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Research article

Using social robots as inclusive educational technology for mathematics learning through storytelling

Usando robots sociales como tecnología educativa inclusiva para el aprendizaje de matemáticas a través de la narración

Antonio Vitale[1]: University of Macerata, Italy.
a.vitale11@unimc.it
Umberto Dello Iacono: University of Campania "Luigi Vanvitelli", Italy.
umberto.delloiacono@unicampania.it

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Abstract

Introduction: This exploratory study investigates the potentials of social robots as an inclusive educational technology to enhance mathematics learning. **Methodology:** More specifically, we investigate the effectiveness of the social robot Pepper in engaging students in inclusive didactic activities through storytelling and providing them with immediate, personalized and emotional feedback. Our focus is on integrating innovative artificial intelligence (AI) with Universal Design for Learning (UDL) principles. The research sample consisted of five students, engaging with Pepper in inclusive mathematics sessions. **Results:** Our results suggest that the use of Pepper significantly increases student engagement by providing them personalized support. **Discussions**: The robot's capacity for dynamic and empathetic student interaction creates a more stimulating and encouraging learning environment. **Conclusions**: This study shows the potential of social robots in inclusive education, especially when it comes to enabling tailored learning experiences for students in mathematics education that adapt to

[1] **Corresponding author:** Antonio Vitale. University of Macerata (Italy).

their various needs. The results of this study need to be validated through future research involving more participants over a long period of time.

Keywords: inclusive mathematics education; universal design for learning; social robots; educational robotics; narrative; human robot interaction; artificial intelligence; digital education.

Resumen
Introducción: Este estudio exploratorio investiga las potencialidades de los robots sociales como tecnología educativa inclusiva para mejorar el aprendizaje de las matemáticas. **Metodología**: Más concretamente, investigamos la eficacia del robot social Pepper para involucrar a los estudiantes en actividades didácticas inclusivas a través de la narración y proporcionándoles un feedback inmediato, personalizado y emocional. Nos centramos en la integración de la inteligencia artificial (IA) innovadora con los principios del UDL. La muestra de la investigación consistió en cinco estudiantes que participaron con Pepper en sesiones inclusivas de matemáticas. **Resultados:** Nuestros resultados sugieren que el uso de Pepper aumenta significativamente el compromiso de los estudiantes al proporcionarles apoyo personalizado. **Discusión**: La capacidad del robot para la interacción dinámica y empática con los estudiantes crea un entorno de aprendizaje más estimulante y alentador. **Conclusiones**: Este estudio muestra el potencial de los robots sociales en la educación inclusiva, especialmente cuando se trata de permitir experiencias de aprendizaje a medida para los estudiantes de educación matemática que se adapten a sus diversas necesidades. Los resultados de este estudio deben ser validados mediante futuras investigaciones que incluyan a más participantes durante un largo periodo de tiempo.

Palabras clave: educación matemática inclusiva; diseño universal para el aprendizaje; robots sociales; robótica educativa; narrativa; interacción humano-robot; inteligencia artificial; educación digital.

1. Introduction

Everyday, artificial intelligence (AI) is revolutionizing many fields of society and educational settings are no exception. The development in educational contexts of AI, known as AIED (Artificial Intelligence in Education) has launched an entire series of technological advancements and effective pedagogical impacts (Roll & Wylie, 2016). The aim is to analyze and improve static teaching-learning processes through the implementation of tools like intelligent tutors and continuous feedback (Bayne, 2015). These tools have the characteristic of being effective, adaptive, and personalized with the aim of addressing the individual needs of students by empowering teachers to use of pedagogical models, learning domain models, and learning models (Luckin et al. 2016) for producing interactive lessons, analyzing in detail the performance of the class, and engaging students through dynamic learning (Tsai et al., 2020). If they are properly planned and implemented, they can contribute to increasing learning freedom (Holmes et al., 2019).

The development of AI in educational contexts has merged education, psychology, neurology, linguistics, sociology and anthropology, in a single interdisciplinary cluster (Pham & Sampson, 2021) by bringing huge benefits for both teachers and students by holding increasing importance. According to Woolf et al. (2013), AIED must be considered as a crucial transition moment, because it may help solve certain problems in education concerning learning by trying to make it more collaborative, accessible and available to students. The breakthrough points can be grouped into these key areas or themes:

- Personalization of learning (Dishon, 2017): AIED proposes strong points in relation to both content adaptation and personalized curricula. It could be able to analyze the specific teaching situations of each individual student and to adapt various teaching tasks according to their needs and even manage to implement personalized learning paths according to their difficulties.

- Automatic assessment (Cui & Li, 2019): AI could autonomously evaluate student work by providing teachers with any information they need to understand the overall performance of the class.

- Intelligent tutoring - learning motivation (Bingham et al., 2018; Holstein et al., 2017): AI systems could analyze learners' specific difficulties by supporting them in their personal cognitive development by answering their questions and giving appropriate feedback in real-time.

- Inclusion: AIED could support teachers in designing effective and inclusive learning activities for students (Ip et al., 2019), also with disabilities (Petti et al., in press).

All of this, related to the continuous progress of AIED, could promote the development of learning environments (virtual, digital and technological) in which the learner has resources always available and that can proceed in a personalized and flexible way in their learning experience (Barana et al., 2020). This is essential to develop personalized one-to-one teaching between machines and students (Huang et al., 2021). At the moment, the most developed AIED tools are: e-learning (Reister & Blanchard, 2020; Singer-Brodowski et al., 2019), intelligent conversational software agents (chatbots) (Schachner et al., 2020), virtual assistants (Jee, 2019), online platforms for self-learning (Moreno, 2019), and robotics (Jawaid et al., 2020). As far as robotics is concerned, one goal is to teach, to learn, and to solve problems (Baker et al, 2019) by involving students and providing them with the opportunity to take an active role in the construction of their own knowledge. Different modes of AIED not only influence the amount of what students learn but how they learn, demonstrating high levels of engagement of students (García-Martínez et al., 2023), encouraging their creative ability to shape their thoughts (Barak & Zadok, 2009).

Some teachers have employed these tools to support many activities, they have enhanced both the use of technology in the classroom and traditional teaching processes. However, they did not focus on a student-centered learning (Hall, 2010; Harper & Milman, 2016). Some of them have not fully exploited the enormous potential of these AIED tools, and they claimed that technology is not necessary to do their work (Aflalo, 2014). Other teachers have stated that their opposition to the integration of technological tools is due to the lack of time available for their activities (Dimock & Boethel, 1999). However, as AIED applications are relatively newly developed, there is a lack of acceptance and understanding of how teachers perceive the integration of AI into their daily teaching practices. The education system is still lagging behind the progress of AI (Roll et al., 2021) and this gap is wide every day. There is a gap in the research on the best ways for teachers to learn how to work with AI tools (Puttick et al., 2015). There are still few studies in the literature related to the development of innovative teaching practices through the use of social robots on personalized learning. Moreover, there is a lack of studies on how to use AIED tools to create dynamic, interactive and inclusive learning environments (Delgado et al., 2015).

Nowadays, the integration of newly emerging technologies in various educational settings is changing the teaching and learning process. Social robots can be considered a key part of these innovations because they can enhance human interaction to facilitate education. They can encourage active engagement and also they can facilitate the access to educational contents. In order to do this, it is essential to integrate the educational aspect. In this respect, the Universal Design for Learning (UDL) (CAST, 2011) could prove to be an effective strategy for making learning accessible, useful, and targeted to every student. It is an educational method that aims to make learning effective and accessible to all students.

Our work aims to analyze how Universal Design for Learning (UDL) principles can be integrated with AIED developments. The first principle of UDL, which emphasizes the importance of providing a variety of modes of representation to meet the learning needs of all students, can be integrated with the potential of AI. In this context, the social robot Pepper is capable of providing immediate, emotional and personalized feedback to students. Through dynamic and personalized interactions, this integration could promote increasing student participation and engagement. In this regard, our research question is as follows:

- RQ: To what extent is Pepper (through immediate, emotional and personalized feedback) able to engage students in inclusive mathematics sessions?

2. Theoretical Background

Social robots combined with UDL principles have the potential to revolutionize education by providing inclusive learning experiences. This integration can be used for improving teaching practices, reducing educational barriers and ensuring that all students can reach their full potential in every task.

2.1. Social Robots

Social robots are defined as tools equipped with embodied AI capable of collecting, producing and analyzing data from the surrounding reality and interacting with it (Brignone et al., 2021). They can interact with the user as naturally as possible through social behaviors thanks to the variety of sensors and actuators. Due to the possibility of voice and face recognition, social robots have the ability to propose questions and personalized answers. Moreover, they are mobile and have a display for images and videos. They could choose an appropriate emotional support strategy based on the user's emotional mood, assisting with a meta-cognitive learning strategy, deciding when to take a break, and encouraging appropriate help-seeking behavior (Belpaeme et al., 2018) with the feedback.

Brown & Howard (2014) used the humanoid robot DARwIn-OP (Darwin) as a SIRT (Socially Interactive Robotic Tutor) with the idea to understand how the use of SIRT in tablet-based mathematics tests, compared to non-interactive methods, was able to increase or maintain student engagement. Darwin engaged with the learner by giving verbal cues and encouraging gestures (feedback) while the student worked through the mathematical exercise. The study showed that compared with the group without SIRT, there was an increase in student attention in the group that used SIRT.

In school context the use of formative assessment (William, 2007) is relevant: the advantage of this is to support personalized learning by involving learners to understand their progress thanks to the continuous feedback. Furthermore, it is necessary to understand how social robots' capability towards continuous feedback works in an inclusive way of learning while keeping in mind the affective aspect of mathematics (Hannula, 2020).

In our work, we used the social robot Pepper. It is a semi-humanoid social robot produced by SoftBank Robotics (ex Aldebaran Robotics). Pepper is able to read feelings, can speak and move around. It also includes a tablet display. It possesses remarkable abilities: with the functioning of sensors, microcomputers, and actuators, it engages with the person in front of it by creating customized reactions based on what the person suggests to it.

Figure 1.

The Social Robot Pepper

Source: Own elaboration (2024).

The use of social robots in educational contexts is crucial. It is important to understand what emotional factors come into play in the social robot-user relationship and how social robots can be integrated into educational contexts. In this regard, pedagogy plays a crucial role in human-robot interaction (HRI) especially when the users are students. Our aim is to design pedagogically sound sessions that are personalized, inclusive and dynamic. The idea is to program Pepper to adapt to students' specific needs by offering personalized support through immediate, situational and emotional feedback (Lehmann & Svarny, 2021).

2.2. The design of inclusive education

Universal Design for Learning (UDL) is an innovative educational framework having the main aim of addressing the specific needs of all learners, including BES learners, by making learning accessible and inclusive through the use of so many teaching strategies and technological tools. UDL can create environments in which every learner can grow, and increase their interest, responsibility and active participation (Rose & Meyer, 2007). UDL was developed by researchers at CAST (Center for Applied Special Technology) by developing guidelines (CAST, 2011) grouping them into three basic principles (Cottini, 2019):

- *Representation*: multiple forms of presentation and representation to give students different options for acquiring information and knowledge.

- Expression: multiple forms of action and expression, to give students different alternatives to show what they know.

- Engagement: multiple forms of engagement, to give students different motivation to learn.

Students learn in a different way, so it is necessary to offer materials tailored to their needs. This can foster students' involvement in education practices, motivating them in their choices. A classic example of involvement is feedback. Moreover, it is essential to understand how students can express what they have learned. Standard assessments are often used: written test and or oral test. However, it is essential to provide students with a choice of different forms of expression that may be more familiar to them. The implementation of UDL through the integration of cutting-edge artificial intelligence technologies can lead to a personalization of student's learning experiences through feedback (e.g., "maybe you need to revise something") that can also be emotional feedback (e.g., "you are on the right track"). AI can be seen as a key link with aspects of UDL to create inclusive learning sessions. It is necessary that everyone's right to have the best opportunities to achieve educational success (Cottini, 2019) is a basic prerequisite to having a strong understanding of what are the best teaching methodologies to put in place to promote an inclusive education. One way forward, in our opinion, could be the one indicated by Cottini (2019): designing flexible learning activities from the beginning to provide more opportunities for each student to feel welcomed and stimulated.

3. Methodology

In this section-we provide some details about the participants, tools and materials used and the didactic activity. Finally, we describe how we collected and analyzed data.

3.1. Participants

The activity involved five students attending:

- the first year of high school (one student, P1, 13 years old);
- the third - year of high school (three students, P2, P3, and P4, 17 years old);
- the third - year of middle school (one student, P5, 13 years old).

Student privacy was guaranteed, making sure that the data collected is handled with security and used exclusively for educational research and improvement purposes.

3.2. Tools and materials

For our study, we used Pepper, which was configured and programmed with the following sessions: Initial welcome interaction, presentation of educational contents, answering questions, and engaging the student in interactive exercises. The sessions were carried out in a laboratory of the Department of Psychology of the University of Campania "Luigi Vanvitelli". For data recording we used Pepper's functionalities (video camera, microphones, motion sensors, movements, voice responses). Each session takes about 15 minutes. At the end of the session, the students answered an anonymous questionnaire on the learning experience. Records are stored in a secure database and organized by date, session, and participant.

3.3. Didactic activity

The didactic activity involved each student working one-on-one with Pepper. There are five sessions with Pepper, each with a specific focus:

(1) beginning presentation;

(2) beginning activity;

(3) problem understanding;

(4) problem solving;

(5) conclusion.

Session (1): Beginning presentation

Each student was introduced to the activity and started the interaction with Pepper.
In the first stage of the interaction, Pepper hands out welcome sentences, introduces itself using the voice: *"Hi, I'm Pepper. I'm very glad you're here with me today!"* and asks the student what emotions they are feeling: *"How are you?"*. After receiving consent from the student, the session (2) starts.

Session (2): Beginning activity

Pepper begins to explain to the student the activity they are going to perform together: "*Today we are going to work together through a beautiful activity. This will be useful for you to understand a lot of new things. If something is not clear to you and you would like further explanation, I will be available for any explanation. Are you ready?*". Our idea was to implement a mathematics session on the Pythagorean Theorem as storytelling (Zan, 2012; Zazkis & Liljedahl, 2019):

> For the birthday of Federico, his dad decided to build a beautiful tree house in his garden. The tree is 20 dm long. During the building, Federico says: "Wau Dad, it's beautiful! I'm going to do lots of parties with my friends!" His dad answers: "Of course son. I will try to complete it as soon as possible. All that remains is to build a wooden ramp to climb it, to be placed at a distance of 15 dm from the tree. Please do me a favor: go to the garage and get the piece of wood to build the ramp." Federico is overjoyed to help his father, but he does not want to waste any more time because he intends to organize a lot of parties with his friends right away. He needs to understand right away how long the ramp has to be. Can you help him?

At this point, the dynamic interaction between Pepper and the student begins. Pepper asks the student if the story is clear and if she wants to start the activity: "*If you want to listen to the story again, say: 'repeat the story', otherwise say 'let's start*'). Thus, the student can ask Pepper to repeat the story.

Session (3): Problem understanding

Right now, a comprehension phase of the story begins, aimed at finding out whether the student really understood the information in the story told by Pepper. Pepper starts asking the student questions related to the understanding of the story giving them a lot of feedback regarding their answers (for example, "*Great! Now let's start our activity! What did you* *understand about the story?*" and "*Thank you for your explanation! From the telling of the story, there were two significant items. Touch my head to find out the first item or touch my hand to find out the second item*"). More specifically,

- if the student touches Pepper's head, on the tablet appears three options regarding the tree height and the student has to choose one of them;

- if the student touches Pepper's hand, on the tablet appears three options regarding the distance at which the ramp should be placed from the tree.

Pepper provides out loud congratulatory feedback if the answer chosen by the student is correct, that is, *"Perfect, you are so great! My compliments"* and automatically moves on to other questions about understanding the story. Otherwise, Pepper provides encouraging feedback by inviting the student to reformulate the answer, that is: *"Ops! Attention! Could you try to answer again?"*.

At this point, Pepper asks the student: *"Did you have difficulty understanding the data in the story?"*. After receiving the student's response. In case of difficulties by the student, Pepper proposes emotional feedback and starts a session on those difficulties. Otherwise, Pepper starts a new session regarding the solution of the problem.

Session (4): Problem solving

Pepper asks the student aloud: *"If you were Federico, could you tell me how he can find the right ramp?"*. The implementation of the story can follow different paths:

(1) In the case of a negative answer, Pepper says: *"Don't worry, I can help you"* and offers the student suggestions. A new narrative begins on the Pythagorean Theorem with the support of pictures that the student can view on the tablet. Pepper focuses on the statement of the Pythagorean Theorem and the properties of the rectangle triangle and proposes a contextualized example of the application of the Theorem. Thus, the student receives suggestions on how they can calculate the length of the ramp.

(2) If the student responds *"yes"*, Pepper offers congratulatory feedback: *"Great, I'm glad you know how to help Federico. Can you explain how to do that?"* After offering the feedback, Pepper invites the student to find the length of the ramp by giving the student as much time as necessary to be able to communicate the result to Pepper. In this regard, Pepper will say to the student: *"Thank you for doing the calculation. Now let me show you some hypothetical results. Could you tell me which one is correct?"*
In the case that the student gives the wrong answer, Pepper says: *"Don't worry, take it easy. I'll help you now!"* At this point, the story's implementation starts again from step (1).
If the solution communicated by the student is correct, Pepper provides positive feedback by saying: *"Yeah, you are brilliant! You have exactly found the length of the ramp. Can you communicate it to Federico?"*.

Session (5): Conclusion

At this point, the interaction proceeds toward the final part. After the student has given Pepper the correct information about the length of the ramp, she sees the picture on the Pepper's tablet in which Federico is overjoyed to see his house completed. In this regard, Pepper offers this feedback to the student: *"Perfect, as you see Federico is overjoyed."* Then, Pepper narrates the dialogue between Federico and his father: *"Look Dad. Thanks to the support of the person who helped me, I am so happy"*. Then, Pepper offers this feedback to the student: *"Thanks to your help Federico can organize parties with his friends. You are really special to him"*. Eventually, Pepper thanks the student for the task and says goodbye.

At the end of the session, the student answers an anonymous metacognitive questionnaire aimed to lead the student to reflect on the entire activity. Below are some questions from the questionnaire:

- What do you think about the activity?
- Did you enjoy doing this activity? If yes, why? If not, why?
- Was it fun to do this activity? If yes, why? If not, why?
- Do you think you did better than usual?
- Is it fun to do Math in this way?
- What do you think about the social robot Pepper and about your interaction with it?

3.4. Data collection and analysis

The data collected concern

- video and audio data of Pepper-participant interaction session: these data allowed us to observe the interactions between Pepper and the students, the spatial positioning of the students, their gestures, the conversations between the participants and Pepper, their tones of voice, and their emotional responses;
- responses to the final anonymous questionnaire.

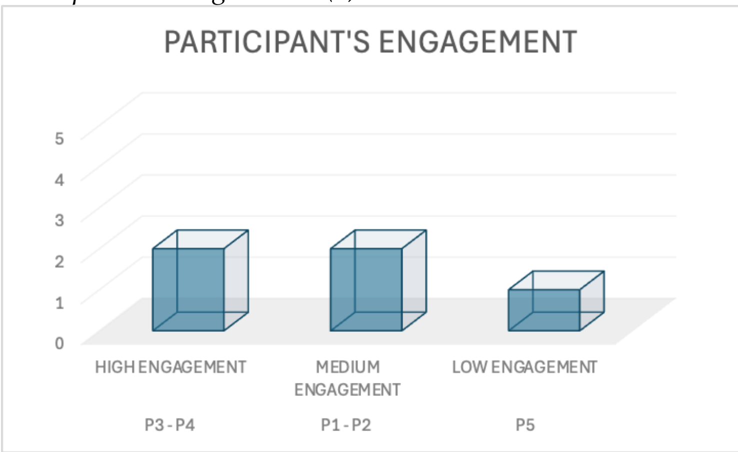
With the aim to analyze the dialogues and verbal interactions, we initially transcribed the audio recordings that include the timing of the interactions with the purpose to simplify the analysis synchronized with the video data. Then, we analyzed the transcripts to identify recurring themes: type of interaction, emotional response, non-verbal behavior, explicit requests, accuracy of comprehension of the problem, waiting time and the student's behavior analysis for assessing engagement, teamwork and response to Pepper. We used a spreadsheet to count the number of occurrences of each interaction type. Finally, we created pivot tables to aggregate and summarize the data. Regarding the final questionnaire, all answers were transcribed and analyzed by finding relevant and recurring issues.

4. Results

In this section, we first show the results of the data analysis for each of the student interaction sessions with Pepper. Finally, we show the analysis of the responses to the final questionnaire. Regarding session (1), the following Figure 2 shows the level of engagement of each participant (P1, P2, P3, P4, and P5) also with reference to the feedback received from Pepper.

Figure 2.

Interaction Pepper-participants during session (1)



Source: Own elaboration (2024).

Figure shows that 80% of the participants engaged during the initial interaction with Pepper. Pepper's immediate and personalized feedback ("*in this activity that we are going to do together, I am going to tell you a beautiful story about Federico and his dad. I ask you, please, to take special attention to the telling of the story because you will play a very important role. If it's okay with you, can we start?*") was critical in maintaining participants' engagement and motivation. For P1 and P2, the feedback was effective: the participants had fun during the interaction and they smiled; for P3 and P4, the feedback was extremely effective: they continually interacted with Pepper with their feedback ("*you're cute*"); for P5 it was indifferent: she just nods. All participants were curious about the story and interested in giving their input.

Concerning session (2), Pepper told the storytelling and it asked participants whether the story was clear or not. The use of mathematical storytelling and Pepper's feedback (*"Can you help Federico?"*) allowed all participants to fully engage themselves in the learning process. All participants (100%) decided to "help Federico". P1-P3-P4 asked to listen to the story again. All participants took notes referring to the narration except for P4: P1 and P3 during the retelling of the story, P2 and P5 during the first narration.

Regarding session (3), Pepper continually asked the participant questions with the purpose of determining whether or not they have truly understood. All the participants (100%) had no difficulty either related to understanding the story data and related to identifying them.

Concerning session (4), the following Table 1 shows the performance of each participant in addition to the feedback that Pepper provided.

Table 1.

Performance of each participant during session (4)

Participant	Pepper's help	Pepper's feedback and motivation	Solving the problem
P1	Yes	Effective because it suggests to P1 the use of Pythagorean Theorem.	Yes
P2	No	Gratifying because It congratulates P2 on the work done.	Yes

P3	Yes	Effective because it suggests to P1 the use of Pythagorean Theorem.	Yes
P4	No	Very effective because It understand the participant's mistake and it guides him to resolution.	Yes
P5	No	Very effective because It understand the participant's mistake and it guides him to resolution.	Yes

Source: Own elaboration (2024).

All participants were able to solve the problem in a few minutes. P1 and P3 succeeded after asking Pepper for help. P1 asked Pepper's help and Pepper focused on the statement of the Pythagorean Theorem and the properties of the rectangle triangle and proposed a contextualized example of the application of the Theorem. As the story comes to a close, Pepper offered more feedback saying: *"As you may have realized, we have illustrated the circumstance you are facing in a mathematical world. What do you think?"*. P1 answered: *"I believe I understand."* and in a few minutes P1 performed all the calculations, solved the problem and nodded at the Pepper' question *"Can you tell Federico how long the ramp should be?"*

P3's sentence, "It's wonderful" as a response to Pepper's feedback, *"As you may have guessed, we have illustrated the circumstances you face in a mathematical world. What do you think?"* shows her involvement in the activity and the pleasure she is taking in interacting with Pepper. P2, P4 and P5 did not ask Pepper for help.

P2 did not ask Pepper's help and began an interaction with Pepper:

> Pepper: *"Great! I'm glad you know how to do it! Can you explain how you can help Federico?"*
> P2: *"I don't know exactly how to do it"*
> Pepper: *"Ok! What is the process you plan to do?"*
> P2: *"We have the length of the tree of 20 dm and we know that the distance of the ramp from the tree is 15 dm. To find the length of the scale we must apply the Pythagorean Theorem"*
> Pepper: *"Great! I'm so happy that you could help Federico!"* (Pepper gave P2 some time to do the computations. P2 completed them in 1 minute. P2 finished and touched Pepper's tablet)
> Pepper: *"Thank you for doing the computations. Now I will show you some hypothetical results. Could you tell me which one matches yours?"*.
> (On Pepper's tablet appeared a picture in which there were these figures: 25 dm; 22 dm; 30 dm; 40 dm; other results)
> P2: *"25 dm."*
> (Pepper placed a congratulatory feedback)
> Pepper: *"you are brilliant!"*

P4 and P5 also did not ask Pepper for help at first, but indicated an incorrect answer to the problem (P4: "*30 dm*"; P5: "*other results*"). Specifically, P5's reasoning was to subtract the length of the tree from the length of the ramp ("*Ehm...I have to subtract from the 20 dm of the length of the tree, the 15 dm of the ramp*"). Then, they received feedback from Pepper ("*Ops! This isn't the right length of the ramp! Now I'll give you a little hint!*") which focused on the statement of the Pythagorean Theorem and the properties of the rectangle triangle and proposed a contextualized example of the application of the Theorem. Pepper's feedback helped both P4 and P5 who responded enthusiastically to Pepper (P4: "*I believe that mathematics is so important!*"; P5: "*I believe that this is a simple way to explain!*") and answered correctly to the problem.

Regarding session (5), to Pepper's concluding feedback (*"Thanks to your help Federico can organize parties with his friends. You are really special to him"*), enthusiastic responses from participants followed. In particular, .P1 answered *"it makes me happy!"* and P3 and P4 smiled.

Concerning the final questionnaire, almost all participants (80%) said they enjoyed the activity and felt positive emotions. The following are some of the participants' responses concerning the activity and interaction with Pepper: *"It's way funny thanks to the storytelling and to Pepper's interaction!"*; *"It was an alternative mathematical lesson!"*; *"It was very funny and interesting because I felt like a protagonist in the story to help Federico"*; "*Pepper helps me*". From these responses it is evident that the combining of storytelling and interaction with Pepper is a key aspect in increasing participants' engagement and enjoyment in doing math problem solving activities. In addition, almost all (80%) said that they did better in mathematics and that it's fun to do mathematics in this way.

5. Discussion and conclusions

In this paper, we showed the results of an experimentation with a didactic activity with the social robot Pepper involving 5 participants. The didactic activity consisted of 5 sessions:

(1) beginning presentation;

(2) beginning activity;

(3) problem understanding;

(4) problem solving;

(5) conclusion.

At the end of the sessions, participants answered a final metacognitive questionnaire. We wondered to what extent Pepper, through immediate, emotional and personalized feedback, is able to engage students in these inclusive mathematics sessions.

Data analysis showed that, in the first session, there was an increase in engagement during the initial interaction with Pepper for 80% of participants due to Pepper's immediate and personalized feedback, in accordance with Brown & Howard (2014). All participants were curious about the story and interested in giving their contribution. There was a break in affective biases toward mathematics: the participant was not afraid to do an exercise but in addition she was motivated to do it. We observed how participants were able to immerse themselves in the learning process in the second session through the use of mathematical storytelling and Pepper's multimodal skills. This approach was in accordance with the first principle of UDL and addresses different learning preferences and needs by offering a variety of modes of engagement and representation (Rose & Meyer, 2007). The integration of AI and UDL allows all participants to engage in a dynamic system (audio-video) in which they feel fully involved and immersed. In the third session, we handled the cognitive and strategic aspect of storytelling. Pepper's continuous feedback in the fourth session acted as formative assessment and helped all participants to understand the story, the data of the problem and to find a solving strategy in agreement with William (2007), this formative assessment approach allows active involvement of students in their learning process and promotes self-regulatory and metacognitive skills.

Analysis of responses to the final metacognitive questionnaire showed that 80% of participants said they enjoyed the activity and the dynamic interaction with Pepper, characterized by the ability to identify and respond to emotions, helping to create a supportive, encouraging learning environment by improving their performance compared to usual. The session with Pepper made learning mathematics more enjoyable and less intimidating. This positive change in attitude toward mathematics is crucial to foster a growth mindset and encourage students to persist in their learning efforts, contributing to a sense of self-efficacy among students.

Our work has shown the use of social robots such as Pepper, combined with UDL principles, has the potential to create more inclusive and accessible learning environments. By offering multiple modes of representation, expression and engagement, substantial improvement in these aspects was observed in all participants due in part to the use of the narrative approach. This is perfectly in line with Bruner (1986), which emphasizes the role of narrative in cognitive development and understanding. The use of real scenarios helped participants contextualize and understand all mathematical concepts effectively. The implementation of a dynamic, interactive and inclusive environment allowed participants to feel like part of the resolution process.

However, in this paper we presented a still exploratory study. Future research should explore larger and more diverse populations over extended periods to validate and generalize the findings. Investigating the potential of AI tools in various subjects beyond mathematics could also provide a more complete understanding of their educational benefits.

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Authors' contributions:

Conceptualization: Vitale, Antonio; Dello Iacono, Umberto; **Software:** Vitale, Antonio; **Validation:** Dello Iacono, Umberto; **Formal analysis:** Vitale, Antonio; Dello Iacono, Umberto; **Data curation:** Vitale, Antonio; **Writing-Preparation of the original draft:** Vitale, Antonio **Drafting-Re-visioning and Editing:** Dello Iacono, Umberto; **Visualization:** Vitale, Antonio **Supervision:** Dello Iacono, Umberto; **Project Management:** Dello Iacono, Umberto; **All authors have read and accepted the published version of the manuscript:** Vitale, Antonio; Dello Iacono, Umberto

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AUTHORS:

Antonio Vitale
University of Macerata, Italy.

Antonio Vitale is a PhD student in Teaching & Learning Sciences: Inclusion, Technologies, Educational Research and Evaluation (special pedagogy and inclusion curriculum) at the University of Macerata. His research interests focus on the use of artificial intelligence systems (social robot Pepper) by exploiting its potential as an inclusive educational technology to improve mathematics learning. In detail, his research fully integrates an innovative artificial intelligence tool (Pepper) with Universal Design for Learning (UDL) principles to engage students in inclusive educational activities through storytelling and providing them with immediate, personalized and emotional feedback.
a.vitale11@unimc.it

Orcid ID: https://orcid.org/0009-0000-0998-0461
ResearchGate: https://www.researchgate.net/profile/Antonio-Vitale-10
Academia.edu: https://independent.academia.edu/AntonioVitale65

Umberto Dello Iacono
University of Campania "Luigi Vanvitelli", Italy.

Umberto Dello Iacono obtained his Ph.D. in Mathematics, Physics and Applications at the University of Salerno. Currently, he is researcher in Mathematics Education at the University of Campania "Luigi Vanvitelli". His research interests concern argumentative thinking and problem solving in digital environments and the integration of digital technologies into mathematics teaching and learning processes. In recent years, his research has also focused on mathematics teachers' professional development regarding mathematical text comprehension, the use of digital technologies in the mathematics teaching/learning process, and the design of learning environments for inclusive and accessible mathematics.
umberto.delloiacono@unicampania.it

Orcid ID: https://orcid.org/0000-0003-0224-1046
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=57190584928
Google Scholar: https://scholar.google.it/citations?user=8DPIzVEAAAAJ&hl=en
ResearchGate: https://www.researchgate.net/profile/Umberto-Dello-Iacono