# A Framework to Foster Diversity in Collaborative Activities

Leandro Luque
Escola Politécnica
Universidade de São Paulo and
Fatec Mogi das Cruzes
Sao Paulo, SP 05508–010
leandro.luque@fatec.sp.gov.br

Leônidas de Oliveira Brandão
Instituto de Matemática e Estatística
Universidade de São Paulo
Sao Paulo, SP 05508–090
leo@ime.usp.br

Anarosa Alves Franco Brandão
Escola Politécnica
Universidade de São Paulo
Sao Paulo, SP 05508–010
anarosa.brandao@poli.usp.br

***Abstract*—Dynamic lectures are collaborative settings in which learners and educators interact with each other and among them to produce, learn, and consolidate knowledge. To take part into collaborative settings, individuals must be able to communicate with others, be aware of the artifacts used and of the objects of interest, among others. On their foundation, these requirements depend on motor and cognitive-related abilities such as arm movement, perception, recognition, and memorization. Impairments may influence these abilities and consequently pose challenges to the participation in collaborative settings. To the best of our knowledge, there is not a guide, a method nor a framework to orient anyone who wants to analyze the scenario of collaborative settings in order to create conditions for the inclusion of individual in such activities. In this context, this paper presents the *Colab4All - Collaboration for All*, a framework created to support the analysis of collaborative settings involving people with impairments. The framework uses the well known Human Processor Model with two complementary objectives: first, to derive questions that must be asked to support the analysis previously mentioned, and then to combine these questions with a collaboration model in order to establish the way potential challenges can be addressed. In order to test the proposed framework, we used it to orient a research on the inclusion of individuals with blindness in a class activity based on graphical notations. The results of such research were tested in a real setting and presented promising results. We consider that the framework proposed in this work is a first step to orient research, derive collaborative and inclusive models, and to define requirements for technology that supports such collaborative settings involving people with impairments.**

## I. INTRODUCTION

We want to live in a world where everyone, regardless of age, gender, impairment or any other characteristic, can fully participate in society. Certainly, there are activities that are not appropriate for specific groups of people due to any peculiarity. Nonetheless, lots of individuals are still unnecessarily segregated from social activities, such as education [1] and certain types of occupation [2]. Various of these activities have a collaborative nature.

Considering the importance of making collaborative activities accessible to individuals with impairments, the research in this field has contributions for different types of impairments. For instance, Kunz et al. [3] investigated the inclusion of individuals with visual impairment in brainstorming sessions, considering mainly non-verbal communication; Antia et al. [4] examined the social skills and behavioral problems of learners with hearing impairment who attended general education lectures; Bagatell et al. [5] assessed a therapy effectiveness in classroom participation of learners with autism spectrum disorders. Nevertheless, there are gaps that must be filled [6], [7].

Four years ago, we started a research on the inclusion of individuals with blindness in collaborative e-learning lectures that use graphical notations [8], [9], [10], [11], [12], [13], [14]. As we did not find a guide, a method nor a framework to orient the research, the identification of the aspects that had to be explored was based on our experience and on the findings of similar studies.

In order to take part in collaborative activities, individuals must be able to: (i) communicate with others; (ii) be aware of the artifacts used and their feedback; (iii) be aware about the object under screening and changes made to it [15], among others. On their foundation, these requirements depends on motor and cognitive-related abilities such as arm movement, perception, recognition, and memorization. Impairments may influence these abilities and consequently pose challenges to collaborative activities.

Hence, understanding impairment-related possibilities of impact on collaborative activities would be of great value to orient research, derive collaborative models, and to define requirements for technology that supports such collaborative activities involving people with impairments.

The *Human Processor Model*, also known as *Model Human Processor (MHP)*, has been used in the *Human-Computer Interaction (HCI)* field since its early days to evaluate human performance in tasks [16]. It considers humans as information processors and seeks to understand the different cognitive processes involved in a task and how they interact and influence humans' perceptions and actions. While it does not take into account social cognition processes, it considers what is required even to allow these processes to happen. Some studies based on the MHP have been criticized for being grounded on the idea of an average user [17], a tricky and not straightforward concept. While we agree that people are different and, mainly when one considers people with impairments, the idea of an average user is vague, if the

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MHP is used to identify possible challenges in tasks and to recommend ways to address these challenges, it would be independent of the idea of an average user.

In this context, this paper presents a collaboration framework based on the MHP to support the analysis of collaborative activities involving people with impairments. As aforementioned, it can be used to orient research, derive collaborative models, and to define requirements for technology that supports such collaborative activities involving people with impairments - but not restricted to them. It can foster diversity in such activities. So far, we have not found any similar proposal in the literature. In order to test the proposed framework, we used it to derive a collaborative model for the inclusion of individuals with blindness in a class activity based on graphical notations. This model was tested in a real setting and presented promising results.

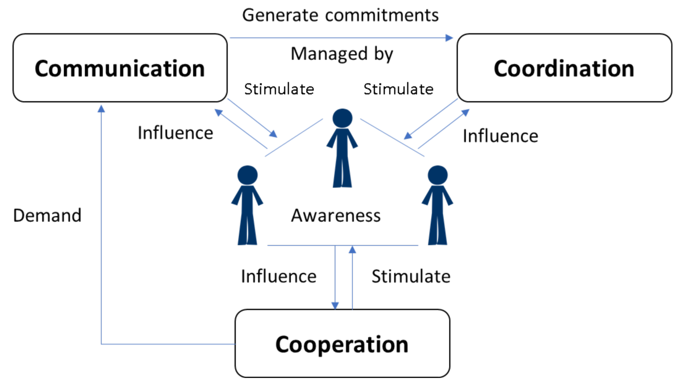


Fig. 1. A representation of the main components of the 3C Model [20]. The words presented near an arrow illustrates the relation between components. For instance, Coordination stimulates (provide information) for Awareness. Also, what is perceived (Awareness) influences Coordination.

## II. Background

In this section, we discuss the basis for defining Colab4All, our framework to foster diversity in collaborative activities. We begin with the discussion about the nature of collaborative activities and their main components, and close with the foundations of some human information processing models.

### *A. Collaboration Models and The Nature of Collaborative Activities*

In order to contextualize collaborative activities, it is important to start defining what we mean by *collaboration*. Collaboration is understood as a collective effort to reach a common and non-conflicting goal. Examples that fit such definition include building a house, co-creating a document or a diagram, among others. Some authors differentiate it from other similar terms, such as cooperation and competition [18]. When we use the term *cooperation*, we mean the work carried out jointly by the participants of collaborative activities, as defined by Fuks et al. [20]. This means that in cooperation the participants could have different goals, such as different learning objectives, while working in a common task. The difference of competition and the previous terms is out of the scope of this work.

Collaboration is generally studied through collaboration models. Such models usually decompose collaboration or collaborative activities in components (communication, coordination etc.) as well as establish the dependencies and relationships among them. Collaboration models can be used for understanding [21], classifying [22], and assisting the implementation of collaborative systems [23], [24]. Next, we present some collaboration models the can be found in the literature.

Fuks et al. [20] proposed 3C, a collaboration model that decomposes collaboration in three main components: coordination, cooperation, and communication (Figure 1).

In 3C, the work carried out jointly by the participants of the collaborative activity is represented by the Cooperation component. This work is carried out in a space shared by participants, whether physical or virtual. It involves acting on objects of cooperation. An object can be, for example, a mindmap [25] created jointly by the participants. Before, during and after the collaborative work, communication between participants may be necessary in order to exchange messages, negotiate commitments, define responsibilities, roles, and tasks. This aspect is represented in the model through the Communication component. Commitments generated via communication and due to prior knowledge assist in the coordination of work - Coordination component. It is a two-way path, since coordination influences the moments in which communication takes place. Coordination organizes the team assigning tasks, setting orders, and specifying boundaries. Coordination also involves the articulation of different tasks. Another model auxiliary component is the awareness. Through the awareness, a participant is informed about what is happening and what other people are doing, having access to information necessary for conducting the work.

Focusing on systems architecture and implementation, Calvary et al. [23] proposed the Clover model. The authors organize systems to support collaborative activities in three specific spaces: production, coordination, and communication. The production space denotes the objects that model the collaborative elaboration of artifacts, such as a document. The coordination space comprises dependencies between activities. The communication space supports face-to-face communication, both synchronous and asynchronous. Although they specify and discuss the main elements of collaborative work, these models do not focus on awareness.

Neale et al. [26] bring awareness to the center of attention. The authors propose a collaboration model that focuses on the underlying relationships related to distributed group work processes. According to the authors, communication, coordination and engagement are the basis for understanding how groups work. The authors also highlight a contextual factor. People manage the context and social fabric that binds them in very complex but subtle ways. Besides, they use the context to understand how to organize their individual efforts within the framework of their social interactions as part of groups.

However, they do this largely as background activity, without being fully aware of how the context shapes their behavior. The context is composed of the activities themselves. It is more than just a container that frames activities. It involves the internal states of the actors themselves and develops dynamically as part of normal interactions with others. Also, the context is defined by some questions: (i) Who is present? (ii) What are they doing? (iii) Are they bored? (iv) Who else is there? (v) What is their relationship to others? (vi) What are the artifacts of interest? (vii) What is happening around people? and (viii) What are the subtle circumstances of people's lives and situations outside the immediate context that shapes their behavior in the current situation? The authors state that without this information it is hard to understand why people do what they do, especially when they do things contrary to what is expected or planned.

The discussed models, despite their differences, present similar components. We will use these components later to establish relations with the Model Human Processor (MHP).

### B. Human Information Processing Models

Human-Computer Interaction (HCI) is a multidisciplinary field related to the design and implementation of interactive computing systems [27]. Even though HCI has an experimental bias, theories have been developed in the field since its early years. These theories are mainly based on Psychology, Ethnography, and Semiotics [28]. Some of these theories understand the interaction between humans and computers as a set of information processing tasks [17] and tend to analyze humans as information processors, establishing an analogy with computers. This is the case of the Human Processor Model, also known as Model Human Processor (MHP).

A well known version of MHP was developed by Card et al. [16]. It summarizes in an engineering model the psychology research to the date it was proposed. Such model establishes an analogy between the way humans perceive, remember, and act, and the way a computer works. It has been widely used to predict and study the human limitations and performance when interacting with computers [29], [30].

The MHP sees humans as systems comprised by different types of processors, memories, and other resources. An important complement to this model was the inclusion of an attention component [31] - a limited resource representing the capacity that all processors share to pay attention to an information or a process. The Figure 2 illustrates the MHP components and the Figure 3 illustrates the information processing process with the addition of the attention resource.

The model has three memory components: sensory memory (SM), long-term memory (LTM), and working memory (WM). These are structures and processes involved in the storage and subsequent retrieval of information. Memory-related processes involve three stages: encoding, storage, and retrieval. As there is no consensus regarding the modality of such memory components [32], it is not clear whether these are different systems or only represent different levels of information processing inside the same system.

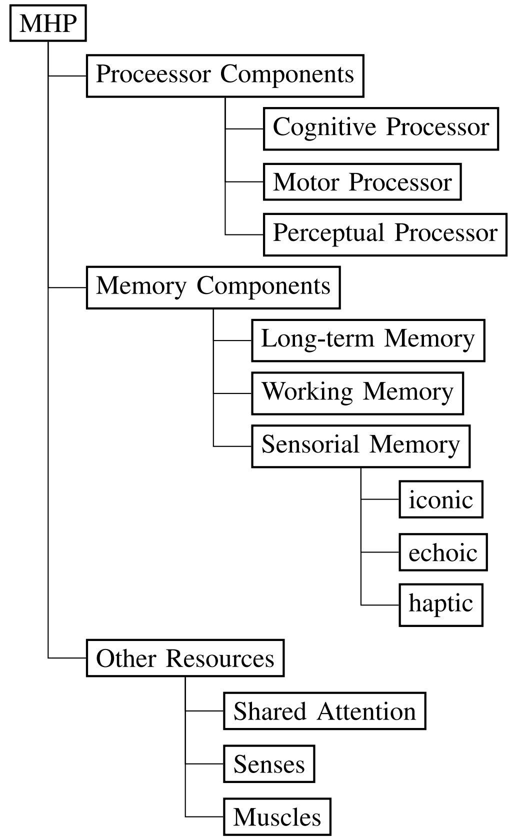


Fig. 2. MHP components

The MHP also has three processor components: perceptual processor (PP), cognitive processor (CP), and motor processor (MP). In addition, it comprises a shared attention resource, sensors for perception, and muscles to act on the external environment.

Any input from sensors is first stored in the SM. It works like a relatively automatic frame buffer for stimuli received through the human senses with limited capacity. There are three main types of SM: iconic, echoic, and haptic. These are exclusive storages for visual, auditory, and tactile information, respectively. Each of them has a particular decay speed, in which information is lost. For instance, the iconic short-term sensory memory holds information for about 250ms, with variations depending on a person's age [33].

While much information stored in the SM is lost, those ones that receive attention are processed by the PP, which uses information from the LTM to recognize symbols in it: letters, syllables, words, phonemes, icons, among others. This processor codes information in SM in cycles of about 100ms each [34]. The coded information is then stored in the WM.

The term *working memory* is sometimes considered a synonym of short-term memory, although it refers to the structures and processes used for the temporary storage and manipulation of information, of which short-term memory is just one component [32]. Most adults can store between 5 and 9 items in their working memory. Miller [35] put this idea

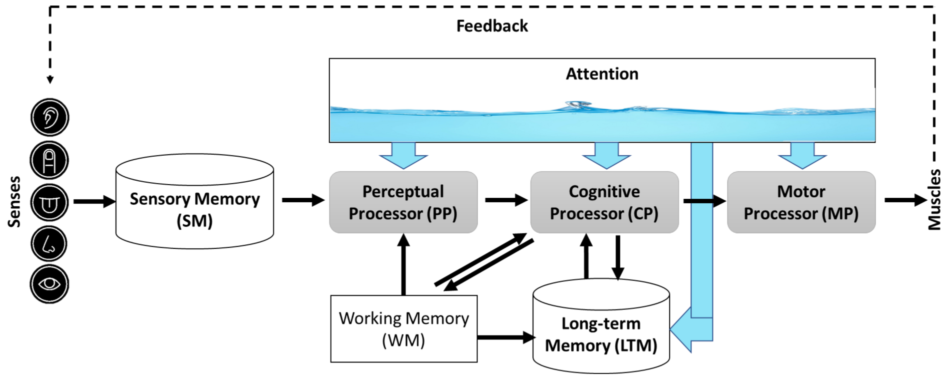


Fig. 3. Components of MHP with an attention resource.

forward and called it the magic number 7 (+-2). However, he did not explore the amount of information that can be stored in each item. The decay time of information in the WM is less than one minute [36].

The CP takes the symbols identified by the PP and performs more complex processes, such as comparisons, reasoning, and decisions. During these processes, it can also store new symbols in the WM.

According to the Atkinson-Shiffrin memory model [37], when information is being attended to in the WM, it automatically transfers to the LTM. The latter is thought to be unlimited and the information is stored in it by association.

When the CP defines it is necessary to act on the external environment, it activates the MP, which instructs the muscles to execute it. There is an implicit loop feedback here in which the sensors gather information from this action and follow the same processes mentioned above to make any corrections.

## III. The Colab4All Framework

This section presents the Colab4All (Collaboration for All), a framework we created to orient research, to derive collaborative models, and to define requirements for technology that supports collaborative activities involving people with impairments.

In summary, based on relations defined among collaboration and MHP components, the Colab4All defines guiding questions to support the identification of possible challenges that may arise from the participation of a person with an impairment into a collaborative activity. Subsequently, considering the answers for the guiding questions, the framework suggests aspects that must be further investigated.

### A. Preliminary Assumptions

In order to develop the framework, we made some preliminary assumptions, described next. Firstly, we consider that an activity (non-atomic execution) can be split into subactivities (non-atomic executions), which can be split into tasks (atomic executions). A task may be categorized into two groups regarding its interdependence with other tasks: procedural and non-procedural. Procedural tasks are those that must be performed in a specific sequence to be accomplished properly. There are two types of procedural tasks: (i) fixed sequence tasks, which must be executed in a non-variable sequence; and (ii) variable sequence tasks, which represent alternative paths that may be taken in order to complete an activity. Non-procedural tasks are those in which the order of completion is not necessarily specified.

Secondly, we consider that a collaborative activity comprehends the communication, cooperation, coordination, and awareness components, as described in the 3C model [20].

Thirdly, as mentioned in the introduction, we do not use the MHP to calculate lower and upper performance bounds because of the difficulty of defining an average person, mainly because we consider people with impairments. We use the MHP to identify possible challenges in tasks and to recommend ways to address these challenges.

Finally, one can use both information about impairments and disabilities when applying the Colab4All. While information about impairments generally considers abnormalities of psychological, physiological or anatomical structures, or functions, information available about disabilities is generally presented regarding any restriction or lack (resulting from an impairment) of ability to perform tasks.

### B. Relationship Among Collaboration and Processing Components

We started the definition of the Colab4All by establishing the relationship among collaboration and processing components. Additionally, we analyzed how some impairments can influence these components and what questions must be made by a researcher in the field.

*1) Communication:* The communication process comprehends three components: a message, a channel, and a common code; and two entities: a sender and a receiver, as shown in Figure 4. Many researchers studied the communication process in terms of its relation to processing components [38], [39].

All processing components are important for communication [39]. In order to produce a valid message, the senders' cognitive processor must be able to (i) retrieve information from the long-term memory - the message content, code, and its rules -, a process that involves using the working memory; (ii) organize the content and encode it properly.

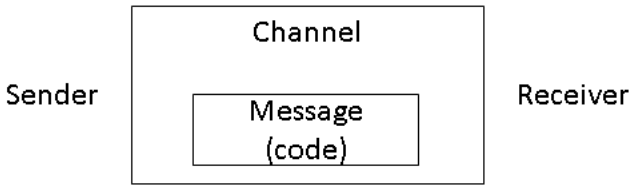


Fig. 4. A representation of communication's components

Furthermore, it must send orders to the motor processor so that it coordinates the muscles related to the communication channel. Analogously, in order to understand a message received, the receiver's perceptual processor must be able to access the sensory memory, retrieve information from the long-term memory (previous knowledge, the code, and its rules), decode it, and send it to the cognitive processor. Subsequently, the receiver's cognitive processor must be able to organize and store the information, at least during the time it will be required to perform the activity. The working memory is used in this process.

Considering these processes, it is possible to identify some challenges that may arise if someone with an impairment is taking part of a collaborative activity. These challenges may be explored through the guiding questions in Table I.

TABLE I
COMMUNICATION-RELATED GUIDING QUESTIONS AND CONSIDERATIONS.

| |
|---|
| - Are participants able to learn the code used during a task? |
| - Are participants able to encode messages properly? |
| - Can participants send a message through the commonly used communication channel? |
| - Can participants receive a message through the commonly used sensor? |
| - Is the knowledge required to learn the code and to construct a valid message available to all participants? |

If one or more of these challenges are identified, the following aspects must be studied:

- If a participant is not able to learn the code:
  - May the code be simplified?
  - Are the tools and method used to teach the code appropriate?
  - Are there other codes that may be used (e.g. gestures in replacement for words)? If yes, are these codes sufficient to transmit the message?
- If a participant is not able to encode messages properly :
  - Can the messages produced by the participant (using a different code) be understood by others?
- If the channel/sensor cannot be used by the participant:
  - Are there other channels/sensors that may be used in order to replace or to be used in parallel to the commonly used?
  - What code can be used in such channel/sensor?
  - Is the code computational equivalent to the existing one? If not, what is the impact of the absence of computational equivalence?
- If the knowledge required to learn the code and construct a valid message is not available to participants:
  - May this knowledge be constructed during the time available before the activity?
  - Is it possible to use a different code?

*2) Coordination:* Coordination comprehends the definition, understanding and processing of a set of rules, which are generally defined and agreed by the participants, and may be implicit within the activity context. A lecture, for example, has some implicit rules regarding the moments in which learners can make questions and interact with others. The rules may be defined prior to the activity or be created during the activity, in response to what participants consider appropriate to do. All MHP components play an important role in coordination.

First, in order to understand a set of coordination rules, an individual must follow the process of receiving a message. The received message must be properly stored in the long term memory, which will naturally happens if the individual pays attention to the rules temporarily stored in the working memory. Considering the rules are available, the coordination process comprehends communication cycles that strongly use the cognitive processor. Each information received by the individual must be used to create a scenario. As an example, during a lecture, when an educator looks at a learner and makes her a question, it must be perceived as an indicator that the learner must answer the question in sequence. To do that, in addition to the communication process, an individual must constantly use its cognitive processor to verify if the scenario corresponds to a set of rules. In the presented example, the results of such processing may result in an activation of the motor processor and the muscles to answer the question or to stop answering if an interruption happens.

Given that, in addition to what was discussed about the communication process, the guiding questions presented in Table II may help one to identify challenges that may arise from the participation of a person with an impairment into a collaborative activity.

TABLE II
COORDINATION-RELATED GUIDING QUESTIONS AND CONSIDERATIONS.

| |
|---|
| - Is the participant able to process and memorize a set of coordination rules? |
| - Does the participant have the cognitive skills required to relate the collaborative activity context to the rules? |
| - Is the participant able to follow known rules? |

If one or more of these challenges are identified, the following aspects must be studied:

- If the participant is not able to process/memorize rules or does not have the cognitive skills required to relate the context and the rules:
  - Is it possible to continuously inform the participant about the rules at the moment they are necessary?
- If a participant does not have the cognitive skills required to relate the collaborative activity context to the rules:

  - May a tool or a person be used to inform the participant about that?
- If the participant is not able to follow known rules:
  - Investigate how the participant deviation from the expected behavior harms the collaborative activity.

Individuals with frontal Traumatic Brain Injury (TBI), for instance, may be impulsive and have difficulties following rules due to a damage on the cognitive processor. In order to include an individual with such impairment in a collaborative setting, it is important to study what kind of behavior deviations happen and if they make her participation unfeasible.

*3) Cooperation:* The cooperation process depends on the type of activity being conducted. It can require: fine motor skills, such as for threading a needle; fast sensory response, as for playing a game; great memory capacity, as for remembering large lists of commands and instructions; great cognitive processing capacity, as for understanding a model and editing it. Consequently, the dependence among collaboration and MHP components also varies.

However, we suggest a researcher to analyze aspects related to each of the MHP component, such as:

- What sensors are used by the activity?
- How many sources of information must a participant deal with?
- How many items must be stored in the working memory for specific tasks?
- May the number of information sources and the items that must be stored in the working memory overload the participant?
- What cognitive skills are required?
- What information must be stored/recovered from the long term memory?
- What are the muscles required to act during the activity?

*4) Awareness:* The awareness processes comprehends a continuous analysis of sensory information in order to identify what others are doing, what is the current status of the object and how did it come to the current status, if the artifact been correctly used during the activity, among others.

In order to process awareness information, in addition to what it was presented to the communication process, the participant's cognitive processor must be able to: (i) retrieve information from the long-term memory - the activity steps and the different states in which the object or artifact may be and what the associated meaning is - a process that involves using the working memory; (ii) relate the information gathered about the activity state with the work being done and react properly.

The dependence among awareness and MHP components varies depending on the activity. However, we suggest a researcher to make the following questions:

- The information about the activity state and what participants are doing are available through sensors and channels that all participants can use?
- The awareness information together with other information sources may overload participants?

### *C. Activity Context, Tasks, and Participants*

After understanding how collaboration components depends on processing components, it is necessary to define for a specific activity what tasks compose it and how these tasks depend on collaboration components.

The challenges posed by participants' impairments on collaborative activities occur on the task level. If all tasks are successfully conducted and chained, it is expected that the related activity is successfully conducted. While it does not mean that the activity reached its goals, since it may depend on external factors, the activity success is an important metric under control.

As the tasks that compose an activity are determined by its goals, it is initially important to define and analyze the activity context. Also, it is important to decompose the activity into its constituent tasks and to identify participants and their profile. While the activity goals and context are known beforehand, its decomposition into tasks may not be straightforward.

A variety of information sources are useful for identifying tasks, such as: (i) existing documentation and training materials; (ii) task observation records and description, among others. Among the techniques that can be used to decompose an activity in tasks are: Hierarchical Task Analysis (HTA) [40] and GOMS [41]. After using these techniques, the tasks can be described using a task diagram, representing the tasks and their relationships.

In parallel to decompose an activity into tasks, it is necessary to identify the skills and knowledge required to support tasks execution and to document it.

After identifying that information, it is important to establish existing dependencies among tasks, sensors, muscles, memories, and processors. We suggest the use of three tables to establish these dependencies. Table III is the first table and it establishes the dependencies between perceptual and collaboration components, specifying what kind of information is required to be obtained in order to conduct the task. For instance, this table can be used to identify possible information overload while performing the task.

TABLE III
PERCEPTION VS. COLLABORATION COMPONENTS

| | Sight | Hearing | Touch | Smell | Taste | Proprioception |
|---|---|---|---|---|---|---|
| Communication | | | | | | |
| Coordination | | | | | | |
| Cooperation | | | | | | |
| Awareness | | | | | | |

Table IV is the second table and it establishes what type of memory is dominant in a task.

TABLE IV
TYPE OF MEMORY THAT IS DOMINANT IN A TASK

| | Dominant |
|---|---|
| Sensor Memory | |
| Working Memory | |
| Long-Term Memory | |

Finally, Table V is the third table and it establishes how each processor is used in the task.

TABLE V
HOW EACH PROCESSOR IS USED

| | Use | |
|---|---|---|
| Perceptual Processor | | |
| Cognitive Processor | | |
| Motor Processor | | |

### *D. Analyzing What Impacts May an Individual Impairment Have*

After relating collaboration and processing components, and analyzing the activity context, tasks, and participants, one can define which tasks can be affected by the impairment.

The tables defined in the last step may be used to identify which tasks will be affected by the impairment. In order to do that, it is important to identify how the impairment can impact each human sense, memory, and processor. Based on this information, one can analyze how the impairment may impact each task considering the task requirements defined in the tables.

After identifying possible problems, the questions proposed in the section *Relationship Among Collaboration and Processing Components* may help finding or proposing solutions to the problems.

## IV. APPLICATION OF COLAB4ALL TO THE INCLUSION OF LEARNERS WITH BLINDNESS ON E-LEARNING LECTURES

A couple of years ago, a student with total blindness enrolled in a Software Engineering course taught by one of the authors at a private university in Brazil. This course used the UML - Unified Modeling Language [42] to present object-oriented analysis and design concepts and practices. Some of the course activities were conducted with spatial distance among the participants (e.g. e-learning lectures). The distance among participants created additional challenges for student inclusion because tools such as objects and raised graphs could not be used. This experience motivated us to research and develop technologies to include individuals with blindness in such a collaborative setting.

As we have not found a guide, a method nor a framework to orient the research and development, the identification of the aspects that had to be explored were based on our experience and on the findings of similar studies. After developing the Colab4All, we used it to study an activity conducted during such type of lectures. Based on our findings, we develop a tool to support model-based e-learning lectures and tested with in a series of user studies. The results were promising.

### *A. Activity Context, Tasks, and Participants*

The activity context comprehends a lecture conducted through video-conference in which the educator presents a diagram to learners with some errors. Subsequently, the educator and the learners discuss what the diagram errors are and how they can be corrected. Considering the participants' profile, there were two types of participants during the lecture when taking into consideration impairments: sighted learners and a totally blind learner.

In order to identify the tasks that compose the activity, we conducted a high-level hierarchical task analysis and identified the tasks described in Figure 5. This analysis resulted in 7 tasks.

Due to space restrictions, we will present the analysis for one of theses tasks: point at a diagram element. This task appears in the *Present the diagram* and *Interact with learners* subactivites. This task is related to a movement the educator generally does for pointing at an element in order to contextualize what will be said next. For instance, the educator can point at a diagram element and ask 'What is the error with this element?' or 'This element represents the concept X'. Tables VI, VII, and VIII were created for this task.

TABLE VI
SENSES VS. COLLABORATION COMPONENTS

| | Sight | Hearing | Touch | Smell | Taste | Proprioception |
|---|---|---|---|---|---|---|
| Communication | X | | | | | |
| Coordination | X | X | | | | |
| Cooperation | | | | | | |
| Awareness | X | | | | | |

TABLE VII
TYPE OF MEMORY DOMINANT IN A TASK

| | Dominant |
|---|---|
| Working Memory | |
| Long-Term Memory | X |

### *B. Analyzing What Impacts May an Individual Impairment Have*

On the one hand, the impairment a totally blind individual has is the inability to use the sense of sight. On the other hand, it may result in a high memory capacity [43]. Considering the perceptual-related task requirements, as shown in Table VI, it is possible to verify a high dependency on the sense of sight. Considering this, it was necessary to analyze alternatives to convey the pointing movement-related information to the individual with blindness. Among the studied possible alternatives, we decided to verify whether a tool could support it since it does not result in any extra costs, such as assistants.

Our initial idea was to simulate pointing movement through mouse clicks. In other words, when the educators clicks over a diagram element, it is communicated to the learner with visual impairment. The communication could be done through hearing or touching. Given that the technology to produce sounds is widely available and has low cost (only a speaker is needed), we designed a hearing-based solution. This solution involved synthesizing a message `The lecturer selected the element <name>` when the lecturer selected an element. In order to test this solution, we conducted 5 user tests with 3 participants each, 2 sighted and 1 blind. During these tests, an e-learning lecture on systems requirements with the UML Use Case diagrams was conducted. After the lectures, the

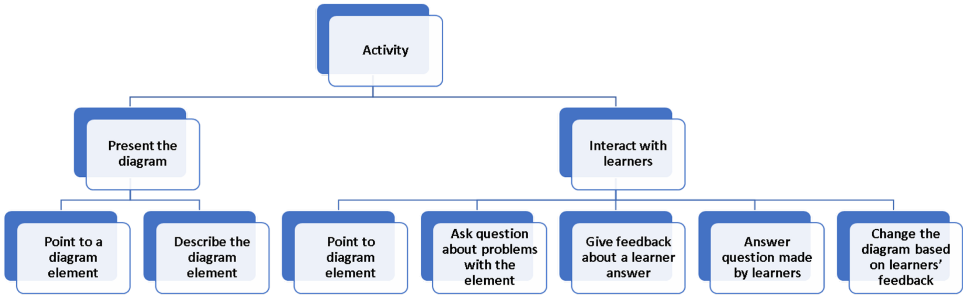


Fig. 5. High-level hierarchical task analysis of the example activity.

TABLE VIII
HOW EACH PROCESSOR IS USED

| | Use | |
|---|---|---|
| Perceptual Processor | Visual perception of the pointing movement and the blackboard | |
| Cognitive Processor | Translate the pointing direction to an element on the blackboard | |
| Motor Processor | Follow the educator with eyes | |

participants had to answer a questionnaire with questions about inclusion and the lecture content understanding. The participants with blindness answered they felt included and were able to follow the lecture content. Also, they presented similar results to sighted participants when considering learning outcomes.

While the tables VII and VIII were not used to analyze the specified task, when considering other tasks, they were useful to identify that the adopted strategy would cause overload on the working memory and perceptual processor. In fact, the participant with blindness had, at the same time, to receive and process information from different auditory sources: the screen reader synthesized messages, the software indication of pointing movements, and those related to verbal communication.

Based on this finding, we changed the system to allow participants with blindness to control how much and when they would like to received auditory feedback about what her and other participants were doing during the activity. They could, for instance, hear only a beep sound when the lecturer pointed at an element and, then, if necessary, discover which element has been selected. With this new configuration, the whole activity was successfully performed.

## V. Framework Limitations

Colab4All is not a silver bullet to the inclusion of people with impairments in collaborative activities. While it can help researchers defining what are the main aspects that must be studied when considering the inclusion of people with impairments in collaborative activities, it has some limitations. For instance, it does not provide answers nor definitive solutions. It provides a reference for researchers studying and analyzing such inclusion process. Doing so, it requires the usage of appropriate research methods in the subsequent steps. In other words, even if the researcher correctly uses Colab4All, a wrong choice of research methods in subsequent steps may not result in a successful inclusion process.

## VI. Conclusions and Discussion

We presented the Colab4All, a framework to foster inclusion in collaborative activities. The framework defines guiding questions that can be used to identify possible problems when people with any impairment participate into collaborative activities. Based on guiding questions' answers, the framework proposes aspects that must be investigated to verify whether and how the inclusion is possible.

The framework was successfully applied to a real setting: diagram-based e-learning lectures involving people with blindness.

While the framework is not a silver bullet to the inclusion of people with impairment in collaborative activities, it has the potential to help researchers in the field to define what are the main aspects that must be studied when considering this inclusion process.

We consider it a valuable contribution to the field.

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