Designing Social Robots as Embodied Mediators in Education: the Potential of Participatory Design *

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***Abstract*— In the last decades, robotic research and development started to aim beyond industrial applications and focus on designing social robots. In this transitional era of Robotics, some aspects of their design seem to need reconsideration, particularly the embodiment dimension. The participatory design approach has been implemented successfully in designing products and processes related to humans, with a user-centered methodology, including the stakeholders in the early design stages. This work presents two cases of participatory design implementation in social assistive robots development. In the case of the STIMEY robot, a human-like toy-sized robot for students, an extensive participatory design process took place with qualitative focus group discussion (127 stakeholders). A deductive qualitative content analysis approach led to five combinations of dimensions used to design a SAR, which could be considered general design guidelines. In the case of the DAISY robot, a flower-like robot for students with autism, the participatory design was intended to define part of the features and characteristics of the robot. The researchers decided on the rest of the design issues based on the relative educational theories. This combinational approach made it possible to quickly and thoroughly address all design issues and come up with a unique and defined final choice.**

In both cases, the evaluation of the prototype robots through a task-oriented robot-assisted learning sequence indicated that participants endorsed the final design of the robots for physical interventions. The different implementations of participatory design in the above two cases could show the adaptability and the potential of the participatory method in the design process of social robots' appearance, physical presence and embodiment.

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I. Introduction

We are in the fourth decade that robotics has been introduced and found applications in Education. Initially, robotics was proposed mainly as an educational subject [1]. Subsequently, the goals and the application areas have broadened, and educational robotics found various roles as educational tools, learning environments, and context for a multidisciplinary approach to STEM, Art, Reading, skills, etc. [2] [3]. The second significant utilization of robotics in education is the case of Socially Assistive Robots (SARs) [4]. SARs and their potential applications in the general classroom [5] and special needs education [6] have received considerable attention in the last decade. Many research cases show that SARS can fulfill the needs of both students and teachers [7] by implementing a variety of roles, like tutors, facilitators, mediators, etc. [8], [9]. The design of social robots for educational applications attracts the attention of many researchers. The complex and fuzzy nature of the social interactions makes the design process of social robots much more complicated than the design of the initially mentioned educational robots. And this becomes even more demanding since the designer has to decide the value of many variables concerning dimensions like appearance, size, behavior, personality, verbal and nonverbal expressions, voice, movements and spacial motion, ethical issues, etc. [10], [11], [12]. Meanwhile, a similar situation is underway in industrial robotics, where cooperation between humans and robots extends beyond the safety issues and demands the study of social interaction for effective and reliable collaboration [13], [14]. Observing the evolutions of robotics applications in the fields of Education and Industry, we notice a transitional era in which the robots expand their character from utility tools (e.g., learning tools or assembling tools) to collaborators with social features (e.g., learning facilitators or collaborative coworkers). In this transitional era of Robotics, some aspects of their design process seem to need reconsideration.

The Participatory Design approach [15] has been implemented successfully in designing products and processes related to humans, with a user-centered methodology, including the stakeholders and end-users in the early design stages. Indeed, from the beginning involvement of end-users and stakeholders in the design process could offer a crucial contribution to the interdisciplinary team of researchers during the "Fuzzy Front End" stage, which is the very early phase of a new product design and development [16]. The designing team needs to analyze the "what is" and empathize with the situation in that phase. The above justifies the trend and the number of works implementing the participatory design approach to develop SARs in Education [17], [18], [19].

The current work aims to present and compare two cases of participatory design implementation in social assistive robots development in Education. The first case concerns the design of a learning facilitator social robot in the role of a student's pal. The second case involves the design of a mediator social robot in the role of a student's workfellow for students with Autism Spectrum Disorders (ASD). The work focuses on physical presence, embodiment, and appearance in both cases. Although they have in common that they rely on participatory design, they differ in the scope and duration of the approach.

II. Social robot in education: a participatory design for physical presence, embodiment, and appearance.

A. Learning facilitator social robot in the role of a student's pal.

In the context of the project STIMEY (under the EU call Horizon2020), we designed and developed a learning facilitator social robot in the role of a student's pal. Initially, we conducted research in mapping the stakeholders' requirements for a SAR to be used in the typical class settings within the formal education for students between 10-18 years old. This initial research aimed to provide a set of guiding design principles for the developers. A qualitative focus group discussion took place, and the participants were 127 stakeholders from five European countries representing various affiliations in the field of education. A deductive qualitative content analysis approach revealed 121 themes of analysis, which fitted into 11 theory-driven categories.

Additionally, 46 themes of analysis were classified under five new categories following an inductive approach. The deductive and inductive content analysis results were further exploited in two Two-Step Cluster Analyses. The analyses revealed five tentative combinations of the dimensions, which can be the basis for designing a SAR sketched by education stakeholders. Concerning the issues of physical presence, embodiment, and appearance, the first analysis revealed 37 themes that were grouped into 15 subcategories under six categories as follows:

- Embodiment of the robot
  - Anthropomorphic
  - Non-anthropomorphic
  - Zoomorphic
  - Caricatured
- User modeling
  - Dynamic
- Personality
  - Tool-like
  - Artificial being
  - Non-artificial being
- Dialogue
  - Natural language
- Human-oriented perception
- User-friendly
  - Size and weight of the SAR
  - Movement
  - Aesthetics of the SAR
  - Material for the construction of the SAR

Almost all of the above categories are identified from or related to the existing taxonomies [20], [4], in a way of validating the analysis results.

The most popular category, the "Embodiment" of the robot, focuses on themes that describe the physical body and the robot's resemblance with other beings such as humans, non-humans, animals, or toys, having as most cited subcategory the humanoid attributes body.

The second more prevalent category, "User Modelling," considered the robot's appearance as something that can be changed, customized, and adapted to end-users needs, tastes, and suggestions.

An extensive portion of the appearance themes were all classified into the same category "User-friendly". The appearance can be perceived as user-friendly when the end-user finds it appealing, mindful of end-users needs and wishes, or intuitive since it can make sense to the average end-user. Thus, the category "User-friendly" does not refer to features that support the functionality of the SAR but to the functional result of the appearance.

The previous qualitative analysis of the texts the stakeholders produced led to the categories (dimensions) the stakeholders consider crucial for the topic. At the same time, the subcategories are the properties of these dimensions. Although the list of the values that the stakeholders assign to the properties is helpful for the developers, they do not provide an idea of how to combine the features in the design process and build a SAR that will meet the stakeholders' requirements. For this reason, we applied two Two-Step Cluster Analyses to our data to reveal tentative combinations of the dimensions for the type of SAR sketched by the stakeholders. We decided to define firstly the roles the stakeholders wish for the SAR and then examine the appearance and embodiment features that they combine to fulfill their expectations for each role. So, the first analysis yielded five clusters, which serve as the five types of roles, that SARs have in education. The second analysis defined the potential combinations of the embodiment and appearance features the stakeholders perceive for each role. Based on the derived combinations, the study concluded and provided the developers with a set of general and specific guiding design principles for developing a SAR to be used in educational settings.

The STIMEY SARA prototype (*Fig. 1*) was developed based on the above-mentioned guidelines. STIMEY SARA is a SAR for Science Technology Engineering and Mathematics (STEM) education. An evaluation of the prototype robot was conducted through a STEM-oriented robot-assisted collaborative teaching-learning sequence [21]. The participated students evaluated the innovative SAR very positively and much higher than the chance level.

Figure 1. The STIMEY SARA robot

B. Mediator social robot in the role of a student's workfellow for students with ASD.

Studies in different contexts show that interventions with SARs could help children with Autism Spectrum Disorders engage in collaborative activities and develop communication skills, body awareness, empathy, etc. [22], [23], [24]. According to the Diagnostic and Statistical Manual of Mental Disorders [25] the diagnostic criteria of ASD are: Persistent deficits in social communication and social interaction across multiple contexts, as manifested by

- Deficits in social-emotional reciprocity,
- Deficits in nonverbal communicative behaviors used for social interaction,
- Deficits in developing, maintaining, and understanding relationships

People with ASD face difficulties in coping with their environment [26]. The stimuli they receive from their environment may be over received as they have high sensitivity to sounds and often in too bright colors and lights. They usually feel annoyed by touches and sometimes receive proximity as an intrusion into their personal space. The vast majority of the people with ASD experience stimuli overload situations and face deficits in sensory processing [27]. Under these circumstances, the embodied character of a SAR, its physical presence, and the haptic/sensory interaction seem to have a vital role in the human-robot interaction in the context of ASD educational interventions.

According to the literature and concerning the appearance and the embodiment, one of the cases in which a robot aimed at children with ASD could be considered appropriate is when it is in the form of a cartoon or animal, but with human speech and expression characteristics [28], [29]. Given this fact, it was decided to create a robot, which will have the shape of a flower with a face, to perform expressions and speech. The choice of the flower was reinforced by the fact that it is a familiar form to all children. On the other hand, the use of human characteristics of the flower utilizes animism - anthropomorphism, a key feature of early childhood (Dennis, 1938). In addition, the flower shape was considered more appropriate than an animal to avoid any connections with possible previous negative experiences that a child may have from a pet.

Aiming to design and develop a robot able to motivate children with ASD to participate in joint activities with their peers and enhance their social skills, we decided to follow a combination of the participatory design approach and experts' scientific knowledge. Initially, the researchers'/experts' contribution intended to define the keystones of the design issues based on the relative ASD education theories and the bibliographic data regarding what characteristics need to have a social assistance robot. After that, the participatory design intended to define the rest features and characteristics of the robot, "the last mile of the design", based on stakeholders' experiences and needs. In this way, it was feasible to develop the design dimensions and principles in a short time and then conclude the design based on the end-users field experience and needs.

The Daisy robot has been designed and developed at the LIRES lab (laboratory of Informatic and Robotic Applications in Education and Society, University of Macedonia) to function as an embodied mediator workfellow in the case of students with ASD [30].

Daisy is a semi-autonomous robot in the shape of a flower that resembles a stuffed soft plush toy, with light blue and purple color (Fig. 2). The face of the robot has two eyes with discreet eyebrows that blink and look around and a mouth that speaks words and phrases with the lip sync technique. The robot has about 400 preinstalled verbal phrases categorized according to their meaning (e.g., greetings, acquaintance, routine, emotions, numbers, colors, rewards, games, etc.). Through speech-to-text recognition techniques, any other desired expression can be incorporated. The eyes and mouth can form many facial expressions, like happiness, questions, waiting, embarrassment, laughter, shame, etc. The robot performs sequences of movements and facial expressions and can be controlled remotely by a mobile app via a wifi connection.

An evaluation of the prototype was contacted in two phases. In the first phase, experts implemented a) cognitive walkthrough method [31] and b) heuristic evaluation [32] to evaluate the use of the Daisy robot through the implementation of a task list and to propose necessary improvements. The proposed improvements concerned a) the operation of the robot b) the educational exploitation of the robot and c) the appearance and the embodiment of the robot. In the second phase, stakeholders (six teachers, ten students with ASD and five students with typical development) evaluated the Daisy robot through pilot implementation of educational activities. In all the pilot implementation cases, the children showed enthusiasm and interest in interaction during their first contact with the robot Daisy. They mobilized to engage in dialogue and physical contact with it (e.g., to touch it, pet it, hug it, touch it to their face, etc.) (Fig. 3 and Fig. 4). The physical presence and embodiment of the

Daisy seemed to be an important factor both in creating the initial motivation to start the communication and in the rich interaction afterward since it was not limited only to verbal and visual communication but also strongly to physical interaction. Also, the use of the Daisy in research work that was carried out afterward showed that the body and its shape worked positively in the implementation of educational, including actions and improvement of social skills [9], [30], [33].

Figure 2. The Daisy robot

III. DISCUSSION AND CONCLUSIONS

Although physical activities are not the purpose of SARs, their physical presence and embodiment play a significant role in accomplishing their mission. The embodiment and the physical presence of the SARs contribute in a variety of ways to their tasks: offer tangible interaction [34], present the information in a physical context [35], enhance the communication through non-verbal expressions [36], [37], etc. Therefore, the appearance and embodiment of the robots are an essential part of their design and, in fact, with special weight since these characteristics can manipulate a human into building the mental model of SARs' overall abilities [38]. On the other hand, the participatory design approach gives participants the roles of users, testers, and even the design partners, making it appropriate in more challenging design settings [39].

Two cases of educational SARs' design have been presented in this work and their embodiment aspects. Both cases implement a participatory design approach to bring stakeholders' experiences and need to a subject that is not defined by the experts thoroughly.

In the case of the STIMEY SARA robot, an extended inclusion of the stakeholders took part from the beginning of the design process in the form of focus groups. A deductive qualitative content analysis of the data led to five combinations of dimensions used to design a SAR, which could be considered tentative combinations of the dimensions. The further analysis defined the potential combinations of the embodiment and appearance features the stakeholders perceive for each role of the SAR. Based on the derived combinations, the study concluded and provided the developers with a set of design principles (not explicitly defined characteristics) for developing a SAR to be used in educational settings.

In the case of the DAISY robot, the participatory design was intended to define part of the features and characteristics of the robot, mainly in the second phase of the design process. Meanwhile, the researchers/experts decided firstly on the fundamental of the design issues based on the relative educational theories.

The difference between the two cases concerning the participatory design implementation of the educational SAR's appearance and embodiment regards the stage of the design process at which implemented the participatory approach and its consequences. The implementation of the participatory design that started at the very early stage of the STIMEY robot led mainly to general but extended and thorough guidelines pivotal for the developers, at the cost of a demanding and time-consuming process. On the other hand, implementing the participatory design at a later stage of the STIMEY robot design made it possible to quickly and thoroughly initially address all pedagogical design issues and come up with a unique and defined final choice. In both cases, the evaluation of the prototype robots through a task-oriented robot-assisted learning sequence indicated that stakeholders and end-users endorsed the final design.

Figure 3. The Daisy robot acceptance of embodiment (petting)

The different implementations of participatory design in the above two cases could show the adaptability and the potential of the participatory method in the design process of SARs' appearance, physical presence and embodiment. On the other hand, it became apparent that the participants' lack of previous experience and familiarity with social robots did not allow them to present a complete and detailed view of the SARs' in education and contribute it at the beginning of the design process. This led either to a general but extended and thorough pattern of design principles or to the need for initial intervention by experts, which could be interpreted as reflecting the state and characteristics of the transitional robotic era we are going through.

Figure 4. The Daisy robot acceptance of embodiment (hugging)

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