose HInt solutions whose descriptive material (i.e., manual and demonstration videos) was available for them to access and use. Thus, even though the students did not have access to the partner technology for direct interaction, they could explore it from its description material and characterize it using the concepts and ontology of Semiotic Engineering extended to HInt. In one case, a group selected a fiction film technology to characterize and describe this existing solution in the light of Semiotic Engineering for HInt. We considered this example valid for the case study because: (1) the selected solution possessed the attributes and characteristics of a partner technology, and (2) this technology was described and its use was illustrated in the film.

Considering the above, we collected the following data for analysis: the field diary [Leitão and Prates, 2017] of the paper's authors and materials generated by the students. The field diary contained notes based on our observations of students' questions and comments expressed during lectures, activities, and class discussion sessions. In turn, the materials generated by the students considered for this analysis

[3] Optional courses have no prerequisites, but the students' enrollment number indicated that they had started their undergraduate course at the latest in 2020

[4] The didactic material used in the course, including the instructions for the activities, as well as the scripts for the discussion sessions are available for consulting and use in the subfolder *HInt-EngSem_Disciplina* available at the link: `https://bit.ly/3W1pr6u`.

included: 01 individual exercise on applying the original Semiotic Engineering; 01 individual exercise on applying Semiotic Engineering extended to HInt; 01 case study report on the application of Semiotic Engineering to explore existing HInt; 01 case study report on the application of Semiotic Engineering to support the design of future HInt; as well as 02 individual experience reports on the application of the proposed extension. It is worth noting that the class consisted of 25 students, who formed 7 groups to conduct the case studies.

As described later in *Subsection 5.2.4*, the data collection and analysis of the course complied with the ethical norms of research and they were conducted with the consent of both the DCC/UFMG and the students. The methodology for data collection via workshop is presented below.

5.2.2 Data Collection via Workshop

To evaluate the extension of Semiotic Engineering concepts and ontology to HInt from the perspective of HCI researchers and professionals, we offered a workshop (06 hours) to 14 participants of the *HCI 2023 event* on October 16, 2023. Similar to the undergraduate course, the workshop entitled: *"Evolving is Necessary: Moving from Interaction to Human-Computer Integration"* addressed the present and future of HInt in the light of Semiotic Engineering, divided into three modules[5]: (1) Introduction to the HInt paradigm and partner technologies; (2) Semiotic Engineering Theory extended to HInt; and (3) The next steps for HInt within the HCI scope.

For each teaching module (each lasting approximately 2 hours), we presented and explained the content. Subsequently, the workshop participants formed groups (4-5 people) to practice the module's content. Specifically, in the module about the Semiotic Engineering theoretical framework extended to HInt, we introduced the extension proposal, and the participants applied the acquired knowledge to characterize different examples of existing partner technologies using the Semiotic Engineering ontology for HInt. Since direct interaction with these technologies was not possible, participants performed the characterization based on printed descriptions, which included images and textual information. At the end of this practical activity, we gathered with the workshop participants to discuss the usefulness of the Semiotic Engineering extended to HInt, as well as the future of HInt in the HCI context. The discussions were: (1) guided by scripts prepared during the planning phase of this research and (2) conducted within a predetermined interval (30-60 minutes) during a module.

Similar to the course, the workshop also took place in the second semester of 2023. However, the duration and content covered in the workshop were more limited. For this reason, the workshop focused on using Semiotic Engineering extended to HInt as a theoretical lens to support the study and characterization of existing HInt solutions. Even so, the workshop provided valuable insights for the evaluation proposed in this paper, because it allowed us to assess the Semiotic Engineering for HInt from the perspective of HCI researchers and professionals (i.e. a different target audience compared to the course).

[5]The material used in the workshop is available for viewing and use in the subfolder *HInt-EngSem_Minicurso* available at the link: `https://bit.ly/3W1pr6u`.

From the workshop, we collected the following data for subsequent analysis: (1) Field diary with notes based on our observations of the participants' questions and comments expressed during the practical activities and discussion sessions and (2) Experience reports from the groups regarding the application studies conducted. As detailed later in *Subsection 5.2.4*, the evaluation of the Semiotic Engineering theoretical framework for HInt via the workshop took place with the authorization of the general coordination of the *HCI 2023 Event* and the workshop participants. The methodology adopted for analyzing the data collected via the course and workshop is presented below.

5.2.3 Analysis of Collected Data

Given the goals of this evaluation, we analyzed the data collected during the course in four dimensions: learning; applicability; usefulness; and suggestions. After the end of the course and following the Thematic Analysis methodology proposed by Braun and Clark [Braun and Clarke, 2006], we conducted an in-depth analysis of the data collected (including both inter-subject and intra-subject reading - e.g., reading the same question/activity across all students, and reading the complete activity for each student) [Leitão and Prates, 2017; Nicolaci-da Costa *et al*., 2004]), and we generated open coding for all collected materials. The codes were generated by the first author and then discussed and consolidated with the second author of this paper. After consolidating the codes, we identified themes associated with these four dimensions. It is important to highlight that we predefined the dimensions based on the aspects we intended to evaluate within the theoretical framework. However, we carefully examined whether additional dimensions were needed to categorize the generated codes and themes. Once again, this association of the codes and themes with the dimensions was conducted by the first author, and then discussed and consolidated with the second author [6]. By structuring our analysis around these four dimensions, we were able to investigate and discuss whether the students were able to learn, apply, and identify the advantages and limitations of the Semiotic Engineering theoretical framework extended to HInt.

We conducted the *Learning and Applicability Analysis* taking into account: the correction of individual exercises and group activity reports, as well as the analysis of our field diary and the students' individual reports. This analysis allowed us to identify and classify the students' difficulties while learning and using the Semiotic Engineering concepts and ontology extended to HInt, as well as to verify whether the students were (in fact) able to apply the proposed extension in practice. The thematic analysis of these materials resulted in the classification of the types of difficulties/questions that arose during the learning and application of the Semiotic Engineering for HInt, as well as evidence of the applicability of the proposed extension to support the study, design, and evaluation of HInt in the HCI context. In turn, we conducted the *Usefulness and Suggestion Analyses* through thematic

[6]The researchers responsible for this analysis have been working in HCI teaching and research for over 10 years. Additionally, they have experience in conducting qualitative research involving the collection and analysis of data generated by third parties

analysis of our field diary notes and the students' individual experience reports on the advantages, limitations, and next steps of the Semiotic Engineering extended to HInt. The analysis of these materials resulted in themes that expressed the students' perspective on the usefulness, limitations, and future of HInt in the light of Semiotic Engineering.

In relation to the workshop, we conducted a Thematic Analysis of our notes and the participants' reports to identify and classify their perceptions of the advantages and costs of learning and using the Semiotic Engineering for HInt as a theoretical basis for approaching this new HCI paradigm. As a result, the analysis of the workshop data allowed us to: (1) Improve the course content related to the extension of Semiotic Engineering to HInt, which had not yet been taught; and (2) Generate indicators related to the applicability and usefulness of Semiotic Engineering extended to HInt from the perspective of HCI researchers and professionals.

Taken together, the results of *Phase II - Evaluation from a third-party perspective* provide new evidence of the benefits and limitations of extending Semiotic Engineering to conceptualize, explore, and explain HInt as an HCI paradigm. The main results of the second phase of this research are presented in the *Section 7*. Next, we present the ethical considerations of this research phase.

5.2.4 Ethical Considerations

As the second phase of this research involved collecting and analyzing data generated by third parties, we submitted the evaluation proposal for review and approval by the Research Ethics Committee of the university where we conducted the research. Thus, we sent the project proposal describing the proposed research and data collection from the course and workshop to the institution's Ethics Committee. It is important to highlight that we took special care to ensure voluntary participation of the research participants (i.e., ensuring that they felt free to decline participation in the research if they did not wish to participate). As part of the submitted project, we sent to the Ethics Committee: (a) the consent letter from the Department of Computing of the educational institution; (b) the consent letter from the Organizing Committee of the HCI 2023 Event; (c) the Informed Consent Form; as well as (d) the message to be sent to the research participants after the end of the course and workshop to indicate the beginning of the analysis and remind them of the option to withdraw consent (if consent had been given). The project was approved by the Ethics Committee (*Ethical Appreciation Certificate: 70874823.9.0000.5149*) before the research began.

Specifically regarding the course, on the first class day, we informed the students about our intention to collect the materials generated during the course for later analysis. This way, we aimed to ensure that the students had the right to decide - consciously and voluntarily - about their participation in this research. At the time, we also informed them that: (a) data collection and analysis would take place after the end of the course, (b) participation was voluntary, and the students' decision would not influence the conduct of the course or their grades. Furthermore, we informed the students that they could withdraw their consent even after the course had ended.

Approximately one month after the beginning of the course, we presented the Informed Consent Form to the students, which explained and ensured their rights upon agreeing to participate in this research. After reading the document and clarifying any questions, each student made their voluntary decision and handed us a signed copy of the Informed Consent Form. Upon completing the course and finalizing the grades in the institution's academic system, we emailed the students to inform them about: (a) which materials would be analyzed and (b) the option of withdrawing their consent before the analysis began. All the actions described above aimed to: (a) prioritize the well-being of the students in the course, regardless of their decision to participate in this study, and (b) ensure the voluntary collaboration of those who agreed to participate.

Similarly, we informed the workshop participants about our intention to collect and analyze the materials generated by them. Thus, during the first hour of the workshop, we presented the Informed Consent Form, which explained and ensured their rights when agreeing to participate in this research. Each participant received two copies of the consent form, read one of them, clarified their questions, and made their voluntary decision. After expressing their decision, each participant handed us one signed copy and kept the other. At the end of the workshop, we reiterated the right of the workshop participants to withdraw their consent before the analysis began.

All 25 undergraduate students and all 16 workshop participants signed the Informed Consent Form, agreeing to the collection and analysis of the data of this evaluation. Furthermore, no participant withdrew their consent after the course or workshop had ended.

As previously mentioned, this section provided a detailed description of the methodology phases and steps adopted for conducting this research. The following sections (i.e., *Section 6 and Section 7*) present, respectively, the main results and contributions of the evaluation proposed in this paper.

6 Proof of Concept Results

As detailed in the *Subsection 5.1*, we conducted a proof of concept to demonstrate the applicability of extending the Semiotic Engineering theoretical framework to structure and describe the partnership between humans and technologies as an extension of traditional HCI. In this proof of concept, we characterized ten distinct and existing partner technologies according to the Semiotic Engineering ontology extended to HInt. These are:

- *App for monitoring health*, a monocomponent HInt technology focused on helping users acquire and maintain healthy habits [Alharbi and Huang, 2020; Ho, 2018; Stephanidis *et al*., 2019];
- *Exoskeleton*, a monocomponent HInt technology that extends, improves, or restores the user's physical capabilities by providing support, assistance, or strength to bodily movements [Britton and Semaan, 2017; Dengel *et al*., 2021];
- *FingerReader 2.0*, a multicomponent HInt technology that assists a visually impaired user in identifying objects

(e.g. shopping items and banknotes) in a physical store [Boldu *et al*., 2018; Mueller *et al*., 2019];

- *Semi-autonomous Car*, a monocomponent HInt technology focused on assisting the user in driving a vehicle [Farooq and Grudin, 2016; Gil *et al*., 2019, 2020; Mueller *et al*., 2020];
- *Smart Alarm Clock*, a HInt technology that helps users organize and keep their daily commitments on time [Farooq and Grudin, 2016; Mueller *et al*., 2020];
- *Smart Assistant for Smart-TV*, a multicomponent HInt technology focused on recommending content and personalizing the user experience while using a Smart-TV [Ho, 2018; Niess and Woźniak, 2020; Stephanidis *et al*., 2019];
- *Smart Band*, a multicomponent HInt technology that works as the user's partner in maintaining health and well-being [Alharbi and Huang, 2020; Stephanidis *et al*., 2019];
- *Smart eBike*, a multicomponent HInt technology that helps the user control the speed of an electric bicycle [Andres *et al*., 2019, 2018, 2020];
- *Smart Watch*, a multicomponent HInt technology that works as the user's partner to help them with personal organization, health and well-being [Alharbi and Huang, 2020; Stephanidis *et al*., 2019];
- *Youtube*, a monocomponent HInt technology that has the autonomy to recommend content in video format and personalize the user experience during the interaction.

We chose these technologies because, in addition to working as users' partners in different contexts, they differ in other aspects (e.g., composition and teams involved in design) to promote integration. Thus, through these examples, we can demonstrate whether the extension of Semiotic Engineering concepts and ontology to HInt includes all particularities of this new paradigm.

It is important to highlight that, among the ten HInt solutions explored in this phase: (a) six (*Exoskeleton*; *FingerReader 2.0*; *Semi-autonomous Car*; *Smart Alarm Clock*; *Smart Assistant for Smart-TV*; and *Smart eBike*) were characterized based on their respective descriptions available in the literature (i.e., available in the publications that presented them [Andres *et al*., 2019, 2018, 2020; Boldu *et al*., 2018; Britton and Semaan, 2017; Dengel *et al*., 2021; Farooq and Grudin, 2016; Gil *et al*., 2019, 2020; Ho, 2018; Mueller *et al*., 2019, 2020; Niess and Woźniak, 2020; Stephanidis *et al*., 2019]) and (b) four partner technologies (*App for monitoring health*[7]; *Smart Band*[8]; *Smart Watch*[9]; and *Youtube*[10]) were characterized based on our informal inspection (via our direct interaction). **Figure 4** summarizes the characterization of these ten partner technologies, structured based on the concepts and ontology of Semiotic Engineering for HInt. For each analyzed solution, **Figure 4** presents the *interlocutors*, the *design space*, the *types of communication* and the *aspects that influence quality* of the proposed HInt. It is worth noting that in this Figure a *Type of <Element>* column has been defined to represent the elements of the ontology (i.e., designer, sender, channel, and deputy) that can be characterized as either single or multiple.

From **Figure 4** we can observe that the 10 analyzed partner technologies: (1) promote HInt in different application domains; and (2) present differences in relation to the *type of designer*, *type of sender*, *type of channel* and *type of deputy* involved in the proposed integration. However, the concepts and elements of the Semiotic Engineering ontology for HInt include these differences and apply to defining and structuring the communicative process mediated by these technologies, regardless of the design decisions of the proposed HInt solution.

In addition to structuring the elements involved in the partnership mediated by the explored HInt technologies, we also generated the intended integrated metacommunication of each analyzed HInt solution. Below, we present 1 (out of 10) example - *FingerReader 2.0* - to demonstrate the applicability of the integrated metamessage template in reconstructing, describing, and understanding the design proposal of HInt solutions that integrate with the user in different use contexts. Additionally, *Appendix A* presents another example of an integrated metamessage generated from this proof of concept, describing the existing solution — the *Smart Assistant for Smart TVs*.

According to Boldu *et al*. [2018]; Mueller *et al*. [2019], **FingerReader 2.0** is a HInt solution designed to enhance accessibility by assisting a blind individual with the task of shopping. In general terms, the intended integrated metacommunication of *FingerReader 2.0* can be described as follows:

(1) Who are you? Visually impaired user;

(2) What have I understood that you want or need to do? I have understood that you need more autonomy to make your purchases, without being dependent on third parties;

(3) What have I understood that you want that a partner technology does for you? I have understood that you need a solution with autonomy to assist you in identifying products available for purchase in physical stores;

(4) This is the HInt Solution that I have created for you:

- *(4a) What is the partner technology and its components? FingerReader2.0, an autonomous and intelligent technology composed of multiple components: (i) a ring with an embedded camera, physically connected to a bracelet and (ii) a headset*;
- *(4b) What will the partner technology do autonomously for you? FingerReader2.0 will assist you in identifying objects, texts and colors so that you can be more independent during your shopping*;
- *(4c) What is the nature of partnership that you both establish regarding: Agency (i.e., Autonomy Level)? Controlled mainly by technology; Scale (i.e., HInt Level)? Individual; HInt Type? Fusion and symbiosis simultaneously, because FingerReader2.0 is physically coupled to your body, and you both cooperate as partners in the shopping task; and How are you both physically coupled? On-Body*;
- *(4d) To achieve the integration purposes, how many and with which components do you need to interact directly?; 01 Component, FingerReader2.0; and finally*,
- *(4e) How can or should you and the partner technology interact*

[7] https://www.samsung.com/br/apps/samsung-health/

[8] https: //www.samsung.com/watches/galaxy-fit/galaxy-fit2-scarlet-sm-r220nzrazto/

[9] https://www.apple.com/br/watch/

[10] https://www.youtube.com/

HINT TECHNOLOGY EXAMPLE	HINT INTERLOCUTORS				HINT DESIGN SPACE								HINT COMMUNICATION PROCESSES				HINT SIGNIFICATION PROCESSES					ATTRIBUTE THAT QUALIFIES
	Type of Designer				Type of Sender					Type of Channel					Type of Deputy							
	Designer	Multiple Designers	User	Hint Technology	Sender	Multiple Senders	Receiver	Integrated Message	Code	Single channel	Multiple Channels	Context	Designers-User Integrated Metacommunication	User-System Communication	Designer's Deputy	Collective Deputy	Intention	Content	Expression	Signs	Semiosis	Integrated Communicability
App for monitoring health	o		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o
Exoskeleton	o		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o
FingerReader 2.0	o		o	o	o		o	o	o		o	o	o	o	o		o	o	o	o	o	o
Semi-autonomous Car	o		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o
Smart Alarm Clock	o		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o
Smart Assistant for Smart-TV		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o	o
Smart Band		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o	o
Smart eBike	o		o	o	o		o	o	o		o	o	o	o	o		o	o	o	o	o	o
Smart Watch		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o	o
Youtube	o		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o

Figure 4. Existing partner technologies structured in the light of the Semiotic Engineering theoretical framework extended to HInt.

and integrate for the partnership between you both to take place? When you arrive at the shopping location, you should wear the FingerReader2.0 on one of your hands and point your finger, with the ring, towards the objects you want to identify (e.g. shopping products or banknotes). Using an embedded camera, FingerReader2.0 recognizes the object and describes it to you via audio. Thus, FingerReader2.0 helps you identify the products available for purchase by describing them in terms of textual information and colors. Additionally, this HInt solution helps you make purchasing decisions (e.g., it compares the prices of different brands of the same product and makes recommendations based on this comparison).

Based on the integrated metacommunication content, we can observe that *FingerReader 2.0* is a ***HInt solution***, designed by ***a single design team***, whose focus is to establish a ***partnership (by fusion and symbiosis) with blind individuals*** for performing shopping tasks. At design time and during integration, this ***single team*** of designers ***acts as the sender*** of the integrated metacommunication of the *FingerReader 2.0*. In turn, the ***visually impaired user is the receiver*** in the communicative process that takes place during this integration. The integrated metacommunication takes place through the ***"blind individual-FingerReader 2.0" communication*** and its content (i.e., integrated metamessage) is conveyed via the ***multiple channels, the wearable device, and the headset*** of the *FingerReader 2.0*. Therefore, the *FingerReader 2.0* is the ***designer's deputy*** during HInt. Since ***intention, content and expression (i.e., signs and signification systems)*** influence the quality of the intended partnership, *FingerReader 2.0* will satisfy the ***integrated communicability*** criterion if, during integration, the blind users can generate interpretations and meanings (i.e., semiosis) compatible with the ***semiosis that the designer has crystallized*** on the interface of this partner technology.

Taken together, the application examples presented in this proof of concept demonstrate the completeness and applicability of extending the Semiotic Engineering to structure and describe existing HInt solutions, regardless of: (a) the nature of partnership, (b) intelligence, (c) composition of partner technology and (d) number of teams involved in the design of the solution. Thus, these application examples show that the Semiotic Engineering theoretical framework extended to HInt provides a useful theoretical foundation to support the study, design, and evaluation of HInt. Next, we present the results of the evaluation of Semiotic Engineering for HInt from a third-party perspective.

7 Evaluation Results from the Third-Party Perspective

As detailed in the *Subsection 5.2*, in addition to the proof of concept, we also evaluated the Semiotic Engineering theoretical framework extended to HInt from the perspective of different interest groups to better delineate its benefits and limits. We conducted this evaluation by offering a course at DCC/UFMG and a workshop at the *HCI 2023 event*, where participants had the opportunity to learn and apply extended Semiotic Engineering to assist in the study, design, and evaluation of HInt.

Based on the correction of the proposed activities, as well as the thematic analysis of our field diaries and the participants' experience reports, we evaluated the learning, applicability and usefulness of the Semiotic Engineering ontology extended to HInt from the perspective of the course and workshop participants. It is worth noting that the analysis of the data from this research phase was conducted by the main author of this paper and validated by the second author. Next, we present the profile of the course and workshop participants who collaborated with the proposed evaluation.

7.1 Participants' Profile

The course was offered to Computer Science and Information Systems students at DCC/UFMG. Initially, we recommended that enrolled students should have knowledge of HCI. However, as it was an optional course, we also allowed the enrollment of individuals who were studying HCI in the same semester of the course (i.e., 2023/2). The course had the participation (from start to finish) of 25 students.

Among the 25 participants in the course, 14 were undergraduate students in Information Systems, and 11 were undergraduate students in Computer Science. Regarding prior knowledge of HCI, 17 students had already taken this course in previous semesters (between 2020/1 and 2023/1). All students voluntarily agreed (by signing the Informed Consent Form) to the collection and analysis of the materials they produced for the evaluation proposed in this paper. Throughout this paper, the course participants will be referred to by the code ***CP***.

Regarding the workshop at the *HCI 2023 event*, 16 people attended in the morning (09:00-12:00) and, among them, 14 remained until the workshop ended at 18:00. The two people who did not complete the workshop explained their partial attendance due to the need to take part in other activities that took place at the event in parallel with the workshop afternoon session.

Regarding the profile, the majority (10) of the workshop participants are researchers/professors in the HCI field, including 08 PhDs and 02 Master's degree holders. The two participants with Master's degrees also work in the HCI industry. The workshop also included the participation of: (a) 03 master's students who work in both research and the HCI industry and (b) 01 undergraduate student in the HCI scientific initiation program. Two participants did not disclose their respective fields of education and professional activity. Similarly to the course, all the workshop participants signed the Informed Consent Form and voluntarily agreed to collaborate with this research. Throughout the text, the workshop participants will be referred to by the code ***WP***. Next, we present the results of the evaluation of the Semiotic Engineering theoretical framework extended to HInt from the perspective of the course and workshop participants.

7.2 Evaluation from the Perspective of HCI Students, Researchers and Professionals

As explained in the *Subsection 5.2.3*, we evaluated the Semiotic Engineering for HInt across four dimensions[11]: **Learning**; **Applicability**; **Usefulness** and **Suggestions**. Through the dimensions *Learning* and *Applicability*, we investigated and discussed: (a) whether it is possible to learn and use the Semiotic Engineering extension for HInt and (b) whether the Semiotic Engineering concepts and ontology extended to HInt apply to characterizing, exploring and describing other partner technologies, different from those used by Barbosa and Prates [2022] as a reference for developing the proposed extension. In turn, the dimensions *Usefulness* and *Suggestions* provided insights into the participants' perceptions of the benefits, limits, and future directions for consolidating and advancing HInt in the light of Semiotic Engineering.

During the analysis of the collected data, we identified a convergence between the results of this evaluation obtained through the course and the workshop (i.e., all the indicators that emerged from the analysis of the workshop data also emerged in the course). However, the course provided richer and more detailed indicators. That is because, compared to the 6-hour workshop, the course lasted 60 hours, allowing us a deeper exploration of the use of the Semiotic Engineering theoretical framework extended to HInt. Considering the above, this section presents and details the evaluation results obtained via the course. Throughout this presentation, we will indicate which results were convergent with the evaluation of the proposed extension via the workshop. Additionally, *Appendix D* was generated to present a mapping of the convergence between the results of the evaluation of the Semiotic Engineering for HInt via the course and the workshop.

7.2.1 Learning

Based on the analysis of the performed activities, as well as our notes and the students' experience reports, we identified that the majority of students (14 out of 25 – 56%) did not report any difficulties during their learning and use of Semiotic Engineering concepts and ontology to define and explore HInt. According to the students: (a) the classes and (b) the course materials contributed to a better understanding of the content related to the extension of Semiotic Engineering to HInt. The report from participant CP22 highlights this perception: *"As I already had knowledge of HCI and we had very didactic and interactive classes on the extension of Semiotic Engineering, it was easy to understand the theory focused on HInt"* [CP22]. However, some students (11 out of 25 – 44%) reported temporary difficulties related to: (1) understanding certain theory concepts and (2) limited access to examples of partner technologies used in the course activities.

Regarding the difficulty in understanding certain concepts, eight students (32%) reported difficulties when differentiating the elements: (a) *Designer and Sender* and (b) *User and Receiver*, which are used to characterize the interlocutors and the design space of HCI in the light of the original Semiotic Engineering. In the perception of these students, these terms are redundant to represent the design team and users when defining and characterizing HCI as a communicative process. However, after further explanations and examples of the use of these elements during the classes, the students understood the necessity of these concepts in ontology. As these elements are also used in the Semiotic Engineering ontology extended to HInt, this difficulty may (temporarily) affect the learning of this theory for HInt. However, as these concepts are included in the original ontology, we consider this difficulty inherent to the original Semiotic Engineering terminology and it is not exclusive to the proposed extension.

Another difficulty identified was in characterizing a HInt solution as a *Collective Deputy*. As explained in the *Subsection 3.2*, this definition is related to the number of different interactive interfaces that together communicate the integrated metamessage (independently of the number of teams involved in its design). However, initially, four students (16%) understood that the definition of Collective Deputy was related to the number of teams involved in the design of the HInt solution. This misunderstanding was also reported by a group of five workshop participants (31%). Thus, upon identifying this difficulty, we: (a) explained and exemplified again the definition of Collective Deputy to the course students and

[11] An overview of the thematic analysis results, including the codes generated and associated with each theme, can be found at: `https://bit.ly/4cCOMwj`

workshop participants; and (b) revised this definition in the didactic material and in the text presenting the extension of Semiotic Engineering to HInt to explicitly clarify that the collective deputy characterizes HInt solutions whose integrated message is conveyed (together) by different interfaces which may have been designed by a single or multiple design teams.

Regarding the limited access to HInt examples, seven course students (28% of 25) and three workshop participants (18% of 16) reported difficulties in: (a) identifying the Type of Designer/Sender (whether single or multiple), when this information is not explicitly communicated in the interface of an existing HInt solution; and (b) characterizing some aspects of a partner technology (e.g., nature of partnership), when it is not possible to access and interact with the existing HInt solution. These difficulties are evidenced by the following reports: (i) *"My greatest difficulty was in obtaining information that would be internal to the technology development process, such as the number of designers, for example"* [CP18] and (ii) *"Some technologies may be difficult to characterize with the framework if we do not have access to and interaction with the solution"* [CP13] and (iii) *"How can we precisely define the level of autonomy and whether, beyond being autonomous, the solution is intelligent, without access to and interaction with the existing solution?"* [WP9]. This difficulty in characterizing a solution based only on its description (i.e., without interaction) is not a limitation of the extension of Semiotic Engineering to HInt. Instead, it is a difficulty imposed by the restriction of access to some examples of partner technologies. We can conclude this because these difficulties did not arise when: (a) the students had access to the example and (b) during the use of the extension to propose a HInt solution.

Considering the above, these results indicate that, despite some temporary difficulties, the participants of this evaluation were able to learn and use the concepts and ontology of Semiotic Engineering extended to HInt. Next, we present the results addressing the applicability of extended Semiotic Engineering to support the study, design and evaluation of existing and future HInt.

7.2.2 Applicability

For the applicability analysis, we conducted two kinds of case studies. The first study focused on the analysis and description of real HInt solutions (i.e., reverse engineering), and the second focused on the prototyping of future partner technologies, using the Semiotic Engineering theory for HInt as a basis.

In the first study, the students were divided into groups, and each group characterized an example of an existing solution in the light of Semiotic Engineering for HInt. In total, seven different HInt solutions were explored: (1) *Alarm.com Solution*[12], whose partnership focus is on home protection and security; (2) *Amazfit GTS 4*[13], a smartwatch that helps the user with personal organization, health, and well-being; (3) *Iron Man Armor*[14], a Marvel superhero who supports public safety; (4) *Drone DJI Mini 3 Pro*[15], whose partnership focuses on image production/editing; (5) *Oura Ring*[16], a wearable device that assists the user in health and well-being; (6) *Steam recommendation platform*[17], a user partner in entertainment; and (7) *VS Code*[18], a code editor that assists the user in pair programming.

Among the seven partner technologies studied, four (*Alarm.com Solution*, *Iron Man Armor*, *Drone DJI Mini 3 Pro* and *Oura Ring*) were characterized in the light of Semiotic Engineering for HInt based on their respective description provided by the supplier and three (*Amazfit GTS 4*, *Steam recommendation platform* and *VS Code*) were described based on informal inspection (via interaction) by the group members. **Figure 5** summarizes the characterization of the elements involved in the partnership mediated by each analyzed HInt solution. For each characterized solution, **Figure 5** presents the *types of interlocutors*, the *design space*, the *types of communication* and the *aspects that influence the quality* of the proposed HInt.

In addition to characterizing the elements involved in the partnership mediated by each partner technology, the groups also generated the intended integrated metacommunication of their respective analyzed HInt solution. To illustrate, the **VS Code** metacommunication is presented (as generated by the group that explored this solution) to evidence the use of the integrated metamessage template to describe and understand the design proposals of these partner technologies. As a complementary example, *Appendix B* presents the integrated metamessage for the Drone DJI Mini 3 Pro, generated by one group via the reverse engineering of an existing HInt solution.

[VS Code Integrated Metamessage]

(1) Who are you? Programmer using VS Code editor;

(2) What have I understood that you want or need to do? I have understood that you need a solution to help you code a program;

(3) What have I understood that you want that a partner technology does for you? I have understood that you need an autonomous and intelligent solution that suggests lines of code to accelerate the development process;

(4) This is the HInt Solution that I have created for you:

- *(4a) What is the partner technology and its components? VS Code, a solution composed of 01 Component*;
- *(4b) What will the partner technology do autonomously for you? This solution will allow you to develop code in pairs, in which your partner will be an artificial intelligence with the autonomy to generate and suggest parts of code during the development of your program*;
- *(4c) What is the nature of partnership that you both establish regarding: Agency (i.e., Autonomy Level)? Equally shared control; Scale (i.e., HInt Level)? Individual; HInt Type? Symbiosis; and How are you both physically coupled? Off-Body*;
- *(4d) To achieve the integration purposes, how many and with which components do you need to interact directly?; 01 Com-*

[12] Alarme.com Solution - `https://international.alarm.com/pt/home-bz/`

[13] Amazfit GTS4 - `https://www.amazfit.com/products/amazfit-gts-4`

[14] Iron Man - `https://marvel.fandom.com/pt-br/wiki/Armadura_do_Homem_de_Ferro`. It is important to highlight that, as the armor is fictional, the students based their analysis on the description given in the films

[15] Drone DJI Mini 3 Pro - `https://www.dji.com/br/mini-3-pro`

[16] Oura Ring - `https://ouraring.com/`

[17] Steam recommendation - `https://store.steampowered.com/recommender`

[18] VS Code - `https://code.visualstudio.com/`

EXISTING HINT TECHNOLOGY	HINT INTERLOCUTORS				HINT DESIGN SPACE								HINT COMMUNICATION PROCESSES				HINT SIGNIFICATION PROCESSES					ATTRIBUTE THAT QUALIFIES
	Type of Designer: Designer	Type of Designer: Multiple Designers	User	Hint Technology	Type of Sender: Sender	Type of Sender: Multiple Senders	Receiver	Integrated Message	Code	Type of Channel: Single channel	Type of Channel: Multiple Channels	Context	Designers-User Integrated Metacommunication	User-System Communication	Type of Deputy: Designer's Deputy	Type of Deputy: Collective Deputy	Intention	Content	Expression	Signs	Semiosis	Integrated Communicability
Alarm.com Solution	o		o	o	o		o	o	o		o	o	o	o		o	o	o	o	o	o	o
Amazfit GTS 4		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o	o
Iron Man Armor	o		o	o	o		o	o	o		o	o	o	o		o	o	o	o	o	o	o
Drone DJI Mini 3 Pro	o		o	o	o		o	o	o		o	o	o	o		o	o	o	o	o	o	o
Oura Ring	o		o	o	o		o	o	o		o	o	o	o	o		o	o	o	o	o	o
Steam Recommendation Platform		o	o	o		o	o	o	o	o		o	o	o		o	o	o	o	o	o	o
VS Code	o		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o

Figure 5. Existing partner technologies characterized by the course groups in the light of Semiotic Engineering for HInt.

ponent, the VS Code editor; and finally,

- *(4e) How can or should you and the partner technology interact and integrate for the partnership between you both to take place? Initially, you must install VS Code. Once installed, you simply type your code. While you are typing, this partner technology has the autonomy and intelligence to generate and provide code suggestions related to the project context. In addition to context-based recommendations, VS Code can also assist in creating code based on comments and generating unit tests. Based on the suggestions offered by this partner technology, you decide whether to accept them (with or without adaptations) or to reject the provided suggestions.*

In the second case study, each group applied the theoretical framework of Semiotic Engineering for HInt to support the proposal of a future partner technology. To motivate the development of this work, we invited two different partners (one from academia and one from industry) to present a real demand for which a HInt solution would be appropriate. Each partner recorded a short video describing their demand. The videos were presented to the students and remained available throughout the study. Each group chose the demand they wanted to address and proposed a solution. Thus, in this application study, seven distinct potential HInt solutions were presented. These are: (1) *Assets Enhancer*; (2) *DesignIt*; (3) *Pixel Sprite Generator*; (4) *HoloWatch*; (5) *Needbud*; (6) *NeedyuMore* and (7) *Needy AI Office Copilot Ultra Plus*. Among these proposals, the *Assets Enhancer*, *DesignIt* and *Pixel Sprite Generator* solutions were proposed to address the demands of the *Pixel Sides Project*, an initiative coordinated by a professor from another university, which focuses on developing HInt solutions to assist game designers in creating images from different perspectives. In turn, the *HoloWatch*, *Needbud*, *NeedyuMore*, and *Needy AI Office Copilot Ultra Plus* solutions were proposed to meet the request of the *Tech Human* company[19], which aims to evolve its product *Needyu*[20] into a partner technology that assists users in decision-making after a previously recorded conversation (e.g., a meeting or medical consultation).

For each proposed solution, the respective group presented a non-functional prototype, as well as a characterization and description of the future partner technology in the light of Semiotic Engineering for HInt. **Figure 6** was generated to illustrate how each solution was structured by its respective proposing group, using the ontology of Semiotic Engineering for HInt as a basis. This figure summarizes the interlocutors, the design space, the types of communication and other aspects that influence the quality of the intended integration for each partner technology.

In addition, the groups used the integrated metamessage template to make explicit their respective design intentions and decisions regarding: (1) who the solution is intended for, (2) what the users' needs or desires are, (3) what the intended partnership is and (4) how the user and the proposed solution should interact to achieve the integration goals. The intended integrated metamessage of the **Needy AI Office Copilot Ultra Plus** solution is presented below to illustrate the use of the template extended to HInt [Barbosa and Prates, 2022, 2023, 2024a] to support the design and description of future partner technologies. An additional example of applying the integrated metamessage template to describe a future HInt solution is available in *Appendix C*.

[Integrated metamessage of the (future) HInt solution: Needy AI Office Copilot Ultra Plus]

(1) Who are you? Users who hold corporate meetings online;

(2) What have I understood that you want or need to do? I have understood that you want to hold online meetings and then have access to what was discussed for recording and making necessary decisions;

(3) What have I understood that you want that a partner technology does for you? I have understood that you want a technology with the autonomy to record what was discussed in a meeting and assist you in the actions that need to be taken after that conversation;

(4) This is the HInt Solution that I have created for you:

- *(4a) What is the partner technology and its components? Needy AI Office Copilot Ultra Plus, a multicomponent solution: (i) Needy AI System, a web-based system for online meetings and (ii) Needy App, a smartphone application for managing and controlling actions after meetings*;
- *(4b) What will the partner technology do autonomously for you? This partner technology will record, analyze, and summarize what was discussed during a meeting, as well as identify and suggest actions (both during and after the meeting) based*

[19]Tech Human Website - `https://www.techhuman.com.br/`
[20]Needyu - `https://needyu.com.br/`

FUTURE HINT TECHNOLOGY	HINT INTERLOCUTORS				HINT DESIGN SPACE								HINT COMMUNICATION PROCESSES				HINT SIGNIFICATION PROCESSES					ATTRIBUTE THAT QUALIFIES
	Type of Designer				Type of Sender					Type of Channel					Type of Deputy							
	Designer	Multiple Designers	User	Hint Technology	Sender	Multiple Senders	Receiver	Integrated Message	Code	Single channel	Multiple Channels	Context	Designers-User Integrated Metacommunication	User-System Communication	Designer's Deputy	Collective Deputy	Intention	Content	Expression	Signs	Semiosis	Integrated Communicability
Assets Enhancer	o		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o
DesignIt	o		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o
Pixel Sprite Generator	o		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o
HoloWatch		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o	o
Needbud	o		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o
NeedyuMore	o		o	o	o		o	o	o	o		o	o	o	o		o	o	o	o	o	o
Needy AI Office Copilot Ultra Plus	o		o	o	o		o	o	o		o	o	o	o		o	o	o	o	o	o	o

Figure 6. Future HInt solutions proposed and characterized by the course groups in the light of Semiotic Engineering for HInt.

on the content of the conversation;

- *(4c) What is the nature of partnership that you both establish regarding: Agency (i.e., Autonomy Level)? Equally shared control; Scale (i.e., HInt Level)? Individual and Collective; HInt Type? Symbiosis; and How are you both physically coupled? Off-Body*;
- *(4d) To achieve the integration purposes, how many and with which components do you need to interact directly?; 02 components, the Needy AI Office Copilot Ultra Plus web meeting system and the smartphone app; and finally*,
- *(4e) How can or should you and the partner technology interact and integrate for the partnership between you both to take place? You and all meeting participants must connect to the Needy AI System. Once connected, you can start recording the meeting or the Needy AI System can autonomously detect that a conversation has started and suggest recording the discussion. During the conversation, the Needy AI System may suggest topics to discuss or actions to be taken. Once the meeting and recording are completed, Needy AI System transcribes, summarizes and generates reports of what was discussed for later viewing and consultation via the system interface. In addition, the Needy AI System suggests actions that can be taken after the meeting and sends these suggestions to the smartphone app, Needy App. Through the Needy App you can: (a) check your schedule of past and future meetings, (b) view the summary of past meetings, as well as (c) receive and check the actions suggested by the Needy AI System to support you in decision-making after each meeting.*

From these two kinds of case studies, we can observe that the theoretical framework of Semiotic Engineering for HInt can be applied to support the study and design of solutions that work or could work as partners for users in different application domains. As shown in **Figure 5** and **Figure 6**, and demonstrated through the examples of using the integrated metamessage template, the course students were able to use all the concepts and elements of the Semiotic Engineering ontology extended to HInt to: (a) analyze, understand and characterize existing HInt solutions as an extension of the HCI communicative process and (b) propose, structure and describe future partner technologies as an artifact of integrated metacommunication. Furthermore, during the application of the Semiotic Engineering theoretical framework for HInt, the students and the researcher-authors did not identify any need for new elements/concepts beyond those already included in the proposed extension. In other words, we observed that - considering the conducted case studies - the extension of the Semiotic Engineering ontology to HInt includes the necessary concepts and elements to conceptualize, characterize, describe, and explain the integration between humans and partner technologies as an extension of the HCI communicative process.

It is important to highlight that the (temporary) difficulties faced by some students when characterizing existing solutions based only on their descriptions (e.g., identifying the nature of partnership and type of sender without interacting with the partner technology) were not observed during the characterization and description of the (future) HInt solutions proposed in the course. This observation can be evidenced by the following report: *"It was easier to use the theoretical framework for HInt during the activities of thinking about and proposing a HInt technology. For instance, as I was involved in the proposal, it was easy to identify the type of designer, which was a question I had when analyzing a technology that I had neither developed nor used. Semiotic Engineering for HInt also helped my group to think more carefully about what to consider when proposing a partner system for the user"* [CP18].

Taken together, the results of the applicability evaluation indicate that the extension of the Semiotic Engineering theoretical framework to HInt is applicable for: (1) defining and explaining HInt as a paradigm that extends the traditional HCI communicative process; and (2) exploring, characterizing, and describing the proposed design of partner technologies (both existing and future), independently of: (a) the focus and nature of partnership, (b) the intelligence and composition of the partner technology and (c) the teams involved in the design of the solution. It is worth noting that these results converge with the applicability indicators obtained via the workshop. During the workshop, the participants only carried out case studies applying the proposed extension to the reverse engineering of existing partner technologies (the same ones analyzed by the course students). However, after this application and during the discussion session, the workshop participants reported that Semiotic Engineering extended to HInt provides a theoretical lens with the potential to assist in defining, characterizing and describing the HInt paradigm and partner technologies. Next, we present the results of the evaluation of the Semiotic Engineering for HInt with regard to its benefits.

7.2.3 Usefulness

Through the thematic analysis of our field diary and the students' experience reports, we identified that, from the perspective of the participants in this evaluation, the Semiotic Engineering for HInt is not only applicable but also useful for supporting HCI students, researchers and professionals in the study, design, and evaluation of HInt. According to the majority of students (21 out of 25 – 84%) and the majority of workshop participants (14 out of 16 – 88%), compared to the concepts and ontology of original Semiotic Engineering, the extension of Semiotic Engineering to HInt allows us to: (1) conceptualize and explain HInt as an extension of traditional HCI more explicitly and clearly; (2) better analyze, understand and characterize an existing HInt solution; and (3) better structure and describe a future partner technology, explaining its particularities that transcend interaction. According to the group formed by students CP2, CP13, and CP22: *"The Semiotic Engineering theoretical framework for HInt is useful in defining and describing partner technologies. It provides a more complete structure than the original theory to analyze and propose an integration between users and technological systems"* [Group: P2, P13, and P22 of the course]. In turn, the report from participant WP12 reinforces this perception that compared to the original Semiotic Engineering, the proposed extension offers advantages: *"Knowing the original theory and now the extension, I believe that Semiotic Engineering for HInt will be useful to better understand and describe how the partnership between humans and HInt solutions happens. This understanding can help develop solutions that better meet user needs"* [WP12].

In addition, the majority of students (19 out of 25 – 76%) and all workshop participants reported that the extension of the Semiotic Engineering to HInt, especially the integrated metamessage template, is useful for: (1) guiding the designer in the conception of a partner technology centered on integrated communicability; and (2) helping to reflect on: (a) which aspects to consider in the study, design, and evaluation of HInt and (b) the effects of the design strategies and decisions on the quality of the partnership between humans and the HInt solution. For instance, according to student CP18: *"This extension is useful for HCI students and professionals to study and explain different aspects of the partnership between users and technologies. It can help to think about what should be considered when studying and developing HInt technologies"* [CP18]. In turn, student CP11 states that: *"The extension of Semiotic Engineering to HInt, especially the integrated metamessage template, encourages detailed reflection on key elements that should be considered in developing a HInt technology"* [CP11]. Finally, workshop participant WP16 reports that the proposed extension: *"Helps us think about what needs to be considered when proposing a HInt solution and the impacts that this type of solution can have on its users. For instance, the integrated metamessage template offers an organized structure for considering essential elements in the design of the solution. It helps clearly define who the solution is for, what the user wants to achieve, and the role of technology in this process"* [WP16].

The results presented so far indicate that, regarding benefits, the Semiotic Engineering theoretical framework for HInt is useful as: (a) a theoretical basis for exploring, understanding, and explaining the phenomena involved in the partnership between humans and technologies and (b) an epistemic tool [de Souza, 2005] that can stimulate reflections on the impacts of HInt within the HCI scope. This indicator of usefulness is reinforced by the report of the workshop participant WP9: *"The extension of Semiotic Engineering to HInt has the potential to assist the HCI Community in investigating, explaining and reflecting on the phenomena involved in the design and evaluation of existing and future HInt. Furthermore, this extension can be used in practice so that companies can describe their partner technologies as a HInt solution and better explain the proposed partnership"* [WP9].

7.2.4 Limitations and Future

In addition to the benefits, the participants in this evaluation identified limitations in the Semiotic Engineering for HInt that need to be considered. From the perspective of some students (10 out of 25 – 40%) and the majority of workshop participants (14 out of 16 – 88%), the learning and using the proposed extension requires prior knowledge of the original Semiotic Engineering theory, which represents an additional cost in the learning process for those who wish to use the proposed extension but are not yet familiar with this theory. Student CP11's report expresses this perception: *"To use the extension, I had to remember the Semiotic Engineering theory. If I hadn't known this theory, I would have had to learn it to better understand the extension for HInt"* [CP11].

Furthermore, these students and workshop participants believe that prior knowledge of Semiotic Engineering can be a limiting factor for using this theory extended to HInt outside the academic environment (i.e., in the HCI industry[21]). That is because, originally, to characterize HCI as a special type of communication mediated by a technological solution, the Semiotic Engineering theory uses a specific vocabulary composed of semiotic terms, which students and professionals in the technology field may not be familiar with. As an extension of this theory, the Semiotic Engineering for HInt also presents this limitation. Therefore, from the perspective of these participants, the use of Semiotic Engineering as a theoretical basis for exploring and explaining HInt may be more applicable in the academic/scientific environment than in the HCI industry. The following reports evidence this perception: (i) *"The use of vocabulary that is sometimes specific to Semiotic Engineering Theory (e.g., sender of the solution, designer's deputy, metacommunication) can make it difficult to apply this theoretical framework in the industry without prior training"* [CP18] and (ii) *"We believe that this theoretical basis is very relevant for teaching in courses that address HInt and supporting research on this topic. However, it may be necessary to simplify the language used to make the*

[21] The term "HCI industry" is used in this paper to refer to HCI applied outside the academic/scientific context and the use of the proposed extension in the professional market

proposed extension more easily applicable" [Group: WP3, WP9, WP12, and WP16 of the workshop].

Although these limitations exist, they are inherent to the complexity of the original Semiotic Engineering and not to the proposed extension. Therefore, contrasting the students' perceptions regarding the usefulness of the proposed extension for the HCI Community and its limitations, we can observe that while there are costs associated with learning and using the theoretical framework of Semiotic Engineering for HInt, there are also benefits that add value to the study, design, and evaluation of HInt within the HCI scope. The report from the group formed by students CP11, CP14, and CP21 supports this argument: *"Despite requiring knowledge of Semiotic Engineering, we perceived more advantages than disadvantages with this extension of the theory to HInt. Since it is the first theory that helps to understand HInt, it can be used as a basis to begin exploring the partnership between users and systems"* [Group: CP11, CP14, CP21 of the course]. In turn, workshop participant WP3 emphasizes that: *"Even though it requires prior knowledge in Semiotic Engineering, this extension to HInt is important and will be useful to help us explore the design and evaluation challenges of HInt, both in academia and in the HCI industry"* [WP3].

Based on the perceptions of the benefits and limits of the proposed extension, the course and workshop participants provided valuable suggestions for the next steps towards consolidating the Semiotic Engineering theoretical framework extended to HInt. Through thematic analysis, we identified that the suggestions focus on: (1) Expanding knowledge about the existence of Semiotic Engineering for HInt and stimulating new initiatives based on this extension; and (2) Exploring the Semiotic Engineering theoretical framework for HInt applied in the HCI industry. The suggestions presented were:

- To offer new courses and workshops to disseminate knowledge about HInt in the light of Semiotic Engineering;
- Based on the extension of the theoretical framework, to extend and/or propose other models and methods based on Semiotic Engineering to support the study, design, and evaluation of HInt;
- To evolve and refine the integrated metamessage template to explain ethical aspects related to the proposed HInt;
- To create a version of the Semiotic Engineering for HInt in simplified language for application in the HCI industry;
- To apply the proposed extension in industry to delineate its benefits and limitations in practice (i.e., beyond the academic application);
- To investigate the applicability of the extension to describe/explain non-HInt solutions that share some characteristics of this kind of solution (e.g., interactive technologies composed of multiple interactive interfaces).

The suggestions presented indicate that - although there is room for improvement - both the course students and the workshop participants: (a) recognize the relevance of extending the Semiotic Engineering to HInt; and (b) identified other initiatives, based on this extension, that could contribute to the consolidation and evolution of HInt in the light of Semiotic Engineering. Considering the above, the results presented in this section provided insights about the limitations and future directions of the Semiotic Engineering extended to HInt from the perspective of the participants in this evaluation. As previously reported and explained throughout this section, the results of the evaluation of the Semiotic Engineering theoretical framework for HInt via the course and workshop were convergent and the *Appendix D* summarizes this convergence.

8 Discussion and Limitations

This section discusses the main results and point out the limitations of this research. *Subsection 8.1* focuses on the results discussion, while *Subsection 8.2* presents the limitations.

8.1 Results Discussion

In this paper, we evaluated the extension of Semiotic Engineering to HInt: (1) via proof of concept from the perspective of the researchers who authored this paper and (2) via case studies of its application from the perspective of third parties. This evaluation is important because it involves the use of this theoretical framework by different interest groups, who represent its target audience (i.e., HCI students, researchers, professionals, and other groups interested in HInt). The proof of concept demonstrated the applicability and completeness of the extension of Semiotic Engineering to explore existing HInt solutions. In turn, the case studies conducted during the course and workshop provided indicators regarding: (a) the learning cost, (b) the applicability of Semiotic Engineering for HInt, and (c) the perceptions of HCI students, professionals, and researchers regarding the usefulness, limitations, and future of Semiotic Engineering extended to HInt.

The results of the evaluation from the perspective of third parties indicate that it is possible to learn and use the Semiotic Engineering theoretical framework extended to HInt to explore the partnership between humans and technologies in different application contexts. The analysis of the materials produced during the course and workshop revealed that: (a) the course students (including those who have not yet taken an HCI course) and the workshop participants were able to understand and apply the concepts and ontology of Semiotic Engineering extended to characterize and describe existing HInt solutions, and (b) the course students were able to use this theoretical foundation as a reference for structuring and proposing future partner technologies.

However, according to the participants of this evaluation, learning and using this extended theoretical framework to HInt requires prior knowledge of the basic concepts of the original Semiotic Engineering Theory, and this basic knowledge would be a limitation for applying the extended theory outside the academic context. It is important to highlight that this cost is not specific to Semiotic Engineering Theory or the proposed extension. After all, whenever a theoretical approach is adopted, the concepts used by the theory must be understood by those who intend to apply it. The fact that all the students were able to understand and apply these concepts demonstrates that - with a set of materials explaining and illustrating the theoretical framework - the intended target audience can learn and use Semiotic Engineering extended to HInt.

Regarding the applicability of the Semiotic Engineering ontology extended to HInt, the evaluation results indicated that all the categories (Interlocutors; Design Space; Communication Processes; and Signification Processes) and the proposed elements (both existing and new) – e.g., integrated metamessage template and the property of integrated communicability – were necessary and sufficient to characterize and describe the existing HInt solutions explored via proof of concept, course and workshop, as well as to guide the design and description of future partner technologies proposed by the course students. This indicates that the proposed extension includes the relevant and necessary categories and elements for defining, characterizing, and understanding the partnership between humans and technologies. Furthermore, during the proof of concept and the analysis of the material generated in the application case studies, no other significant characteristics of the partner technologies were identified that could not be described in the light of Semiotic Engineering extended to HInt. Thus, the indicators obtained from this evaluation suggest that there is no need to change the proposed extension of the Semiotic Engineering theoretical framework to HInt, which contributes to its consolidation.

Regarding the usefulness, both the course students and the workshop participants indicated that Semiotic Engineering extended to HInt is useful as a theoretical lens: (1) to define, structure and explain the HInt paradigm as a communicative process between partners that extends the interaction (i.e., communication) in traditional HCI; and (2) to better explore, characterize and describe the design intentions and decisions (i.e., design proposal) of existing or future partner technologies. Furthermore, the results indicate that the extension of the Semiotic Engineering to HInt, in particular the integrated metamessage template, is useful for stimulating reflections and supporting the study, design, and evaluation of HInt centered on the beneficial partnership between humans and technologies that transcends interaction.

Thus, the participants' perception of this evaluation is aligned with the intended goals of the proposed extension of Semiotic Engineering for HInt [Barbosa and Prates, 2022]. It is particularly interesting to consider the results that highlight students' perception of the support for reflection provided by the ontology and the integrated metacommunication template during the analysis and design of a HInt solution. That is because, an essential aspect emphasized by Semiotic Engineering theory is the need to provide designers with epistemic tools (i.e., tools that allow a person to raise hypotheses about the problem, experiment with different solution possibilities, and evaluate the results [de Souza, 2005; Prates and Barbosa, 2007; Prates, 2017]) to support their solution-generation process. However, this concept of epistemic tool was not introduced to the students during the course. Despite not being exposed to this concept and its relevance to Semiotic Engineering, the participants' perception regarding the use of ontology and integrated metacommunication template to support reflection suggests that these extensions would be relevant epistemic tools for HInt designers.

In addition to providing evidence on the applicability, limitations, and benefits of Semiotic Engineering extended to HInt, this evaluation also contributed to envisioning the next steps for evolving and consolidating this HCI theory extended to HInt. According to the participants of this study, it would be interesting to: (1) extend the family of Semiotic Engineering methods to design and evaluate solutions that establish a partnership with users, using the Semiotic Engineering for HInt as a reference and (2) apply Semiotic Engineering extended to HInt in the HCI industry to better delineate its advantages and disadvantages in this context.

8.2 Limitations

Taken together, the findings presented and discussed in this paper are relevant, but they present some limitations that must be taken into account. The first limitation refers to the methodological decision to conduct the application case studies via an undergraduate course and a workshop. In comparison, the course provided us with a deeper insight into the applicability, usefulness, limitations, and future of the Semiotic Engineering theoretical framework for HInt. However, the workshop also provided us with interesting indicators regarding the perceptions of HCI researchers and professionals about HInt in the light of Semiotic Engineering.

This limitation leads us to reflect on how and when to use workshops as a methodological approach to teach and conduct case studies to evaluate new HCI approaches (e.g., theories and methods). Based on our experience in this research, a 6-hour workshop would not be sufficient to obtain the indicators of interest in this evaluation with the same depth as a 60-hour course. However, when it is not feasible to offer a course to conduct this kind of evaluation, offering a sequence of workshops to evaluate new theoretical HCI approaches could be a suitable alternative. It is important to highlight that, although the workshop was conducted after the course had started and before it had ended (i.e., it took place "in parallel"), the course contributed to the planning and realization of the workshop, just as the workshop contributed to improving the course management. That is because, based on our observations about the students' learning regarding the HInt paradigm and the partner technologies, we were able to adjust the teaching material and teaching approach of this new paradigm for the workshop participants. On the other hand, based on our observations about the learning of the Semiotic Engineering theoretical framework extended to HInt from the perspective of the workshop participants, we were able to revise the related content to better explain the proposed extension to the course students.

We also considered the hierarchical relationship between the author researchers and the study participants as a limitation that may have influenced the results of this evaluation, particularly in the course. Although we clarified to the participants that their participation in this research was voluntary and that they were free to express their opinions and perceptions of the addressed content, the fact that the evaluation was conducted via the course and the workshop may have introduced a bias into the responses provided by the course students and the workshop participants on the discussed topics. Since the participants could perceive that we valued the extension of Semiotic Engineering to HInt, they may have expressed more positive comments about the proposed extension.

In addition, specifically in the case of the course, the students' approval was conditional on completing the proposed didactic activities, which made abandoning the application of the Semiotic Engineering for HInt a costly decision for these students. In a different context, the students might not have been willing to invest the same effort into applying the extended Semiotic Engineering to support the analysis and design of the HInt. To mitigate and minimize the potential impacts of this limitation, we took ethical precautions to ensure the students' voluntary participation (as described in subsection 5.2.4). Furthermore, throughout the course, we constantly emphasized to students that: (a) sincerity in expressing their opinions and perceptions about the proposed extension during the activities was both necessary and important, and (b) their grades were based solely on their participation and completion of the activities, not on their opinions.

Another point to consider as a limitation is the context in which the evaluation was conducted. The proof of concept and evaluation from the perspective of HCI students, professionals, and researchers were conducted in the academic context, rather than in the HCI industry context. As suggested by the participants in this evaluation, in addition to the academic application, the use of the proposed extension to support the design and evaluation of partner technologies developed in industry could provide richer insights regarding the benefits and limitations of the Semiotic Engineering extension to HInt. Nevertheless, the evaluation in the academic context provided interesting indicators to: (a) delineate the advantages and disadvantages of Semiotic Engineering extended to HInt and (b) guide the next steps of HInt in the light of Semiotic Engineering, including new initiatives to explore this theory for HInt in the HCI industry.

The limited access to different examples of partner technologies for interaction constrained the HInt domains in which the Semiotic Engineering for HInt was applied and evaluated. In the proof of concept and the conducted case studies, the extension of Semiotic Engineering to HInt was applied and evaluated in the exploration, characterization, and description of examples of integration between humans and technologies in different domains. These are: communication; entertainment; personal organization; image production/editing; pair programming; health and well-being; security and support for the development of arts and games. However, the case studies included only on-body and/or off-body partner technologies. Nevertheless, the evaluation conducted in this study provided evidence regarding the applicability and benefits of the Semiotic Engineering extended to HInt, expanding the examples of HInt used as a reference by the proponents of this extension [Barbosa and Prates, 2022].

Finally, this research is qualitative and does not aim to provide generalized conclusions about the results presented and discussed. Instead, our goal is to present indicators of the applicability and usefulness of the Semiotic Engineering for HInt from the perspective of different interest groups. Thus, although the aspects mentioned as limitations of this study may have influenced the evaluation results, these limitations do not invalidate the relevance and contributions of this research. The findings remain valid and reinforce the evidence that it is possible to learn and use the Semiotic Engineering theoretical framework extended to HInt. Furthermore, despite the learning costs and the potential limitations of its application in industry, the extension of Semiotic Engineering to HInt is useful and adds value to the study, design, and evaluation of HInt as an extension of traditional HCI.

9 Final Remarks

The scope of Semiotic Engineering theory has been extended so that HCI students, practitioners and researchers, as well as other interest groups, can: (a) explore the partnership between humans and technologies and (b) contribute to the evolution of the HInt paradigm within HCI. As this extension is recent, it is necessary to investigate and discuss the applicability and usefulness of Semiotic Engineering for HInt in different application contexts. Given this demand, this study aimed to evaluate the Semiotic Engineering theoretical framework extended to HInt from the perspective of different interest groups.

The results of our evaluation indicated that, despite the limitations associated with the learning cost, the extension of Semiotic Engineering concepts and ontology to HInt is applicable and assists in the investigation, design, and evaluation of HInt as an extension of HCI. In other words, these findings indicate that Semiotic Engineering extended to HInt provides an explanatory and reflective theoretical basis so that people interested in exploring this paradigm can investigate and explain the phenomena involved in the partnership between humans and technologies that transcends the traditional interaction between these agents.

Thus, even though the extension of Semiotic Engineering to HInt has the potential to be more widely used in the academic context, the possibility of learning and applying this theory results in the expansion of knowledge and the acquisition of useful skills [Carroll, 2003], which, in this case, can also contribute to the evolution and consolidation of HInt. Therefore, by learning and applying the Semiotic Engineering theoretical framework for HInt, people interested in exploring this new paradigm become capable of reflecting on which aspects to consider in the study, design, and evaluation of HInt, regardless of whether this extension is (frequently) used in industry

Considering the above, this paper contributed to advancing knowledge and consolidating Semiotic Engineering as a theoretical lens for addressing HInt. The findings presented and discussed in this study provide useful insights and reflections that expand the knowledge of the HCI Community and other interest groups about the existence, applicability, usefulness and limits of the Semiotic Engineering extension for defining, exploring, characterizing and explaining HInt as an extension of traditional HCI. Furthermore, our findings open up opportunities for other initiatives based on Semiotic Engineering (e.g., extending the family of Semiotic Engineering methods) to address HInt and its challenges.

As future work, we suggest investigating the applicability and usefulness of the Semiotic Engineering for HInt in unexplored domains. This investigation could help to better delineate the advantages of the proposed extension in other domains and from different application perspectives, including in the HCI industry context. Another interesting future initiative is to extend and/or propose methods and tools based on Semiotic Engineering to support the study, design, and evaluation of the partnership between humans and technologies. For instance, future work could investigate the applicability and, if necessary, extend: (a) the MoLIC [da Silva and Barbosa, 2007] to assist in modeling HInt and/or (b) the methods [de Souza and Leitão, 2009] to assist in evaluating the integrated communicability of partner technologies.

In addition, it is important to consider that HInt is evolving, and new partner technologies that promote HInt by fusion and/or symbiosis may emerge. Consequently, initiatives related to this new paradigm may also evolve. Therefore, in the future, it will be essential to review the Semiotic Engineering extended to HInt in order to explore its application boundaries in domains in which humans will be increasingly integrated with technology, such as new body-coupled artifacts or intelligent solutions capable of self-organization. For instance, an interesting future work would be to investigate whether the concepts and ontology of Semiotic Engineering extended to HInt apply to exploring and explaining the partnership between humans and technologies that use generative artificial intelligence, which is often unpredictable.

Declarations

Authors' Contributions

GARB and ROP contributed to the planning and execution of this research, as well as to the analysis and discussion of the results. GARB wrote this manuscript. ROP reviewed and edited the manuscript. All authors read and approved the final manuscript

Competing interests

The authors declare that they have no competing interests.

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Availability of data and materials

The datasets generated and/or analysed during the current study will be made upon request.

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A Appendix: Smart Assistant for Smart-TV Integrated Metamessage

Second example illustrating the use of the integrated metamessage template - via proof of concept.

[Smart Assistant for Smart-TV Integrated Metamessage] *(1) Who are you? Smart-TV user; (2) What have I understood that you want or need to do? I have understood that you need a solution to support you in using your TV; (3) What have I understood that you want that a partner technology does for you? I have understood that you need a solution capable of understanding your entertainment demands and, based on this understanding, personalizing your interaction with Smart-TV; (4) This is the HInt Solution that I have created for you: (4a) What is the partner technology and its components? Smart Assistant for Smart-TV, a solution composed of multiple components: (i) Smart Assistant App on the Smartphone, (ii) Smart-TV and (iii) streaming service Apps (e.g., Netflix; Globo Play and Disney Plus); (4b) What will the partner technology do autonomously for you? The Smart Assistant for Smart-TV will: (i) control your Smart-TV based on peripheral information and (ii) recommend content based on your usage preferences; (4c) What is the nature of partnership that you both establish regarding: Agency (i.e., Autonomy Level)? Controlled mainly by humans; Scale (i.e., HInt Level)? Individual; HInt Type? Symbiosis, because you both cooperate as partners in controlling and managing the use of Smart-TV; and How are you both physically coupled? Off-Body; (4d) To achieve the integration purposes, how many and with which components do you need to interact directly?; At least 03 Components, the Smart Assistant; the Smart-TV and the Streaming Apps; and finally, (4e) How can or should you and the partner technology* *interact and integrate for the partnership between you both to take place? You can use Smart Assistant to: (i) turn your TV on/off; (ii) manage channels and streaming, apps and (iii) control aspects such as volume and brightness using voice commands. To do this, activate the Smart Assistant and then verbalize the command (e.g., Open Netflix). Additionally, your Smart Assistant has the autonomy to: (i) collect peripheral information from the environment in which you are watching the Smart-TV (e.g., noise and brightness); and (ii) adjust the TV's settings according to the environment (e.g., reduce the TV's brightness when it detects light in the room), without you needing to verbalize the commands for these adjustments. To personalize your experience, the Smart Assistant recommends content (e.g., TV shows or streaming services) according to your needs and usage preferences. For example, if it learns that you always watch the Brazilian National News from Monday to Saturday, Smart Assistant can suggest a news program broadcast on Sundays (during the evening) to keep you informed. Thus, Smart Assistant for Smart-TV aims to provide a personalized experience during your interaction with Smart-TV.*

Based on the integrated metacommunication content, we can observe that the *Smart Assistant for Smart-TV* is a ***multicomponent HInt solution***, designed by ***multiple design teams***, whose focus is to establish a ***partnership (by symbiosis) with Smart-TV users*** to personalize their TV experience. At design time and during integration, the ***multiple teams*** of designers ***act as multiple senders*** of the integrated metacommunication of the *Smart Assistant*. In turn, the ***user is the receiver*** in the communicative process that takes place during this integration. The integrated metacommunication takes place through the ***"user-Smart Assistant" communication*** and its content (i.e., integrated metamessage) is conveyed through ***multiple channels, the Smartphone and Smart-TV***. Therefore, the *Smart Assistant* is the ***designers' collective deputy*** during HInt. Since ***intention, content, and expression (i.e., signs and signification systems)*** influence the quality of the intended partnership, the *Smart Assistant* will satisfy the criterion of ***integrated communicability*** if, during integration, users can generate interpretations and meanings (i.e., semiosis) compatible with the ***semiosis that the designer has crystallized*** on the interface of this partner technology.

B Appendix: DJI Mini 3 Pro Drone Integrated Metamessage

Second example of an integrated metamessage generated by one of the course groups via the reverse engineering of an existing HInt solution.

[DJI Mini 3 Pro Drone Integrated Metamessage] *(1) Who are you? User interested in taking photos/videos; (2) What have I understood that you want or need to do? I have understood that you need a technological solution to take and edit aerial images; (3) What have I understood that you want that a partner technology does for you? I have understood that you need a autonomous solution to help you take photos/videos from a wide variety of angles; (4) This is the HInt Solution that I have created for you: (4a) What is the partner technology and its components? DJI Mini 3 Pro drone, a HInt solution composed of multiple components: (a) a drone for taking images, (b) a specific remote control for the drone and (c) the DJI Fly app for controlling the drone via smartphone; (4b) What will the partner technology do autonomously for you? This partner technology will fly over a specific area, avoid obstacles (if necessary) and autonomously take images of that area; (4c) What is the nature of partnership that you both establish regarding: Agency (i.e., Autonomy Level)? Equally shared control; Scale (i.e., HInt Level)? Individual; HInt Type? Symbiosis; and How are you both physically coupled? Off-Body; (4d) To achieve the integration purposes, how many and with which components do you need to interact directly?; 02 Components: the remote control device and the DJI Fly app and finally, (4e) How can or should you and the partner technology interact and integrate for the partnership between you both to take place? Image capture can be performed in two ways: (a) manually, in which you control the drone and activate the command to capture images, or (b) automatically, in which the drone is programmed to capture images in a specific area, and the device has the autonomy to fly over the region, avoiding obstacles and capturing in the designated area.*

C Appendix: Assets Enhancer Integrated Metamessage - Future HInt Solution

Second example of applying the integrated metamessage template to describe the future HInt solution: *Assets Enhancer*.

[Integrated Metamessage] *(1) Who are you? Designers working with 2D images for games; (2) What have I understood that you want or need to do? I have understood that you want to create different images for your game, based on an initial image; (3) What have I understood that you want that a partner technology does for you? I understood that you need an autonomous and intelligent technology to support you in the production and enhancement of 2D images; (4) This is the HInt Solution that I have created for you: (4a) What is the partner technology and its components? Assets Enhancer, a monocomponent partner technology; (4b) What will the partner technology do autonomously for you? Given an initial image, this solution will autonomously generate adjustments and recommendations to assist you in creating and editing images; (4c) What is the nature of partnership that you both establish regarding: Agency (i.e., Autonomy Level)? Equally shared control; Scale (i.e., HInt Level)? Individual; HInt Type? Symbiosis; and How are you both physically coupled? Off-Body; (4d) To achieve the integration purposes, how many and with which components do you need to interact directly?; 01 component, the Assets Enhancer system and finally, (4e) How can or should you and the partner technology interact and integrate for the partnership between you both to take place? Open the Assets Enhancer and provide an initial image. This image can be provided via: (a) uploading an existing image, (b) free drawing, and/or (c) verbal or textual description of the image. Based on this initial image, the Assets Enhancer will recommend adjustments to the image and generate complementary images (e.g., the right and left sides of the frontal image) for your game. During the integration, you and Assets Enhancer have the autonomy to manipulate the images. However, for the Assets Enhancer's recommendations to be effectively applied, you must confirm the changes.*

D Appendix: Alignment between the participants' perceptions about the Semiotic Engineering to HInt

	Evaluation participants' perspective regarding the Semiotic Engineering theoretical framework extended to HInt	Course	Workshop
Doubts	To differentiate some concepts of the original Semiotic Engineering that seem redundant (e.g., Designer vs. Sender)	O	
	To characterize some aspects of the HInt solution in the light of Semiotic Engineering extended to HInt (e.g., nature of partnership and type of designer) without interacting directly with the partner technology.	O	O
Applicability	Characterization of the HInt solution design proposal	O	O
	Characterization of the elements involved in the communicative process mediated by partner technology	O	O
Utility	To define and explain the HInt solution better	O	O
	To understand the HInt solution better	O	O
	Epistemic tool to: (a) guide the design of a HInt solution; (b) guide the evaluation of HInt; and (c) support reflections on the effects of design strategies and decisions on the quality of the partnership between humans and technologies	O	O
Limitations	Requires previous knowledge of Semiotic Engineering	O	O
	Specific vocabulary and the complexity of Semiotic Engineering may limit its application in industry.	O	O
Suggestions	To offer new courses and/or workshops to disseminate knowledge regarding HInt in light of Semiotic Engineering.	O	
	Based on this theoretical framework, extend and/or propose other models and methods grounded in Semiotic Engineering for HInt.	O	O
	To evolve the integrated metamessage template to make explicit ethical aspects related to the proposed HInt	O	O
	To propose a version of the Semiotic Engineering theoretical framework for HInt in simplified language for application in the HCI industry	O	O
	To use the extension of Semiotic Engineering to HInt in industry to delineate its benefits and limitations in this context of use.	O	O

Figure 7. Mapping the convergence of the evaluation results of the Semiotic Engineering theoretical framework for HInt via course and workshop.