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SPECIAL SECTION ON TRENDS, PERSPECTIVES AND PROSPECTS OF MACHINE LEARNING APPLIED TO BIOMEDICAL SYSTEMS IN INTERNET OF MEDICAL THINGS

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Developing a Software That Supports the Improvement of the Theory of Mind in Children With Autism Spectrum Disorder

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ABSTRACT The autism spectrum disorder (ASD) is a neurodevelopment disorder that affects areas related to social skills, such as social interaction, communication, planning everyday activities, imagination, and creativity, in a permanent way and since early ages. These skills are very important for everyday routine and should be developed to improve the life quality and integrate people with such disorders in the workplace. Nowadays, there are several applications that were developed to support children with ASD. However, most of those applications were developed in other languages or are aimed at different social contexts. Some of them are simply outdated. Due to the mentioned factors, an application for mobile devices was developed, aimed at supporting professionals that intend to develop skills related to empathy based on the mind theory, in children diagnosed with ASD. In the tests with experts, it was possible to obtain an adequate application both in terms of content and usability for them, allowing the user to feel comfortable with the application and that this can be integrated into their activities without problems. Using the usability tests, the results show that both the users managed to complete the tasks with some time differences. The application was validated by performing several tests with experts and final users with promising results.

INDEX TERMS Autism spectrum disorders, mobile application, special needs, theory of mind, usability, education.

I. INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurological developmental disorder that presents as a lifelong condition in an individual [1]. Abnormalities in the comprehension of an individual's own actions or the intentions of other people is not the only psychological characteristic shared by people with ASD, although it does seem to be a universal anomaly in these individuals [2]. Some people diagnosed with ASD lack almost all of the signs of theory of mind (ToM), which is the ability to infer within mental states (beliefs, desires, intentions, imagination, emotions, etc.) [2]. More commonly, people with ASD present some basic concepts of the theory of mind, but possess some difficulty in applying it to activities of daily life [3].

The Centers for Disease Control and Prevention (CDC), in terms of prevalence, estimate that 1 in 59 individuals present with ASD, this number increasing by 15 percent with respect to previous years. This prevalence makes ASD more common than infantile cancer, juvenile diabetes, and pediatric AIDS combined [4].

Technology is already beginning to change the lives of many people with ASD [5]. Computers can help to compensate verbal problems and problems related to interaction and can facilitate exchanges between people with ASD, experts, and others [6]. New forms of communication are permitted, along with new forms of socialization, in addition to learning and employment options [7]–[10]. As seen in [11], a platform was developed for users with ASD, in which a new

interface colored with the help of audio was presented in order to aid users while learning. Furthermore, in [12] presents a game created to aid small children within the autism spectrum to practice their social communication skills. In [13] is presented a tablet-based system that offers successful views of traditional PECS while incorporating a display support and voice advantage. This system improves portability, small tasks, file format, and image capturing. In [14], the creators elaborate a program whose objective is to teach and train children's skills to regulate the emotions of other people through interactions simulated between the user and a virtual agent. Furthermore, in [15] is presented an application that functions to aid the development of empathy in children with ASD.

Due to the studies previously mentioned, it is shown that technology can be of great assistance in the development of different skills of people with ASD [16]–[18]. The majority of the applications that exist are directed at users that do not speak Spanish. This presents a disadvantage for the Spanish-speaking user, given that the foreign applications are situated in a different context from the one encountered in Latin America.

Due to the aforementioned, this work presents the development of a support application for social skills in children with ASD. The proposed solution was developed for low-cost multi-touch devices, and furthermore focuses on ToM. The contribution of the development of this project is to create an application that is intended to be used as a support for the development of social skills in children with ASD, putting emphasis on activities that will empower the ToM of the human being, this is mainly to help the child to empathize and know what to do in the case of being presented with a real-life situation. Currently, there is a shortage of tools in the area of information technologies that serve as support to the promotion of social skills in people with TEA that speak Spanish. This assertion is due mainly to existing tools having been developed for different enivronments outside of the Latin American context. This application will be directed, principally, to Latin American users. All of this will be focused on multi-touch devices because these are easy to use and are found in large quantities within the population.

For validation, this project worked with professionals associated with ASD, as well as with children with ASD. In order to verify that the application created would be of utility for professionals within ASD as well as with children presenting with ASD, various tests were realized that include direct tests of the system as well as tests that looked at the interaction of children with ASD using the application. In addition, usability testing will be done with non-national users to determine the efficiency and effectiveness of the application's use in education. Developing applications that support education is of paramount importance in order to help users with TEA to interact with the people around them. The proposed solution is available for free in Google Play and currently has been downloaded around 5,000 times.

The rest of the article is organized in the following way: In section II, we analyzed the methodology of the application design. Section III describes the proposed solution. In section IV, we present a preliminary evaluation, followed section V, which presents usability tests and, finally, section VI present conclusions and future work.

II. METHODOLOGY

In past contributions we have utilized the User Centered Design as the work methodology for the development of the software [15], [19]. This type of methodology makes the user the center of all of the design decisions.The systematic approach to addressing this problem is the user-centered design methodology, also known as User-centered design (UCD). The UCD is defined as a philosophy that places the user at the center of the design process, taking into account the characteristics, needs, and desires of the people who will use these products. Its main strategy is the use of techniques and research methods aimed at bringing the user to the center of the design process. This is done with the aim of creating products that are appropriate and useful, taking into account good practices that assure usability. UCD is derived from the field of human-computer interaction as a methodology for developers and designers, generating software and hardware that adequately satisfies the needs of users. The principles of UCD are: 1) early focus on users and their tasks, 2) evaluation and measurement of the use of the product, 3) interactive design [10]. Figure 1 presents, in general terms, how this problem was approached with the defined methodology.

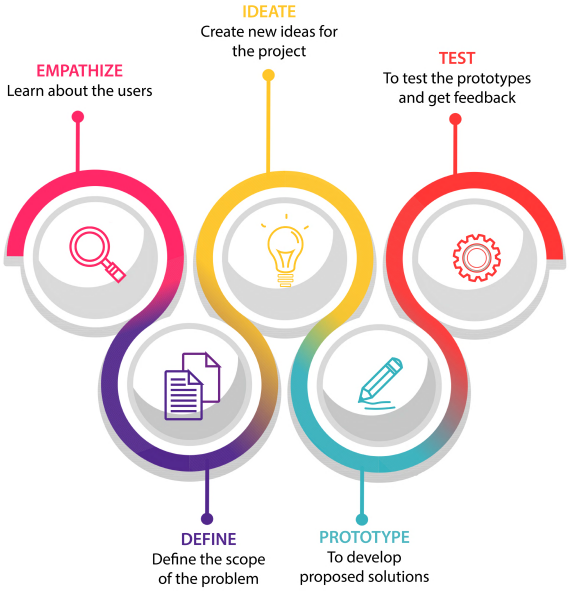

FIGURE 1. Work methodology.

In particular, the empathy stage corresponded to learning about the user. For this, a communication center was visited for 7 months for 3-5 per week. The center was working with children, aged 5 to 12, diagnosed with autism spectrum disorders. It should be noted that before the visits, parents

had to sign an informed consent and the children a consent adapted with pictograms; this was done to facilitate their understanding. This was the first stage to get to know the user, his or her way of working, and the way he or she empathizes with other classmates. In addition to knowing the time you need for each of your activities, see your preferences and learning methods. Since you learned everything you need from our target user, you continue with the next step. Furthermore, in the definition stage, a starting point was established based on the needs of the user. With this approach, it was determined, as a whole with a group of ASD professionals, to focus on empathy, in particular empathy associated with ToM. With the support of professionals we were able to define the way in which the children with TEA interacted with their environment. In this stage, participatory and non-participatory observations were made, which aimed to obtain a greater amount of information about the environment in which the problem was to be addressed. These observations allowed us to make the first drafts of interfaces of the proposed application. Later, they were modified through feedback generated by the school's professionals and the co-reference teacher. In this way we were able to better assess the needs of the system so that it could adequately support the work of the professionals employed in it. For the invention stage, we generated, together, creative ideas for how the solution could be developed; in particular, those ideas supported by technology. For this stage the learning process of each child was reviewed with the support of pictograms. Through observation, the support staff was asked to indicate how the current process of teaching emotions to children with autism works, as well as to demonstrate the use of available technology; this helped to devise what would be the best solution. Then, for the prototype stage, prototypes were generated on paper, like Digital [20]. Paper prototypes are representations of the system, where not all the elements of the application are detailed, but rather the key elements are represented. Paper prototyping highlights cost-effective usability testing techniques that produce quick results to improve the design of an interface. An example of the process is shown in Figure 2. The figure shows the initial prototype, worked prototype, and final prototype. The initial prototype shows the initial design of each of the activities defined in the previous stage. In the worked prototype this is the basis in which the initial prototype were reviewed by the experts and approved for development. And the final prototype shows how the application for mobile devices will be developed.An example of the process is shown in Figure 2.

These prototypes, the initial as well as the final ones, were evaluated in an iterative manner with professionals associated with ASD in the Testing stage. R9: During the testing stage, certain evaluations were carried out in which the users played a key role. Both in end-user testing and expert testing, in the detection of errors in activities or problems with the concepts used. This allowed a new iteration of the system, modifying the aspects to be treated in order to obtain a better application. Thanks to these tests, observations were obtained in terms

FIGURE 2. Process of final paper prototypes.

of improvements to be made. It could also be seen that, in general, the application can be used as a tool to support the development of skills related to Theory of the mind.

III. PROPOSED SOLUTION

The proposed solution is composed of 5 levels, each level consisting of 3 - 5 activities. These activities are associated with Feelings (5), Emotions (5), Intentions (4), Inferences (5), and Beliefs (3). The Senses activity presents activity. In that of emotions, activities are presented related to the recognition of emotions through situations through images. Intentions are presented activities related to intentions through images. In Inferences, activities are related to inferring what is happening in a situation through images. In Beliefs, activities related to daily situations are presented through images. Furthermore, according to the request of various professionals within the ASD field, the proposed application has an evaluation section, which is expected to be of support to the specialist. This section allows the user to keep track of application usage and performance. Finally, a complete navigation scheme of the developed application is presented in Figure 3.

In the first level it is possible to view the main interface, as well as the acknowledgements section. In the second level are contained the 5 working levels. Furthermore, in the first level one can see a general overview of each level in detail. In the second level are found the tutorials for each stage. Beginning at the fourth level are the activities. Finally, it is important to mention that in the case that the child makes an error, he or she will be prompted to try again, and in the case that this new attempt is correct, he or she will be congratulated; this is shown in Figure 4.

IV. PRELIMINARY EVALUATION

The preliminary evaluation was carried out in terms of obtaining relevant feedback for further disclosure. For this, work was carried out at a communication school in Chile. As mentioned in Section II, according to the recommendations of the World Health Organization (WHO), those involved who participated in the study had signed a assent and their parents a consent. The application was used by (3) experts with over

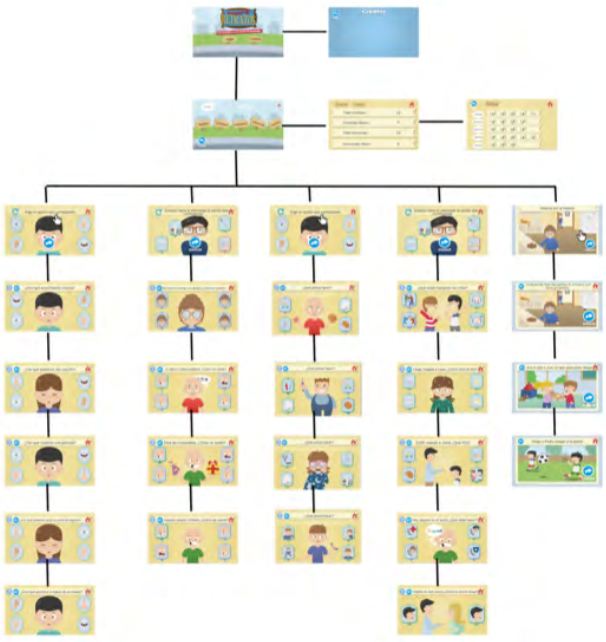

FIGURE 3. Navigation scheme proyect@ retratos.

FIGURE 4. Positive reinforcements proyect@ retratos.

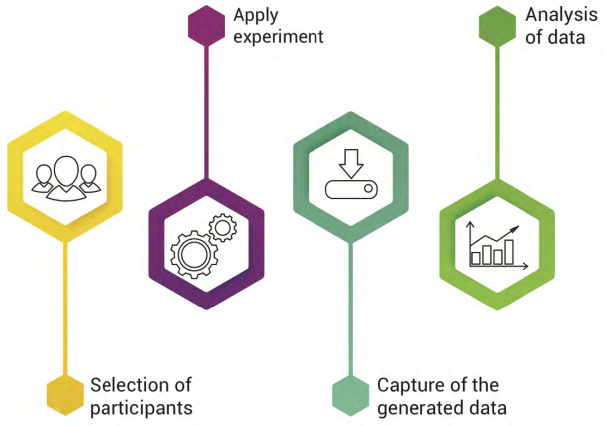

FIGURE 5. Evaluation methodology.

6 years of experience. Furthermore, when the observations given by the experts were provided, we proceeded to evaluate the application with children with ASD. The application was assessed with a total of 15 children between 7 and 10 years of age. Group 1 consisted of 5 children at Level 1 (G1), Group 2 (G2), by 6 Children at level 1, and in Group 3 (G3), 4 children at Level 2. An scheme of the evaluation procedure is show in Figure 5.

TABLE 1. Time used on the test by group.

		G1	G2	G3
	Expected	1.0 min		
Senses	min	1.0 min	0.4 min	0.5 min
	max	2.3 min	1.0 min	1.3 min
	prom	1.3 min	0.5 min	1.2 min
	Expected	1.0 min		
Emotions	min	1.0 min	0.4 min	1.2 min
	max	2.2 min	3.2 min	3.0 min
	prom	1.4 min	1.3 min	2.0 min
	Expected	1.5 min		
Intentions	min	0.4 min	0.3 min	0.4 min
	max	2.0 min	1.0 min	1.4 min
	prom	1.1 min	0.4 min	1.0 min
	Expected	1.5 min		
Inferences	min	1.0 min	1.0 min	0.5 min
	max	1.4 min	1.4 min	2.5 min
	prom	1.2 min	1.1 min	1.4 min
	Expected	1.5 min		
Beliefs	min	2.4 min	1.5 min	1.5 min
	max	4.5 min	2.4 min	10.1 min
	prom	3.2 min	1.5 min	4.2 min

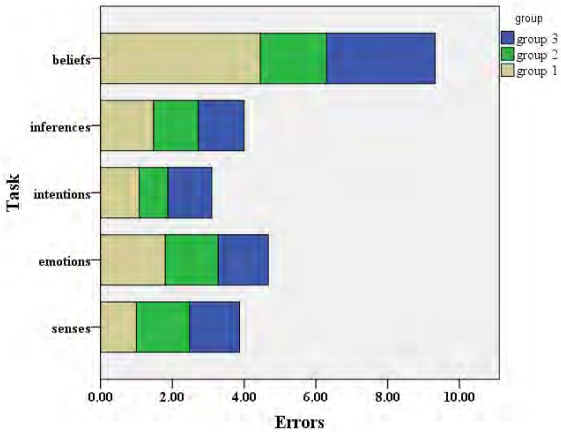

FIGURE 6. Quantity of errors per game.

The time in which users took to complete a specific task is shown in Table 1, where the used is subtracted from the expected time.

An important aspect to mention is that, according DSM-5, ASD Level 1 require lower aid and Level 3 require greater aid. Furthermore, in Levels 1 and 2, among skills to promote, the recognition of emotions is relevant.

Next, in Figure 6, are shown the errors committed by each group:

Taking the data obtained in the tests, which were performed on a 7-inch Tablet, the following observations were obtained that relate to both the activities and to the interactivity between users. This information is presented below.

- In the activities related to emotions, facial expressions should be slightly more defined in some cases to avoid inducing errors.
- When comparing the errors per activity of each group, it is noted that there are certain games that generate a greater number of errors, this potentially due to

increased complexity or difficulty in understanding the images.
- The activities of the last level are more complex than the previous ones, which indicates that it is focused correctly.
- There are activities in which there could be more than one correct alternative, in which case the possibility of adding these alternatives must be analyzed.

Regarding the last point, it is important to mention that children of both levels were in the process of working through a program associated with emotions and beliefs. For this reason, this may also have influenced the high number of errors.

In conclusion, a preliminary evaluation of the application's interface was performed using ocular monitoring. This was performed in order to evaluate if the interface contained any elements that distract the attention of the potential users and that the elements application are located in their expected places.

The test consists of the following steps:

- Explain what the test is about: In this step the test is explained to the person in terms of what is expected. For this test, the user is asked to use the application as desired (in the order that the user deems appropriate, to be wrong on purpose) but on the condition that the user must carry out all the activities.
- Calibrate the program in order to obtain appropriate data: This is one of the more important steps of the test, given that if the system is not well calibrated, the data obtained will not represent what the user is actually observing.
- Perform the test: In this step, the user completes the test based on the given indications.

The tests were carried out by a total of 5 children with autism in order to observe in which section of the application the users experienced difficulty. This was performed in order to verify that the elements of the difficulty area were in the correct places and that a quantity of minimal distractors were present. An eye tracking device (TheEyeTribe) in conjunction with the program Ogama [21] were used to test this. From these tests the following results were obtained, in which the heat map of the first three types of activities carried out by the users is shown. These allowed obtaining the necessary data and to be able to present the following results (see Figure 7).

In Figure 7, at the bottom, it is possible to view a heat map, which is a screenshot with a color code indicating how many looks it attracted for one of the parts. Areas close to red indicate where the users were most set. On the other hand, the green parts indicate that there was a lower grade, and the blue ones were the less visualized areas. By contrasting the top figure with the lower one, it can be empirically evidenced that the graphical elements of the proposed application provide the most relevant information for the user. This is because at the top is the indication (for those who can read), on the sides are the options (4), and in the center is

FIGURE 7. Eye tracking interface proyect@ retratos.

the image of who should attribute the expression. Preliminary evaluation were carried out with the objective of evaluating the application and seeing its functionality in terms of its use. In this way it was possible to see how the user interacted with the application and to improve some aspects and then perform usability tests and expert tests.

V. USABILITY TEST

This section describes the experiments carried out to measure the effectiveness of the use of the developed application. The description of the participants and the procedure are presented following that.

A. TEST WITH EXPERTS

The tests with experts were carried out by two professionals, both of whom possess 2 and 3 years of experience (respectively) working with children with ASD. The tests were developed as such: a list of tasks to be carried out in the application were given to the professionals (as shown in Table 2), and analyses were obtained by said professionals that consist of points in which the application can be improved.

As for the evaluation with the experts, in Task 1 they mention that visually it is understandable where to press to start the activity and to return to the initial screen. With regard to Task 2 and 3, no difficulties were observed in entering and returning. In Task 4, they mention that in an emotions activity (of the grandmother) in the question ''How does it feel?'', a correction could be made to ''How does she feel?''. Activities 5, 6, and 7 do not present any difficulties in terms of their use.

TABLE 2. Tests with experts.

Task	Definition
Task 1: Navigate through existing menus	Load the system, press the Activity button and then return to the home menu
Task 2: Start Feelings activities and then return to the home menu	Load the Feeling activities and then press the return button
Task 3: Start Feeling activities and complete the activities	Load Feelings, complete the activities, and then return to the home menu
Task 4: Start Emotions activities and complete the activities	Load Emotions, complete the activities, and then return to the home menu
Task 5: Unlock all of the activities	Press the unlock button
Task 6: Start any activity and then return to the home menu	Load the activity and then press the return button
Task 7: Start any activity and then complete said activity	Load the activity, complete it, and then return to the home menu
Task 8: Repeat Task 7	

FIGURE 8. Interaction with the app proyect@ retratos .

The aforementioned gives us certainty that the developed application has the appropriate characteristics to be able to use it properly and without any difficulty.

Tests with experts aimed at obtaining feedback from the system in general. These tests were focused on people with experience working with children with ASD. The results show that the application is visually understandable and that experts did not notice difficulties in the design and interaction of the application.

B. TESTS WITH USERS DIAGNOSED WITH ASD

1) PARTICIPANTS

The experiment was carried out with a group consisting of 20 users diagnosed with ASD from a special education school in Tijuana, Baja California, and Mexico. The experimentation process was evaluated by ASD psychologists. The age range of the users was between 5 and 10 years of age. Of the 20 participants with ASD, 9 of them were diagnosed as autism Level 1 and 11 of them as level 2, a diagnosis made by expert psychologists.

2) PROCEDURE

In order to carry out the experiment, a group of 20 children, diagnosed as Level 1 or 2, with ASD were employed. The test was carried out individually for each of the participants in the school facilities mentioned above. In the case of the users with ASD, the instructions on the objective and the use of the application were received by the support staff (psychologists and professors) and with the help of this staff each instruction was carried out. The objective was to choose an activity and, depending on the activity chosen, the app would present a screen, as shown in Figure 8. With auditory support this screen is shown to the user, directing him or her on what to do. The user must drag one of the small images to the image in the center of the screen and with that he or she will have completed the task. This is repeated several times, indicating always what activity the user should perform.

Figure 7. Interaction with the app Proyect@ Retratos

Participants of this experiment used their index finger of their predominant hand to execute each task. A video camera is used to record the interactions of each task and activity chosen and uses the software ELAN 5.01 (professional audio and video annotation tool) to measure the time of each user that was recorded on video.

3) USABILITY METRICS

For this experiment, we considered the following usability metrics [22]:

1) Binary success. If the user did or did not complete the requested task.
2) Levels of success. This denotes the difficulty to the user. It is presented when performing the task, represented in a percentage, where 100% means total success and 0% means failure. A percentage is subtracted when, during the task, one of the following is presented:
   a) 1: No problem. The user completed the task with ease and no help.
   b) 2: Minor problem. The user completed the task but made some minor mistakes or needed a little guidance.
   c) 3: Major problems. The user completed the task but showed real signs of struggle and made several mistakes.
   d) 4: Failure. The user did not finish or gave up on completing the task.
3) Time on the task: Time it took for the user to finish the task.
4) Error rate: Number of errors that the user committed while trying to complete the task.

4) BINARY SUCCESS

After performing the usability tests, children with Level 1 ASD presented a 89% completion rate, while Level 2 presented a 45% completion rate, as shown in Figure 9.

The results show a contrast between the two groups with significant differences in the success rates among the

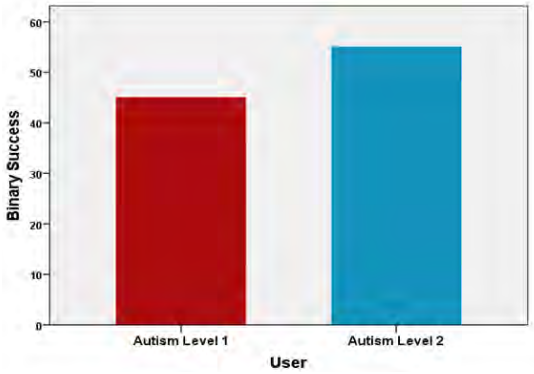

FIGURE 9. Results of binary success of Levels 1 and 2.

TABLE 3. Results of success levels.

	Full Success	Minor problem	Mayor problem	Failure
Level 1	4	5	0	0
Level 2	0	0	5	6

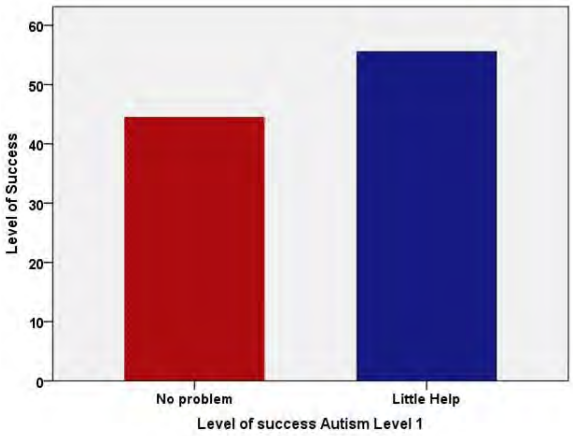

FIGURE 10. Results of binary success of Level 1.

groups.All Level 1 users completed the task while only 5 out of a total of 11 level 2 users managed to complete the task. This was not measured with time, but rather only on whether a user was able to finish the task or not.

5) LEVELS OF SUCCESS AND ERROR RATE

Although binary success gives us an overview of the amount of tasks that users were able to complete, the difficulties that the user might have posed when trying to complete a task should be considered.

Depending on the difficulty presented by the user, the moderator defined a score of levels of success, previously defined in section C, which affects the percentage of completion of the task, as shown in Figure 10 and 11.

The error rate, as presented in Figure 12 and Figure 13, was taken as the sum of the number of errors of all the participants of each group per task.

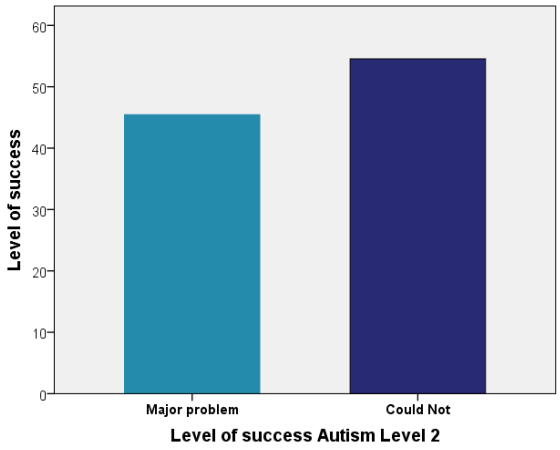

FIGURE 11. Results of binary success of Level 2.

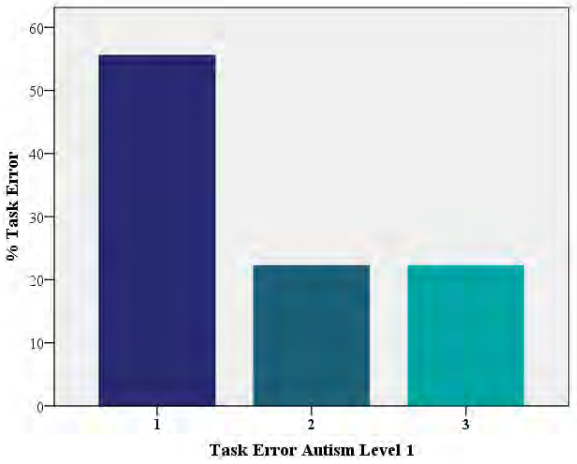

FIGURE 12. Task error ASD level 1.

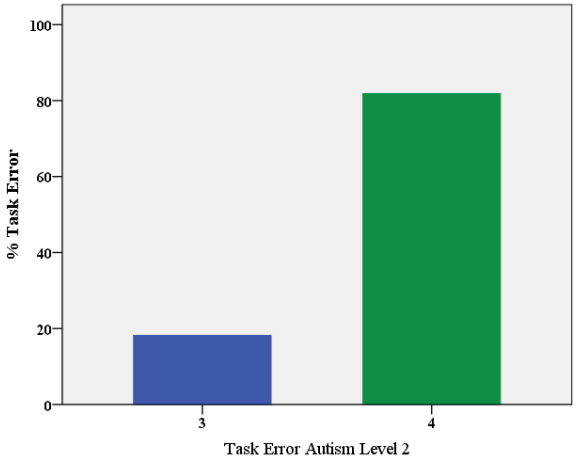

FIGURE 13. Task error ASD level 2.

6) TIME TAKEN PER TASK

The task execution time was only considered for the participants who performed the task and the average calculated based on those results, as shown in Figure 14.

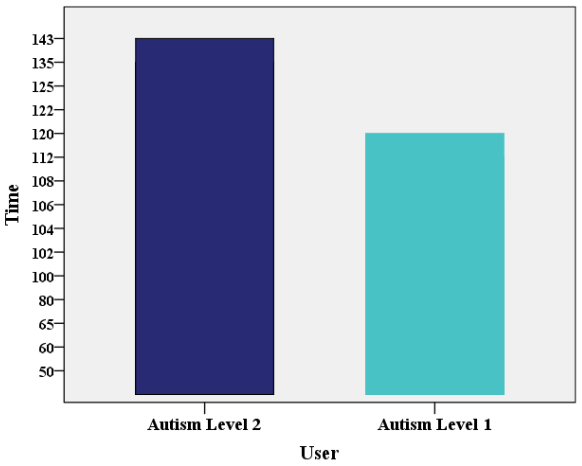

FIGURE 14. Results time of task level 1 and 2 .

The results show a significant variation between the two groups, which show the nature of the spectrum, meaning that the application was designed taking into account the characteristics of the user and what was suitable for him or her. The results show that Level 1 users were the ones who performed the proposed tasks more efficiently using the application. Thus, it can be deduced that it is necessary to develop the application considering the ASD level of the child in order to obtain a better performance in the implementation of each of the tasks.

Testing with ASD users. The main objective was to evaluate usability metrics such as binary success, success levels, task time, and error rate. This evaluation was done in order to test the application with users in an environment in which they carry out their activities on a daily basis. These tests show that the application in terms of usability was effective and appropriate for such users who showed a good acceptance and management of the application.

VI. CONCLUSIONS

Technology has an endless application, which are present in all aspects of daily life. Adding to this, technology has allowed the improvement of the lives of many people with ASD. This is because it helps them to compensate for various verbal and interaction problems, as well as facilitating exchanges between people with ASD, family members, experts, and others. Thus, this compensation and facilitation expands new forms of communication, socialization, learning, and employment options.

Currently, the number of people diagnosed with autism spectrum disorders continues to grow, which reminds us of the needs of people with this condition. However, there is a lack of developed applications in which the skills of each type of user are considered.

This paper presented the design and implementation of an application for mobile devices, which seeks to support the ToM. For this purpose, the User Centered Design was used to generate an application that was in alignment with the needs of this particular group.

It can be concluded that through the co-design of the application with users and professionals, it allowed obtaining a suitable application in terms of content and usability for children with ASD, allowing the user to feel comfortable with the application and, furthermore, that this application can be integrated into daily activities without problems. Additionally in order to be able to evaluate the usability of the application with non-national users, tests were carried out using usability metrics to measure the error rate per user in each task. In addition to the levels of success and to know who could complete the task: the results show that both users managed to complete it with some differences of time. It also measured the time each group of users took performing the task assigned using the developed application. However, the application can be improved even more in some images related to emotions, because they must be clear visually and without many distractors so that the user can identify them in a simple way. Furthermore, it is important to emphasize the importance of technologies in the work of people with ASD, since they allow to expand the working methods, taking them out of the traditional establishments and, in addition, extending the scope of the same ones; furthermore, the importance of collaborative work between different disciplines is demonstrated.

Preliminary results are encouraging, however, longitudinal validation on a larger scale is necessary. The future work corresponds to increasing the number of activities developed and making the application available in different platforms.Additionally, it is expected to be assessed by a larger number of participants of children with ASD. It will also be evaluated by professionals from other institutions in order to have a more complete evaluation of the application design.

REFERENCES

[1] S. Bölte and J. Hallmayer, *Autism Spectrum Conditions: FAQs on Autism, Asperger Syndrome, and Atypical Autism Answered by International Experts*. Boston, MA, USA: Hogrefe Publishing, 2011.

[2] S. Baron-Cohen, *Mindlindness: An Essay on Autism and Theory of Mind*. Cambridge, MA, USA: MIT Press, 1997.

[3] S. Baron-Cohen, A. M. Leslie, and U. Frith, "Does the autistic child have a 'theory of mind'?" *Cognition*, vol. 21, no. 1, pp. 37–46, 1985.

[4] J. Baio *et al.*, "Prevalence of autism spectrum disorder among children aged 8 years—Autism and developmental disabilities monitoring network, 11 sites, United States, 2014," *MMWR, Surveill. Summaries*, vol. 67, no. 6, pp. 1–23, Apr. 2018.

[5] D. M. Blischak and R. W. Schlosser, "Use of technology to support independent spelling by students with autism," *Topics Lang. Disorders*, vol. 23, no. 4, pp. 293–304, 2003.

[6] D. Cabielles-Hernández, J.-R. Pérez-Pérez, M. Paule-Ruiz, and S. Fernández-Fernández, "Specialized intervention using tablet devices for communication deficits in children with autism spectrum disorders," *IEEE Trans. Learn. Technol.*, vol. 10, no. 2, pp. 182–193, Apr./Jun. 2017.

[7] K. I. Boser, M. S. Goodwin, and S. C. Wayland, *Technology Tools for Students with Autism: Innovations that Enhance Independence and Learning*. Towson, MD, USA: Paul H. Brookes Publishing Company, 2014.

[8] J. A. Kientz, M. S. Goodwin, G. R. Hayes, and G. D. Abowd, "Interactive technologies for autism," *Synth. Lectures Assistive, Rehabilitative, Health-Preserving Technol.*, vol. 2, no. 2, pp. 1–177, 2013.

[9] J. Britto and D. R. Kalbande, "Analysis of technological advances in autism," in *Proc. Int. Conf. Inventive Comput. Inform. (ICICI)*, Nov. 2017, pp. 736–741.
[10] R. Munoz, T. S. Barcelos, and R. Villarroel, "CT4All: Enhancing computational thinking skills in adolescents with autism spectrum disorders," *IEEE Latin Amer. Trans.*, vol. 16, no. 3, pp. 909–917, Mar. 2018, doi: 10.1109/tla.2018.8358673.
[11] D. Karahoca, A. Karahoca, N. Özdemir, and B. Karaosmanoğlu, "Designing prototype model to support language development of autistic learners in early childhood," *RED. Revista de Educación a Distancia*, vol. 1, no. 53, pp. 1–9, 2017.
[12] S. Bernardini, K. Porayska-Pomsta, and T. J. Smith, "ECHOES: An intelligent serious game for fostering social communication in children with autism," *Inf. Sci.*, vol. 264, pp. 41–60, Apr. 2014.
[13] M.-E. Chien *et al.*, "iCAN: A tablet-based pedagogical system for improving communication skills of children with autism," *Int. J. Hum.-Comput. Stud.*, vol. 73, pp. 79–90, Jan. 2015.
[14] D. Pacella and B. López-Pérez, "Assessing children's interpersonal emotion regulation with virtual agents: The serious game Emodiscovery," *Comput. Educ.*, vol. 123, pp. 1–12, Aug. 2018.
[15] R. Muñoz, T. Barcelos, R. Noël, and S. Kreisel, "Development of software that supports the improvement of the empathy in children with autism spectrum disorder," in *Proc. 31st Int. Conf. Chilean Comput. Sci. Soc.*, Nov. 2012, pp. 223–228.
[16] R. Muñoz, R. Villarroel, T. S. Barcelos, F. Riquelme, A. Quezada, and P. Bustos-Valenzuela, "Developing computational thinking skills in adolescents with autism spectrum disorder through digital game programming," *IEEE Access*, vol. 6, pp. 63880–63889, 2018, doi: 10.1109/access.2018.2877417.
[17] K. P. Soares, A. M. F. Burlamaqui, L. M. G. Goncalves, V. F. da Costa, M. E. Cunha, and A. A. R. S. da Silva Burlamaqui, "Preliminary studies with augmented reality tool to help in psycho-pedagogical tasks with children belonging to autism spectrum disorder," *IEEE Latin Amer. Trans.*, vol. 15, no. 10, pp. 2017–2023, Oct. 2017.
[18] L. Bozgeyikli, A. Raij, S. Katkoori, and R. Alqasemi, "A survey on virtual reality for individuals with autism spectrum disorder: Design considerations," *IEEE Trans. Learn. Technol.*, vol. 11, no. 2, pp. 133–151, Apr./Jun. 2018.
[19] R. Munoz-Soto *et al.*, "Proyect@ matemáticas: A learning object for supporting the practitioners in autism spectrum disorders," in *Proc. Latin Amer. Conf. Learn. Objects Technol. (LACLO)*, Oct. 2016, pp. 1–6.
[20] A. Lancaster, "Paper prototyping: The fast and easy way to design and refine user interfaces," *IEEE Trans. Prof. Commun.*, vol. 47, no. 4, pp. 335–336, Dec. 2004, doi: 10.1109/tpc.2004.837973.
[21] A. Voßkühler, V. Nordmeier, L. Kuchinke, and A. M. Jacobs, "OGAMA (open gaze and mouse analyzer): Open-source software designed to analyze eye and mouse movements in slideshow study designs," *Behav. Res. Methods*, vol. 40, no. 4, pp. 1150–1162, 2008.
[22] W. Albert and T. Tullis, *Measuring the User Experience: Collecting, Analyzing, and Presenting Usability Metrics* (Interactive Technologies). San Mateo, CA, USA: Morgan Kaufmann, 2013.

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