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SUBMISSION DATE / POSTED DATE

20-06-2022 / 22-06-2022

CITATION

Dimitrova, Maya; Krastev, Aleksandar; Sabev, Negoslav; Nunez-Gonzalez, J. David (2022): Digital and e-Learning Accessibility for People with Special Educational Needs: A Robotic Perspective. TechRxiv. Preprint. https://doi.org/10.36227/techrxiv.20101814.v1

DOI

10.36227/techrxiv.20101814.v1

Digital and e-Learning Accessibility for People with Special Educational Needs: A Robotic Perspective

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Final Draft IEEE 2021

***Abstract*—The paper presents the currently developed framework for analysis of accessibility in digital and e-Learning systems, which extends the subject-object relation by including robots in the interaction process. A mainstream experimental framework in special education – false-belief task - is analyzed from a Piagetian perspective and modified to account for the intermediate role of the robot in supporting the learner acquire new knowledge or access the digital and e-Learning information available in the World. The paper concludes with some ideas for future research.**

Keywords—accessibility, digital systems, e-Learning, robot NAO

I. Introduction

The accessibility issue has been a topic of intensive debate in the recent decades due to its societal and economic significance, and especially recently, when due to a sudden pandemic, the interactions with the external World, including social relations, have become massively web-based. Therefore, a novel approach to understanding 'what true accessibility is' is needed in order to guide the design of future digital and e-Learning systems tailored to the individual skills, abilities, knowledge, experience and needs.

The paper discusses three recent frameworks for design of accessible tools and pedagogical systems in section II. An extension of the third one is presented with emphasis on the interplay of the *extrinsic* and *intrinsic* factors of accessibility. Section III proposes methods to overcome the intrinsic barriers within the genetic epistemology of Jean Piaget. Section IV presents a pedagogical situation in special education, implementing the false-belief task in a robot NAO scenario. The Conclusion section discusses some future work.

II. Layers of Accessibility in Digital and e-Learning Systems

A socially-grounded framework for understanding accessibility is proposed in [1]. According to the authors, the process of increasing the accessibility is understood as removing obstacles and barriers to a person striving to achieve a goal, such as self-realisation, for example. They propose a framework, involving 3 levels of accessibility. The most basic level is the level of social access, broadly understood as removing the economic and socialization barriers in front of a person on their way to achieve their self-realisation.

If a person has a physical disability, for example, the main obstacles to be overcome are related to providing the appropriate physical and digital environment at a certain cost, which is a social issue.

The next level is the physical access level. It involves providing the means in term of technologies to support the current need – text-to-speech converter if a person is blind, provision of subtitles to a video if the person is deaf, etc.

The third level of the proposed in [1] framework is the so called "learning access". Two types of learning access are described – intellectual and motivational – which are important factors, pertaining to the actual learner. A learner can possess the necessary knowledge in order to understand, i.e. *access*, the available information in a textbook, art gallery or science museum, etc. At the same time, the learner may be motivated, or uninterested, in the available information. In the latter case the motivation of the subject is an important internal factor for possible *access* to novel knowledge about the World. Yet this is a direct reference to the role of the teacher who has an important motivational role in any educational system.

In [2] an approach to 'blending' the design of novel accessibility tools with the design of pedagogical tools is proposed as these develop largely independently at the moment. It is based on the recent definition of *disability* from [3]:

"3.14 disability

⟨digital resource delivery⟩ any obstacle to the use of a digital resource experienced because of a mismatch between the needs of a user and the digital resource delivered

NOTE 1 Disability in an AfA context is not a personal trait but a consequence of the relationship between the user and their resource system.

NOTE 2 In an e-learning context, disability refers to a mismatch between the needs of a learner and both the educational resource and/or the method of delivery. [ISO/IEC 24751-1:2008 (2.13)]".

Bulgarian Research Fund for project № KP-06-H42 / 4 (2020-2023), EC for project CybSPEED, № 777720, H2020-MSCA-RISE-2017, and OP Science and Education for Smart Growth (2014-2020) for project Competence Center "Intelligent mechatronic, eco- and energy saving systems and technologies "№ BG05M2OP001-1.002-0023.

XXX-X-XXXX-XXXX-X/XX/$XX.00 ©20XX IEEE

Therefore, in this definition the focus is on the overcoming *any* obstacles – physical or pedagogical – in front of the learner. This requires better system adaptation to the individual skills, abilities, knowledge, experience and needs, which is a designer task to account for the co-evolution of the learner and the presented material to be learned. The authors in [2] discuss at length the relationship between pedagogy and accessibility in the current digital age. They redefine the 'pedagogical tool' as: "any tool that mediates a teacher's action, offering clear and detailed principles regarding learning that can be easily and readily translated into teaching practice. Pedagogical tools therefore not only make links between theory and practice, they help teachers move from the potentially abstract to the concrete" (p. 1110).

In the context of the presented two theories, we see distinct roles of humanoid robots from either the teacher or the learner perspectives. From the point of view of the teacher the robot is simply a 'tool' mediating a 'teacher's action'. From the point of view of the learner, however, the richness of the subjective experience is much broader, including boosting the motivational factors in learning. Numerous studies provide evidence to this, especially in children with learning difficulties [e.g. 4, 5].

A novel framework for accessibility analysis is proposed in [6]. Instead of defining levels, the framework defines *layers* of *access* by the learner of information about the World, including in education and e-Learning. A new systematized model is described - a concept applicable to the aspects of accessibility in terms of autonomous and diverse in nature objects in the physical and virtual space. The model is developed in the dissertation work of N. Sabev "Computer methods and approaches in research and presentation of knowledge about web accessibility for people with disabilities", defended in 2020. The author's contribution is in the systematization of the object - subject relations under conditions of variable dynamics [7].

The layered framework avoids the reference to 'higher' or 'lower' levels in the model representations. Instead, it places the learner at the centre of the representation and the subject - object interaction is mediated by *layers* of accessibility – social, physical or abstract/experiential.

Figure 1 presents a development of the initial framework to account *both* for the accessibility tools in the environment and the subjective knowledge and experience of the learner.

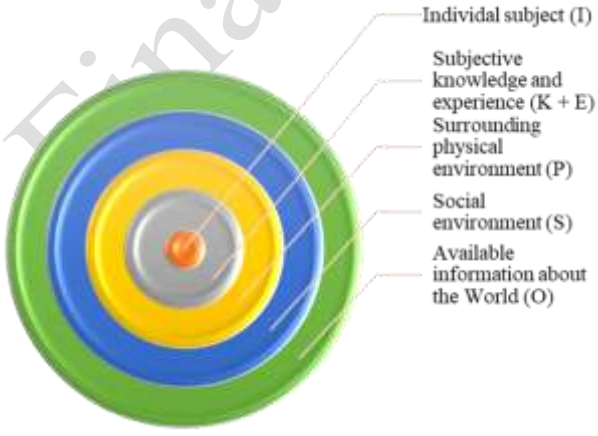


Fig. 1. A layered framework of the digital and e-Learning accessibility for people with special educational needs.

The inspection of Fig. 1 suggests that the individual subject (I) is surrounded by several factors, which can *help* or *hinder* the interaction with the World (W). These factors can be *extrinsic* like the social/economic environment (S) and the surrounding physical environment (P) or *intrinsic* like subjective knowledge and experience (K + E). The subjective knowledge is essential for the teacher to decide how *simple* or *complex* the explanations can be so that the learner grasps the main ideas best. Yet this is not sufficient. We all have memories of motivational cases or discouraging interactions with teachers, which shaped our adult interests and professional aspirations. Therefore the individual subjective experience has to be included in the overall framework despite the difficulties in including diagnostic abilities of the e-Learning systems.

The proposed layered framework of the digital and e-Learning accessibility is intended as a universal one. Yet for people with special educational needs it addresses the amount of external support to be addressed by system designers, which otherwise is being actively sought and acquired by the learners in general. It also allows formalisation of the subject – object relations within possible formal frameworks [7, 8].

III. Overcoming the *Intrinsic* Barriers to Accessibility of Knowledge

One very important stage in the intellectual development of children has been named 'passing the false-belief test' [9]. Actually, the significance of this intellectual achievement in human development cannot be overestimated and will be explained in the text a bit later. The development process in the form of stages has first been identified and explored by Piaget [10] in his justification of the new scientific field called 'genetic (developmental) epistemology'.

Jean Piaget was interested in how intelligence '*emerges'* and develops. His interest was strictly epistemological, yet giving origin and influence of the developmental psychology theory. Piaget was interested in the stages of acquiring *truthful* knowledge [11] – how do we cope with our own illusions or untruths in order to create an objective picture of the surrounding World? For example, a baby likes to play the game of hiding a toy under a pillow. The baby observes that the experimenter takes the toy from under the first pillow and hides it under the second pillow. The baby sees the whole process, yet in seeking for the toy checks under the first pillow first, and then under the second. This process takes a while. With growing up, the baby stops checking under the first pillow and goes directly to check under the second pillow. According to Piaget, the intellect of the baby developed naturally. The cognitive system of the child had overcome the stage of distorted understanding of the surrounding physical environment and reached a stage of more *objective* understanding of the relations among objects in the external World. This process is *emergent* – it appears spontaneously, at a certain moment of maturity of the nervous system – and cannot be forced or stopped *effectively* via pedagogical means.

The Piagetian approach was criticised for neglecting the role of social influences in early education [9]. Nevertheless, it defined the important stages of the *natural* intellectual development from an illusionary world towards a realistic understanding and development of conceptual knowledge. To a large extent the child's attraction to fairy tales and fantasies can be explained by this mental operationalisation of the environment. By exploring the real and imaginary worlds the

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cognitive system constructs a *truthful* knowledge of the world. Fig. 1 can accommodate both aspects of this developmental debate. For example, Vygotsky – often cited as a Piagetian criticist – introduced the notion of "interiorization" of the logical operations from the external world into the subjective world of the child – thereby introducing the *truth* in human cognition as well, often socially-mediated [13]. Both theorists implicitly agree that there are 'levels of truth', which are acquired by the cognitive system in the process of development. Moreover, this refers to both the physical and the social realities. Being more complicated, social realities are acquired at a later stage than physical realities in the process of cognitive development. This effect is often being described in the case of children with autistic spectrum conditions (ASC) [e.g. 14, 15] and can be explained well by a Piagetian framework [9, 10, 11].

In order to describe the specificity of the child's perception of the world and hence the knowledge of it, Piaget defined the concept of *egocentrism*. The cognitive system of the child is *egocentric*. The difficulties in conceptually accommodating the term *egocentricity* have been recognised [e.g. 9]. Yet it has been argued that it best describes the actual developmental phenomenon of placing one's own understanding of *truth* at the centre of the cognitive universe of the child. At a certain stage the child realises that there can be a different perspective of viewing the physical world – like the child understanding that the picture on my side of the card is different form the picture on her side of the card when sitting face to face. But somehow the child believes that their perspective is *truer* than the other's and is preferred for this reason. It takes time and moving to the next intellectual level in order to understand that all perspectives are equally *true*. The educational relevance of this phenomenon is immense. Special attention has to be devoted in the design of educational scenarios when it is necessary to account for this subjective obstacle to the sensory and the logical system of the child.

The Piagetian system is valuable for its focusing - always - on the acquisition of *truthful* knowledge. Truth is *innate* – there is a special internal mechanism for truth acquisition in the cognitive system of the child, which develops gradually and has to be accounted for in teaching. Not all of Piaget's postulates are adequately introduced in education, which would have made it less effortful for the child and the teacher alike.

Of special developmental interest is the stage when the child passes the "false-belief task" [8, 12]. The task has been widely implemented in special education as an intellectual diagnostic tool. The basic experimental framework is the following: The experimenter, the teacher and the child sit at a table with a toy and 2 boxes. The experimenter places the toy in one of the boxes and checks if the child is attentive. Then the teacher leaves the room. The experimenter takes out the toy from the box and places it in the second box. Again, the attentiveness of the child is probed. The teacher comes in. The experimenter asks the child the following question: "Where does the teacher think the toy is"? If the child says that the toy is in the second box, she fails the 'false-belief test'. The child takes the perspective that the teacher's understanding is the same as hers – a striking manifestation of cognitive *egocentricity*. This is characteristic for the early stages of child's cognitive development. At a certain moment the child begins to reason about the perspective of the teacher. If the teacher was away, in no way she would have known that the toy was misplaced. Therefore the teacher would still believe that the toy is in the first box. By saying this, the child passes the "false-belief test".

Experimenters have noticed that the "false-belief test" is difficult for children with ASC. This was interpreted as impaired Theory of Mind (ToM) of the child [e.g.16]. ToM refers to the ability of the child to perceive the other agent as possessing beliefs, different from one's own.

In a substantial review of experimental evidence Choifer distinguishes two different phenomena – non-subject related perspective-taking and subject related perspective-taking to account for some discrepancies in the experimental data [9]. This is a methodological issue, too. At an early age the child can *sense* the fact that the other person sees the world differently. Yet projecting oneself onto the other's feelings and beliefs requires a deep and dynamic process of cognitive analysis of the actual situation involving physical perspective and social *attitude* [e.g. 17]. In terms of the framework in Fig. 1, this is the transition stage from understanding the surrounding physical environment to the understanding of the social environment. This is an *intellectual leap* from understanding the *deterministic laws of physics*, guiding the processes that we observe in our everyday life towards understanding the largely *probabilistic laws of social reality*, guiding the processes of interaction with other human beings. This is why passing the 'false-belief test' is a leap from an egocentric system of seeing the World, where the centre is perceived as and Euclidean coordinate system and dependencies are mostly linear and deterministic, hence *truthful* from any point of view (including the social and biological interactions). The leap is into a largely uncertain coordinate system with different subjective perspectives and difficulties in identifying the *truth* as a belief. Moreover, since beliefs are dynamic, so is the truth – the child becomes an adult via realising that there is no universal truth in the social sphere – it is more a process of consensus among people. This is where the teacher cannot be replaced by a sophisticated pedagogical tool, because education involves role modelling as well.



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Fig. 2. False-belief task with 2 robots NAO.

Yet a possibility exist to help guide the child from the deterministic towards the probabilistic world understanding during learning. It is argued here that this can be achieved by introducing humanoid robotics in education.

IV. Towards a Robot Populated Learning Ecosystem

We have reshaped the format of the most popular 'false-belief' testing experimental setting. The transcript of a scenario with a child, a teacher, a robot and an experimeter is given in Table I.

TABLE I. Scenario with a Robot and Teacher

False-belief Task Scenario with a Child, Robot NAO, a Teacher and an Experimenter
Preliminary acquaintance of the child with NAO NAO: - Hello, my name is Roberta. I'm a robot. What is your name? Child: My name is…. NAO: - Nice to meet you. Do you want to play. Child: Yes NAO: - Well, let's play. Watch what I do. **The experimental situation** NAO sits on the floor. The child watches the scenario with the robot from a distance. A person trained to work with NAO performs the following actions: Shows the robot a soft toy and presses the front tactile sensor on the head, as a result of which NAO says: "It's a toy, give it to me," he said, opening his fingers. The teacher hands the toy to the robot and presses the tactile sensor on his right hand to close the gripping fingers. NAO places the toy on the ground in front of it. The next step is to show NAO a hat. The front tactile sensor on the robot's head is pressed again, after which it says: - It's a hat, give it to me, - then open its fingers. After the cap is given, the tactile sensor is pressed on the robot's right hand. This causes the fingers to close, after which NAO says: - I will hide the toy under the hat, - then NAO drops the hat and covers the toy. The teacher[a] says: - I'll be right back. Then she gets up and leaves the room. After pressing the tactile sensor by the experimenter, the robot lifts the hat and moves it to its right side, then takes the toy and hides it in a box, which is placed on its left side. Then NAO takes the hat and puts it back in the middle of the floor in front of him. The teacher enters and sits by the child. The robot asks the child: - Where does your teacher think the toy is?

[a] Instead of a human teacher, a second NAO robot is used in the present scenario.

Our modified scenario involves an experimenter, a child and 2 humanoid robots NAO – the red one called Roberta and the blue one called Robi (Fig. 2).

In the modified scenario Roberta is sitting in front of Robi and the child with a toy and a hat in her hands. She hides the toy under the hat. Robi stands up and leaves the room. Roberta picks up the hat, takes the toy and places it in a box next to the robot. Then she places the hat in its previous place, but without a toy under it. Robi enters the room. Roberta asks the child what she thinks about Robi thinking where the toy might be.

Our interest in this scenario is related to the specific ontological nature of the humanoid robots. Our view is that these robots are attractive to all children because they help in the transition from the physical layer of the subject – object relation to the social layer in Fig. 1. In the child's mental development a radical intellectual transition is from the *deterministic* physical world to the *probabilistic* one of social attitudes. A humanoid robot shares the features of a physical object – quite deterministic and therefore predictable – with the features of a social entity – capable of a basic dialogue, encouragement, patience and even expression of empatic-like behaviour. In this, we believe that the pedagogical potential of a humanoid robot is an immence and invaluable assistive 'tool' to the teacher. So, it will be an essential part of inclusive education, providing support to the the special type of accessibility to knowledge that no other type of agent (physical or social) can.

V. Conclusions

The paper presented a current debate in the field of developing digital and e-Learning accessibility tools for learners with special needs. Some issues are being largely unresolved theoretically such as the nature of the 'false-belief' task as a tool to diagnose the stage of learner's intellectual development. We proposed an extension of a model for accessibility to account for the phenomenon and described our current stage of design of a relevant scenario with 2 humanoid robots NAO, a child and an experimenter. We plan to test the scenario in real life settings and compare the outcome with the scenario with a human teacher in order to validate our main hypotheses falling out from the proposed layered framework of subject-object accessibility of information and knowledge about the World to the learners with special needs.

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