BRAIN. Broad Research in Artificial Intelligence and Neuroscience
ISSN: 2068-0473 | e-ISSN: 2067-3957
Covered in: Web of Science (WOS); PubMed.gov; IndexCopernicus; The Linguist List; Google Academic; Ulrichs; getCITED; Genamics JournalSeek; J-Gate; SHERPA/RoMEO; Dayang Journal System; Public Knowledge Project; BIUM; NewJour; ArticleReach Direct; Link+; CSB; CiteSeerX; Socolar; KVK; WorldCat; CrossRef; Ideas RePeC; Econpapers; Socionet.

2020, Volume 11, Issue 2, Sup.1, pages: 186-207 | https://doi.org/10.18662/brain/11.2Sup1/104

Cyber-Physical Systems for Pedagogical Rehabilitation from an Inclusive Education Perspective

Maya DIMITROVA[1], **Snezhana KOSTOVA**[2], **Anna LEKOVA**[3], **Eleni VROCHIDOU**[4], **Ivan CHAVDAROV**[5], **Aleksandar KRASTEV**[6], **Rositza BOTSOVA**[7], **Anna ANDREEVA**[8], **Vaska STANCHEVA-POPKOSTADINOVA**[9], **Leire OZAETA**[10]

[1] Associate professor, IR-BAS, Sofia, Bulgaria, m.dimitrova@ir.bas.bg

[2] Associate professor, IR-BAS, Sofia, Bulgaria, kostovasp@yahoo.com

[3] Professor, IR-BAS, Sofia, Bulgaria, alekova.iser@gmail.com

[4] Lecturer, IHU, Kavala, Greece, evrochid@teiemt.gr

[5] Associate professor, SU, Sofia, Bulgaria, ivannc@uni-sofia.bg

[6] Associate professor, IR-BAS, Sofia, Bulgaria, aikrastev.iser.bas@gmail.com

[7] Assistant professor, IR-BAS, Sofia, Bulgaria r_botsova@abv.bg

[8] Associate professor, SWU, Blagoevgrad, Bulgaria, anna_andreeva@swu.bg

[9] Professor, SWU, Blagoevgrad, Bulgaria, v_stancheva@abv.bg

[10] PhD sudent, UPV/EHU, San Sebastian, Spain, lozaeta001@gmail.com

Abstract: The paper presents a linear control system framework for design of technology-based games for pedagogical rehabilitation of children with special learning needs as a central component of the proposed cyber-physical system for inclusive education. The novelty is in explicitly addressing the issue of quantitatively estimating the improvement of games in the desired direction during the design process. An advantage of the proposed approach is its applicability to small groups of children playing diverse sets of games without loss of generalisability of the linear system's model assumptions. Statistically justified experimental results are reported as providing support to the main hypotheses of the present study.

Keywords: *Inclusive education; cyber-physical systems; linear control system framework; pedagogical rehabilitation; ANOVA.*

How to cite: Dimitrova, M., Kostova, S., Lekova, A., Vrochidou, E., Chavdarov, I., Krastev, A., Botsova, R., Andreeva, A., Stancheva-Popkostadinova, V., & Ozaeta, L. (2020). Cyber-Physical Systems for Pedagogical Rehabilitation from an Inclusive Education Perspective. *BRAIN. Broad Research in Artificial Intelligence and Neuroscience, 11*(2Sup1), 186-207. https://doi.org/10.18662/brain/11.2Sup1/104

1. Introduction

Inclusive education relies on novel cyber-physical systems (CPS) and advanced technologies to fulfil its aim and provide individualised education in class. Technically speaking, any school can be considered a complex hierarchical organisation of many functional levels and can be modelled as a CPS. Its operation is based on planned activities aimed at achieving certain goals (acquired knowledge by the learners) within fixed time constraints. Inclusive education, however, poses additional demands on the entire learning process in the classroom by involving children of diverse attentional and motivational resources, who are supposed to follow a coherent teaching process during the lesson. The paper presents a novel formalised approach to the design of advanced educational tools to meet the learning needs of the individual child in the classroom of the future in a better way than today.

The developed educational technologies, presented in the paper, are interactive games with humanoid, non-humanoid and 'semi-humanoid' robots as well as Kinect based motion sensing games. An interdisciplinary group of experts was involved in the process of game design: Computing and robotics researchers, engineers, speech therapists, psychologists, social workers, ergotherapists, kinesitherapists and special education professionals. They formed a coherent interdisciplinary team, working towards a common goal – using novel technological means to support child's individual development. A particular problem in the design of novel games for children with special needs is the process of adaptation of some ad hoc designed games to the individual preferences of the child, as well as the continuous improvement of the novel games along a set of predefined pedagogical criteria. We have included this process in a formalised framework so that the individual adaptation - as a control variable - brings structure, instead of noise, in the entire system, and will be explained in the methodology section.

2. Literature review

Extensive research on pedagogical rehabilitation via technology is being carried out in the last decades (Dimitrova et al., 2019; Ghazali et al., 2020; Pliasa & Fachantidis, 2019; Tanaka et al., 2015; Van den Berk-Smeekens et al., 2020; Wainer et al., 2014). Some of the main drawbacks of the implemented methodological approaches are the following: small group of participants, diverse kinds of symptoms, different learning pace of each child, and demand for constant attention to the step-by-step learning process of the individual child on behalf of the teacher.

In the present work a methodology, aiming at overcoming some of the reported drawbacks, is proposed for design of new technologies in the form of robotic and computerised games for the educational CPS framework for pedagogical rehabilitation when special education is part of inclusive education.

Game evaluation in special education is usually performed by professionals filling in questionnaires off-line for a subsequent qualitative analysis (Pliasa, & Fachantidis, 2019; Toh et al., 2016). Our teachers, instead, were asked to rate each game immediately after the child played the game. This method provides a non-distorted account of every game played by each child in respect to the child's learning needs, since it is done immediately after the game, rather than as a follow-up of the session. The online evaluation is also an essential process, included in the linear control systems framework (LCSF) of novel game design proposed in the paper.

Numerous investigations are being conducted on using robots with children with special needs, most of them focusing on mild to medium cases of autism, attention deficit disorder, hyperactivity, cerebral palsy, etc. (Bayon et al. 2016; Charlton et al., 2005; Dimitrova et al., 2012; Huijnen et al., 2016; Kim et al., 2013). The children involved in the present study have been diagnosed with the following disorders: intellectual disability, autistic spectrum conditions, cerebral palsy, or multiple disabilities. By empowering the child to be in control of complex technological devices, the child learns implicit ways how to react to complex living, nonliving and 'seemingly living' objects such as robots. This augments child's adaptation to the outside world, the family and the overall social environment.

A robot is defined as a semi-autonomous electro-mechanical device of various appearances (non-humanoid, humanoid or 'semi-humanoid'), playing the role of a flexible interface to the software application, which is guiding it (e.g. Choregraphe for NAO[1], etc.). In behavioural terms, the robot is endowed with certain cognitive and/or social abilities; it can initiate dialogue with the child and play the role of an assistant to the teacher (Benitti, 2012; Dimitrova, 2016; Ozaeta et al., 2018;Toh et al., 2016).

The present approach investigates the issue how to design novel educational tools for pedagogical rehabilitation in special education[2] with a satisfactory degree of *construct validity* (e.g. Bolarinwa, 2015). The present

[1] https://developer.softbankrobotics.com/nao6
[2] Project H2020-MSCA-RISE-2017 No 777720 CybSPEED: Cyber Physical Systems for Pedagogical Rehabilitation in Special Education, URL: https://cordis.europa.eu/project/rcn/212970/factsheet/en

study investigates the construct of *evolving game design* for special education. Games are being improved by modifying essential aspects – functions and/or structure of the game - being evaluated by the teachers after every experimental cycle.

3. Piloting of technologies (games) for pedagogical rehabilitation in special education

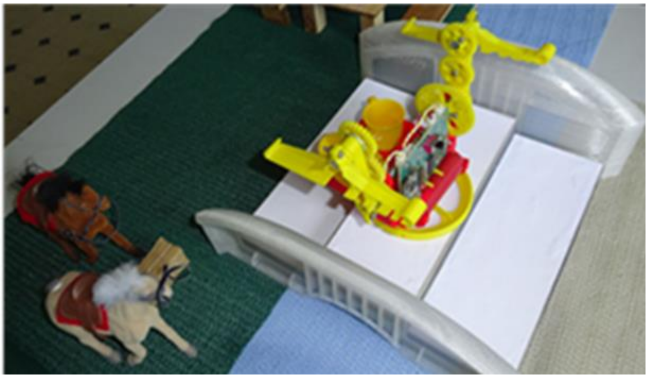

Figure 1. Walking robot BigFoot for scene exploration by the child

The non-humanoid robot, called BigFoot, used in the present study, was designed at IR-BAS (e.g. Chavdarov & Naydenov, 2019) - a walking robot, capable of 3D exploration of the environment.

Figure 2. Minion doll with an anthropomorphic hand controlled via Kinect

The 'semi' humanoid robot was a Minion Doll with an anthropomorphic hand controlled via Kinect, playing a game of number guessing by the robot after the child pointing a number with the fingers of the hand (Figure 2).

The humanoid robot was a NAO robot [3] playing exercises and singing songs with children (Figure 3).

The complete set of implemented games in the present study are given in Table 1. Games 13, 14 and 15 are newly developed games after Experiment 1 for Experiment 2.

Table 1. Games for training novel skills in special education

Type	NO	Game
a. Kinect enabled serious motion-sensing games	1	Shapes and Colors
	2	Flipper
	3	Jumpido and Fun Math
	4	Puzzle
	5	Hand Painting[a]
b. Kinect enabled humanoid robot motion control	6	NAO Imitates Child Gestures
c. Non-humanoid, semi-humanoid and humanoid robotic solutions for special educatio	7	Walking Robot "BigFoot"
	8	"Minion" Doll with Robotic Arm
	9	Gymnastics with NAO
	10	Basketball with NAO
	11	NAO Singing and Dancing - 1
	12	NAO Singing and Dancing - 2
	13	NAO Building with Cubes
	14	NAO Sorting Pictures
	15	Learn NAO

[3] For more information on NAO robot, see https://softbankrobotics.com/corp/robots/.

A. Kinect enabled serious motion-sensing games

The developed Kinect-enabled serious motion-sensing games are of two types: adapted commercial games – Flipper and Jumpido[4] as well as newly designed – Shapes and Colors, Drawing and Puzzle. The Kinect-enabled program uses the motion of child's hands/wrists to interact with the pinball objects on the screen (described in Lekova et al. 2015). The adapted Jumpido game teaches basic math abilities. It is appropriate for children who can understand spoken instructions. The goal of Shapes and Colors game is to hit the falling figure with hands or kick with the leg in a certain direction depending on the given task – either according to colour or to shape. The game develops learning and discrimination of colours and shapes as well as left-right orientation in individual or competitive settings. The goal of Puzzle is to drag a piece of the puzzle into the right place to complete the image. It develops fine motorics and sustained attention. The aim of Hand Painting is to use a gesture interface to paint on the screen. The aim is to train the fine motor skills and discrimination of colours.

B. Kinect Enabled Humanoid Robot Motion Control

A Microsoft Kinect sensor is used for motion-sensing to replicate by teleoperation the human movements in the Choregraphe platform of the NAO robot. Tracking the human motion is made to retrieve a kinematic model of the human from the video sequences and to use it as input to the kinematic modules of the robot (Azimi, 2012; Mukherjee et al., 2015).

C. Non- Humanoid, Semi-Humanoid and Humanoid Robotic Solutions for Special Education

Games with the non-humanoid robot BigFoot. Non-humanoid robots have no external resemblance to a human. The original design of a walking robot BigFoot is an example of a moving robot, capable of climbing stairs and avoiding obstacles by using several mechatronic principles of changing position in space (Chavdarov & Naydenov, 2019). The game with BigFoot enhances spatial orientation, coordination, communication, and sustaining attention of children. After the first experiment BigFoot robot appearance was modified according to the needs of the children. This is described in the respective section below and illustrated in Figure 7 a, b).

Semi-humanoid robot Minion Doll with Robotic Arm. The implemented novel device is a Minion Doll with attached an anthropomorphic hand,

[4] For more information on these games, see https://www.techlearning.com/pd-tips/video-tutorial-create-pinball-games-with-actionscript-3.

designed via 3D printing. Finger detection and gesture recognition (FDGR) algorithms used Microsoft Kinect V2, are implemented to see the gesture of the child and imitate it by the Minion (Botsova et al., 2015).

Humanoid robot NAO. The humanoid robot is defined as possessing somewhat overt or holistic resemblance to a human (Dimitrova & Wagatsuma, 2015). NAO is especially designed for children and equipped with abilities to enhance child's learning. The scenarios, developed with NAO, include individual play with the child, turn-taking game involving pairs of children, and singing and dancing games and gymnastics exercises in groups.

Gymnastics with NAO. NAO is demonstrating positions requiring balance and the children try to repeat them. Gymnastics with NAO helps improve gross and fine motor skills and is very enjoyable for the children.

Figure 3. NAO demonstrates a basketball game

Basketball with NAO. The game aims to achieve turn taking in playing basketball with NAO. One of the children displays the red ball in front of NAO's eyes and then hands it over to the other child. Meanwhile NAO has raised its hand. The other child places the ball in NAO's hand. NAO throws the ball into the basket. Then children change roles in turn. Children enjoy playing basketball individually, too.

Other game scenarios include:

NAO Singing and Dancing – 1. NAO is performing a song, which is especially created for one of the children's day centres.

NAO Singing and Dancing – 2. NAO is performing a popular singing and dancing play, asking children to reinstate how they wash hands and face.

NAO Building with Cubes. NAO grabs a cube and places it on a table, then places another on top. The game teaches children to imitate NAO's actions.

NAO Sorting Pictures. NAO recognises pictures from three different classes – animals, transport, and fruit. The game helps children learn to classify objects.

Learn NAO. NAO is asking the child to touch parts of NAO's body – head, hands, or legs. The game helps learn body parts and directions – left-right.

Table 2 summarises the developed games and the number of children, participating in each game. The first 12 games were included in the repetitive experimental sessions, while the last 3 were newly developed after the first trial.

Table 2: Number of participating children in the developed games

No	Game	No of children in each game March 2016	No of children in each game May 2016
1	***Shapes and Colors***	4	5
2	***Flipper***	6	4
3	Jumpido and Fun Math	2	
4	Puzzle	1	
5	Hand Painting		2
6	NAO Imitates Child Gestures	3	
7	***Walking Robot "BigFoot"***	6	5
8	***"Minion" Doll With Robotic Arm***	5	3
9	Gymnastics with NAO	7	
10	Basketball with NAO	4	
11	NAO Singing and Dancing –1	6	
12	NAO Singing and Dancing – 2	2	

13	NAO Building with Cubes		4
14	NAO Sorting Pictures		1
15	Learn NAO		3
	Total	46	27

The total number of participants in the games in Experiment 1 was 46 and in Experiment 2 - 27. Some children participated twice. Four of the games were tested twice (given in bold italic) and included in the analysis below.

4. Methodology of the present study

We consider one game and N (k=1,…, N) is the number of successive experiments to complete the design of the game, i.e. to validate the proposed construct of *evolving game design*.

Before the experiments, a pilot testing of the games in laboratory settings was performed and then tested in real-life settings (day care centres) in Experiment 1. The results of Experiment 1 are assessed according to previously defined criteria by a survey, consisting of 9 Likert scales. After the assessment, new improvements in the game (control variable $\boldsymbol{u}$) are incorporated. Our MISO (multi-input single-output) linear control system framework (LCSF) demonstrates that the succession of games need not be the same, and their number equated, too. Multi-input are the characteristics of the game and single-output is the abstract increment of child's development as a result of the skill's training trial. This is reflected in the transition from Experiment 1 to Experiment N for each individual child in Figure 4, where $\boldsymbol{x}$ and $\boldsymbol{u}$ are vectors, and y are scalars.

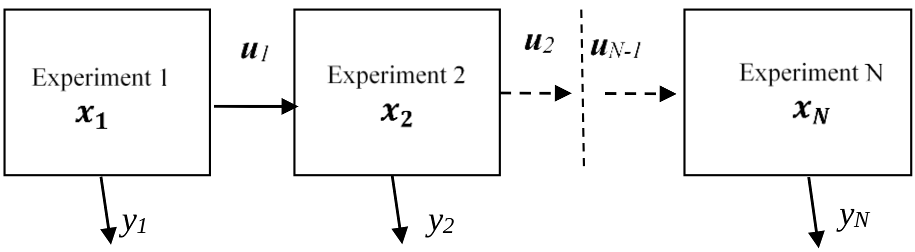

Figure 4. Experimental succession of games within the MISO linear control system.

The assumption, made by the present linear-systems approach, is that the teacher's assessment is the most 'objective' measure of the child's learning progress, achieved via the game. This assessment is more 'objective' than any others' in respect to the individual child - e.g. of a parent or external expert. Therefore, the teacher's evaluation from Experiment k to Experiment $k+1$ is in an almost linear dependence.

Ethics. Teachers collected Informed Consents from parents of all involved children prior to the experiments. Ethics permission for conducting the study was obtained from the Ethics Committees of the involved day centres in the towns of Bansko and Gotse Delchev in Bulgaria. All procedures complied with the "WMA declaration of Helsinki – ethical principles for medical research involving human subjects"[5] and GDPR[6].

Set up and procedure. The 3 groups of games took place in the common area of each day centre. A teacher brings a child to the game scene and helps in explaining the rules of the game. The child plays the game with the constant assistance of the teacher.

Follow-up. Brainstorming sessions are conducted after each experiment with all involved – experts and designers - for qualitative and quantitative assessment of the designed games.

Game evaluation. Right after each game the teacher gives assessment on 9 Likert scales from 1 to 5. The fact that scores are collected in a "paper and pencil" manner is not crucial for the proposed evaluation methodology. Scores can be collected by any type of computer interface or via the touch screen of a smart phone, for example. Criterion 7 "Level of difficulty" of the game was not included in the multidimensional analysis, leaving the number of game dimensions to 8, as given in Table 3.

[5] For more information on the Declaration of Helsinki, see https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects.

[6] For more information on GDPR, see https://eur-lex.europa.eu/eli/reg/2016/679/oj.

Table 3. Evaluation criteria of the proposed games (Matrix A)

Criterion
Appropriateness of the game
Motivation of the child
Impact on cognitive development
Impact on motor development
Impact on social development
Interest of the child
*Level of difficulty of the game**
Role of collective participation
Role in formation of novel policies

*Not included in the state matrix A

A. Formal considerations of the LCSF

The *increment* of skills improvement of the children as a result of the games is represented by *m* in number aspects of the game – in particular here by *m* = 8 assessment dimensions, represented as 8 Likert scales. Each Likert scale is 5 point. The important assumption is that the teachers' assessment is *implicit*, but *objective* since they know best the children and their learning needs. The improvements in the games after each experiment are considered the manipulated (i.e. control) variables ***u***. The process terminates when the game has no further capacity for improvement.

B. System description

- ***N***– number of experiments;
- For the participating child and the tested game (for each experiment) an eight-dimensional state variable $\boldsymbol{x_k} = [x_1 x_2 \dots x_8]^T, k = 1, \dots, N$ is defined, where the vector elements represent:
- $x_1 -$ Appropriateness of the game, $x_2 -$ Motivation of the child; $x_3 -$ Impact on cognitive development; $x_4 -$ Impact on motor development; $x_5 -$ Impact on social development, $x_6 -$Interest of the child; $x_7 -$ Role of collective participation; $x_8 -$ Role in formation of novel policies.
- The initial values of the state vector $\boldsymbol{x_0}$ have been defined after the pilot test of the game in laboratory settings.
- The control variable $\boldsymbol{u_k} = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \in \mathcal{R}^2, k = 1,2, \dots, N$ is a two-dimensional vector, representing the types of improvements of the game. For different situations, the vector can be defined as representing various types of game modifications according to the current pedagogical needs and can be of any dimension. Two types of

improvements are considered in the present study - first, adding new *functions in the games* u_1 and second, adding new *elements in the game construction* u_2, which makes the vector two-dimensional.

- An output *scalar variable* y is defined, representing the integral skills level, attained as a result of playing the games. It is reflected in the average game assessment by the teachers.
- A diagonal state matrix $\boldsymbol{A} \in \mathcal{R}_{8\times 8}$ is introduced with elements on the main diagonal representing the hypothetical state of child's development that will be influenced by the game parameters $x_1, x_2, \dots, x_8$ (Likert scale dimensions).
- A control matrix $\boldsymbol{B} \in \mathcal{R}_{8\times 2}$ is introduced, representing the effect on the child's development by the introduction of the proposed changes in the game (control type u_1 and/or u_2) .
- A matrix $\boldsymbol{C} \in \mathcal{R}_{1\times 8}$ is introduced, representing the (final) overall influence of the game parameters (vector $\boldsymbol{x}$) on the development of the child.
- Then the description of the system is:

$$\boldsymbol{x}(k+1) = \boldsymbol{A}\boldsymbol{x}(k) + \boldsymbol{B}\boldsymbol{u}(k); k = 0,1 \dots, N-1$$
$$y(k) = \boldsymbol{C}\boldsymbol{x}(k), k = 1, \dots, N$$

A simulation will reveal the dependency of the output *y* on the magnitude of u_1 and/or u_2, as stated in the hypotheses below. More elaborate simulation-based predictions of the model will be performed in future studies of the LCSF applicability to novel game design for inclusive education.

c) Main hypotheses

H1. The modifications made after Experiment 1 in terms of adding new functions in the games - u_1, and adding new elements in the game construction - u_2, will bring higher overall ranking of the games, made by the teachers, after Experiment 2.

H2. The bigger the modification of the game (objective parameter), the bigger difference this will make as reflected in the teachers' scores (subjective evaluation, yet more objective than possibly made by parents or experts). Ideally, the dependence is linear.

5. Results and discussion

Experiment 1 was conducted in March 2016 at two day-care centres for children with special learning needs. Experiment 2 was conducted in May-June 2016 at the same centres with the modified games, with most of the previously participating children (18) plus three new participants. The total number of participating children was 21. The number of collected experimental protocols in Experiment 1 was 46 and in Experiment 2 – 27 (73 in total).

The games of interest for the present analysis are given in bold italic in Table 3. They were used to test the formulated hypotheses **H1** and **H2**. The experimental protocols were filled by the teachers after every game of the participating child by assessing the game along the 9 dimensions as Likert scales (8 used in the model and 1 "difficulty" dimension) and writing up comments (if any).

a) Experimental results

Stimulus material - games. All games were presented in the previous section. Two of the games – Puzzle and NAO Sorting Pictures - obtained single protocols and were excluded from the statistical analysis (Table 3).

Difficulty ranking of the games. Criterion 7 in Table 1 evaluates the level of difficulty of the games and was analysed separately. Figure 5 presents the average scores of the game difficulty, given by the teachers.

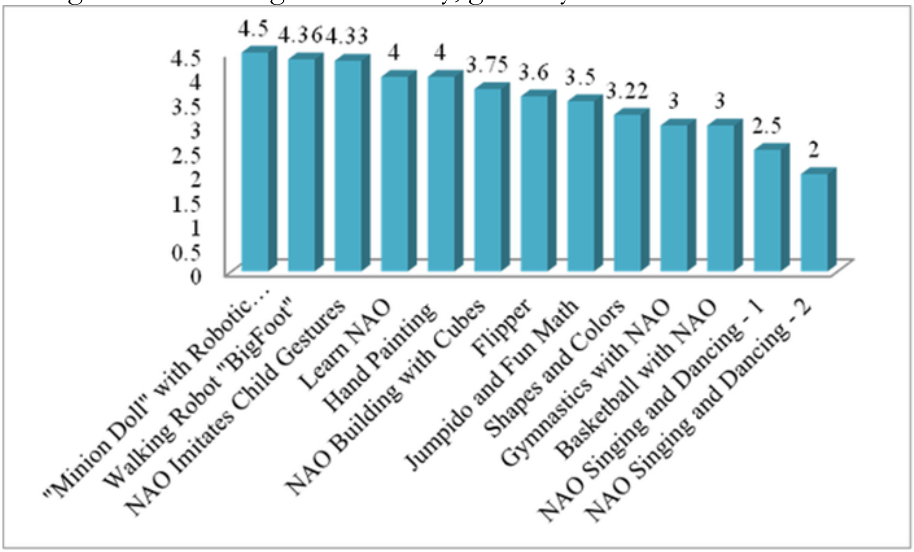

Figure 5. Difficulty ranking of the implemented games after Experiment 2

Single factor ANOVA revealed significant difference of the level of difficulty of the designed games, $F\ (12, 58) = 2.28$, $p = 0.02$. The same relation holds if the three games with only 2 protocols each are taken out of the sample, $F\ (9, 55) = 2.49$, $p = 0.02$. This is in line with the ambition to provide the teachers with a variety of games with varying levels of difficulty for individual work according to the needs of the child. The most difficult games turn out to be the games designed with semi-humanoid and non-humanoid robots - Walking Robot BigFoot - (Figure 1) and Minion Doll with Robotic Arm (Figure 2). The reason for this is, probably, the cognitive load they impose on children with learning difficulties. Understandably, the easiest games are singing and dancing, as well as collaborative games with a humanoid robot NAO (Figure 3). The humanoid robot seems to provide intuitive 'outreach' to the children and is welcomed very emotionally by them.

Ranking of the games by the teachers for overall 'applicability' of the game. A measure for 'game applicability' is considered the mean of all averaged scores for each game and each criterion (except the 'difficulty' criterion). It corresponds to the value of the system's output *y*.

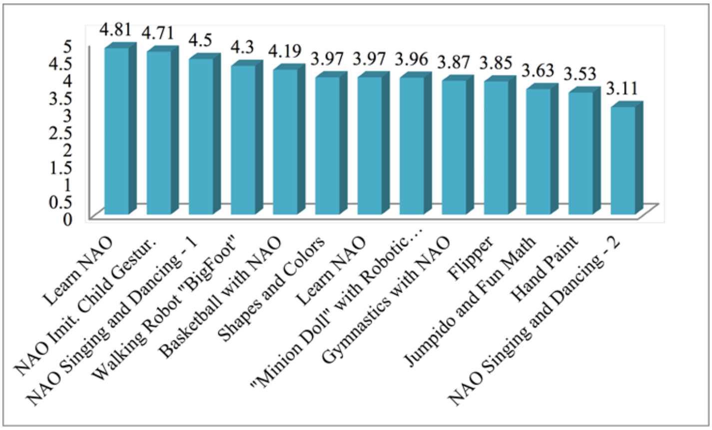

Figure 6. Ranking according to the overall applicability of all games in both experiments

One-way ANOVA revealed substantial differences in the teacher evaluations of all games tested in both experiments, $F(12, 117) = 7.98$, $p < 0.0000$. Highest scores were given to the easy games, whereas the most difficult games were evaluated in the middle of the rank. The teachers assessed as applicable all the games, with varying degree of applicability in their work with children.

b) Test of the main hypotheses

The aim of Experiment 2 was to introduce improvements in line with the main hypotheses of the present study - **H1** and **H2**. In two sessions – Experiments 1 and 2 - we tried to test as many games as possible.

Collecting experimental protocols from the teachers, however, was not easy, because the individual work with the children slowed down the process. Also, it was not possible to assess the individual child performance in group activities. This is the reason for having only 4 games tested in two subsequent experiments according to the proposed model – Shapes and Colours, Flipper, Walking robot BigFoot and Minion Doll with Robotic Arm.

The performed qualitative analysis (brainstorming session of all involved in the game design) after Experiment 1 revealed the following: The games can be grouped into 3 clusters according to their readiness to be included in the teaching programme of the day centres – 1) games of sufficient degree of completeness (Cluster 1), 2) games of approximate degree of completeness (Cluster 2) and 3) games of experimental degree of completeness (Cluster 3). Cluster 1 consists of the following games: Walking Robot BigFoot, Shapes and Colors, Flipper, NAO Singing and Dancing -1, NAO Singing and Dancing – 2, Jumpido and Fun Math. It includes both difficulty and easy games, which are almost complete to go on the market after the final testing of their design. Of these, Walking Robot BigFoot, Shapes and Colors and Flipper are used to test our formal model.

Cluster 2 consists of the games Basketball with NAO, NAO Imitates Child Gestures and Gymnastics with NAO. Only minimal improvements are necessary for these – smoother movements of the robot and better vocation during performance. Although many children participated in these games in both experiments, protocols could not be collected for the formal analysis, because it was difficult for the teachers to fill in protocols for individual children after collective games.

Cluster 3 consists of the games Minion Doll with Robotic Hand and Puzzle. It was necessary to improve the technical implementation of the games in terms of *adding new functions* in the games – u_1 - according to the proposed *evolving game design* approach. The new function was a multimedia effect – the Minion Doll sang a song when the child identified correctly the gesture displayed by the doll.

The game Walking Robot BigFoot was the case with *adding new elements* in the game construction – u_2 - according to the proposed model. Teachers assessed the game extremely high for its appropriateness to enhance child's cognitive development and abstract reasoning abilities (Cluster 1). The reluctance of some of the children to play the game, however, was explained by the teachers with the fact that children carried around favourite toys and did not want to leave them aside for the game. For this reason, the robot was augmented with a platform, where the children could place their toys and perform the game more confidently. Adding the platform was, in fact, the added new element in the construction, according to **H1** (Figure 1).

Another change from Experiment 1 to Experiment 2 was switching the interface from a keyboard to a joystick, which brought the control and the BigFoot robot within the eyesight of the child. This modification of the game, being qualitatively introduced, additionally contributing to both u_1 and u_2, is expected to bring results in quantitative terms, according to the second main hypothesis of the study **H2**: Higher scores will be obtained by the games with changes in the values of vector **u**, which are *bigger* in magnitude, than on games with similar, but *less in magnitude* changes. Two sub-hypotheses were formulated:

Sub-hypothesis 1 (**SH1**). The games, belonging to Cluster 1 – Shapes and Colors and Flipper - require little improvement and will lead to scores, given by the teachers, which will not differ largely from Experiment 1 to Experiment 2. It is also expected that the teacher assessment will be influenced by a 'familiarity effect' in terms of somewhat lowering the score from Experiment 1 to Experiment 2 of identical games (see the text below).

Figure 7. Initial set up (left) - the child controls the BigFoot robot via laptop interface, but pays attention to the toys outside eyesight; Walking robot BigFoot modified after Experiment 1 (right) – The robot is augmented with a platform to place the toys. The child controls its movements toward the toys via a joystick, so that the robot, the toys and the control are within the eyesight of the child

Sub-hypothesis 2 (**SH2**). The game, belonging to Cluster 3 – Minion Doll with Robotic Arm – requiring improvement of the implementation – as well as the game Walking Robot BigFoot, belonging to Cluster 1, but modified according to the child's preferences – will result in significant differences in the assessment of the teachers from Experiment 1 to Experiment 2, since the value of u_2 will be bigger for these games, than for the other 2 games – Flipper and Shapes and Colours.

c) Validation of the evolving game design construct

Two-way ANOVA with replication did not reveal main effect of game, nor main effect of Experiment (1 or 2), however it revealed significant interaction between these 2 factors, $F(3, 56) = 3.70$, $p = 0.017$ (Figure 8). The slight decline in the values for Flipper and Shapes and Colors can be explained with the effect of 'familiarity' on the part of the teachers. As it is known from experimental psychology, a familiarity effect brings faster response to 'old' than to 'new' items in 'old-new' recognition tasks (e.g. Appelman, & Mayzner, 1981). Here, a familiarity effect on the part of the teacher, who is assessing a game for the second time, means that the teachers are faster in recognising 'old' aspects of the game, making them more critical the second time as a result of this cognitive process - thus supporting **SH1**[7].

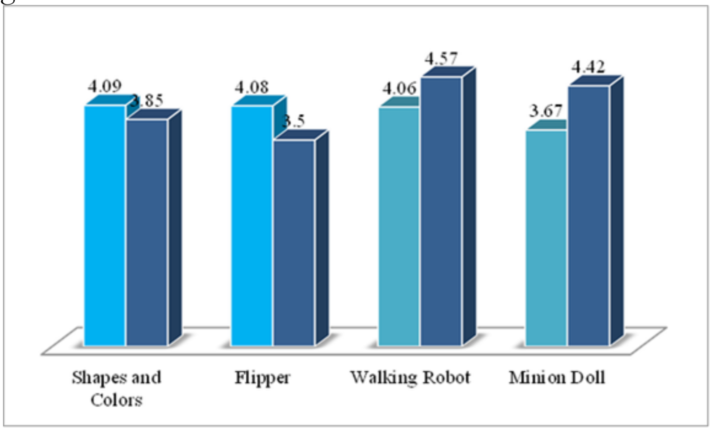

Figure 8. Light bars represent the mean scores for 4 games after Experiment 1; Dark bars - after Experiment 2

The effect of increasing the mean scores for the Walking Robot and Minion Doll games from Experiment 1 to Experiment 2 is clearly seen in Figure 8 and not observed in the other two games – Flipper and Shapes and Colors. Therefore, u_2 is big enough to overcome the possible 'familiarity effect' by increased *saliency* effect (e.g. Ambady & Rosenthal, 1993) from Experiment 1 to Experiment 2 for the Walking Robot and Minion Doll games.

Two-way ANOVA with replication did not reveal main effect of game on the scores, and no interaction, but revealed main effect of Experiment for

[7] This is just an assumption for cases of complex stimuli like games, which needs further investigation in similar experimental conditions.

the games Walking Robot BigFoot and Minion Doll with Robotic Arm in teacher's assessment of children's *motivation* (Criterion 2) and *interest* (Criterion 6) as expected, $F(1, 28) = 4.77$, $p = 0.038$, supporting **SH 2**.

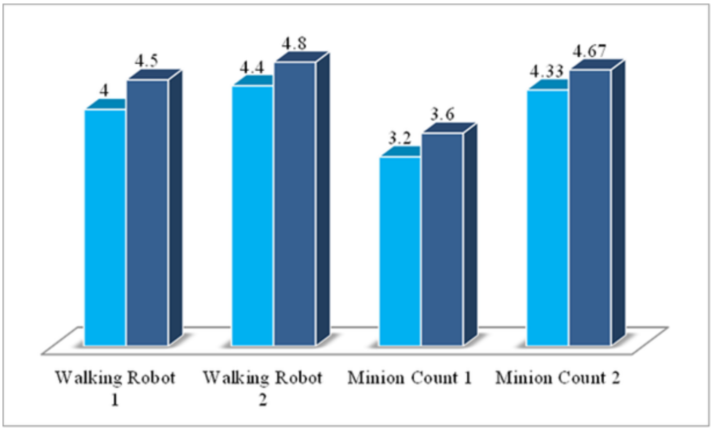

Figure 9. Mean scores for *motivation* (light bar) and *interest* (dark bar) of children playing the Walking Robot and the Minion Doll games in Experiment 1 and Experiment 2

This means that the teachers are confident in giving higher scores after Experiment 2 to the dimensions of *motivation* and *interest* of the child after the game modifications, reflected in u_1 and u_2 of vector $\boldsymbol{u}$, where u_1 refers to the modification of the game Minion Doll with Robotic Hand and u_2 - to the modification of the game Walking Robot BigFoot (Figure 9).

6. Limitations of the paper

A serious problem of the present study is the limited number of participating children. In such a case there is always a danger not to reject a false null hypothesis (Type II error) due to the possibility that the underlying distribution of game features' assessments from Experiment 1 to Experiment 2, given by the teachers, is not normal. However, we have relied on the assumption that the most objective assessment of the games in respect to each individual child's learning needs can, and will be given by the teachers, rather than parents or external experts. Therefore, we expect the increase of the sample size – i.e. number of teachers' opinions on the games in respect to more children involved – to preserve the assumed *normality* of the underlying distributions of the teachers' assessments. A well-known statistical regularity is that, if significant difference is obtained with a small sample, it is most likely to hold with a bigger sample, whereas the opposite does not hold, supporting the expectation that this effect will be replicated in a larger study. Therefore, we expect to obtain similar dependencies to the observed in the present study in our future experiments with newly designed games - same or different - for special education with applicability to inclusive education classes.

Another limitation of the present study is the reliance solely on teacher's evaluations of games in respect to game influence on child's development. A valuable contribution to the current linear systems framework for evaluation of novel educational tools for special education would be including, in parallel, other types of assessment of the influence of games on children development, such as various types of behavioral indicators or bio-signal feedback from clinical practice (e.g. Hamzah et al., 2014; Katmada et al., 2015). This will certainly help validate the construct of *evolving game design* for special education, which was not possible to in the present study, but can be arranged without difficulty in future studies.

7. Conclusions

The paper presented a set of games, designed to provide teachers with a palette of technological means for enhancing the motor, cognitive, and social skills of children in special education. These games are also applicable in inclusive education, especially being in a format, supporting turn-taking games and collaborative play. The paper explicitly addressed the issue of quantitatively estimating the improvement of games in a *desired direction* towards better game applicability. The proposed evolving game design was successful in providing a method for assessing the improvement of games from Experiment 1 to Experiment 2 by implementing a linear control system framework. We believe that the approach is applicable in inclusive education settings and plan to continue developing it in the future.

Acknowledgement

The authors age grateful to the directors and teachers of the day centres in the towns of Bansko and Gotse Delchev in Bulgaria for participating in the study and providing valuable feedback on the de-signed games. This research has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie Grant No 777720 for project CybSPEED (2017-2021), by the Financial Mechanism of EEA under Grant D03-90/15.05.2015 for project METEMSS (2015-2016), and by the European Regional Development Fund within the OP “Science and Education for Smart Growth 2014 - 2020”, Project CoC "Smart Mechatronic, Eco- and Energy Saving Systems and Technologies", № BG05M2OP001-1.002-0023. L. Ozaeta has been supported by a Predoctoral Grant from the Basque Country.

References

Ambady, N., & Rosenthal, R. (1993). Half a minute: Predicting teacher evaluations from thin slices of nonverbal behavior and physical attractiveness. *Journal of personality and social psychology*, *64*(3), 431-441. https://doi.org/10.1037/0022-3514.64.3.431

Appelman, I. B., & Mayzner, M. S. (1981). The letter-frequency effect and the generality of familiarity effects on perception. *Perception & Psychophysics*, *30*(5), 436-446. https://doi.org/10.3758/BF03204839

Azimi, M. (2012). Skeletal Joint Smoothing White Paper. *Microsoft Developer Network*. http://msdn.microsoft.com/en-us/library/jj131429.aspx

Bayon, C., Raya, R., Lara, S. L., Ramírez, O., Serrano, J., & Rocon, E. (2016). Robotic therapies for children with cerebral palsy: a systematic review. *Translational Biomedicine*, *7*(1), 44. https://doi.org/10.21767/2172-0479.100044

Benitti, F. B. V. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education*, *58*(3), 978-988. https://doi.org/10.1016/j.compedu.2011.10.006

Bolarinwa, O. A. (2015). Principles and methods of validity and reliability testing of questionnaires used in social and health science researches. *Nigerian Postgraduate Medical Journal*, *22*(4), 195-201. https://doi.org/10.4103/1117-1936.173959

Botsova, R., Lekova, A., & Chavdarov, I. (2015). Imitation learning of robots by integrating Microsoft Kinect and PID Controller with a sensor for angular displacement in a robot joint. *CompSysTech '15: Proceedings of the 16th International Conference on Computer Systems and Technologies June 2015* (pp. 268-275). https://doi.org/10.1145/2812428.2812455

Charlton, B., Williams, R. L., & McLaughlin, T. F. (2005). Educational games: A technique to accelerate the acquisition of reading skills of children with learning disabilities. *International Journal of Special Education*, *20*(2), 66-72.

Chavdarov, I. & Naydenov, B. (2019). Design and kinematics of a 3-D printed walking robot "Big Foot", overcoming obstacles. *International Journal of Advanced Robotic Systems*, 1–12. https://doi.org/10.1177/1729881419891329

Dimitrova, M. (2016). *Cognitive Theories for Socially-Competent Robotics in Education*. Lambert Academic Publishing.

Dimitrova, M. & Wagatsuma, H. (2015). Designing humanoid robots with novel roles and social abilities. *Lovotics*, *3*, Article 112. https://doi.org/10.4172/2090-9888.1000112

Dimitrova, M., Vegt, N., & Barakova, E. (2012). Designing a system of interactive robots for training collaborative skills to autistic children. *2012 15th International Conference on Interactive Collaborative Learning (ICL), Villach, 2012* (pp. 1-8). https://doi.org/10.1109/ICL.2012.6402179

Dimitrova, M., Wagatsuma, H., Tripathi, G. N., & Ai, G. (2019). Learner attitudes towards humanoid robot tutoring systems: measuring of cognitive and social motivation influences. *Cyber-Physical Systems for Social Applications* (pp. 62-85). IGI Global. https://doi.org/10.4018/978-1-5225-7879-6.ch004

Ghazali, A. S., Ham, J., Barakova, E., & Markopoulos, P. (2020). Persuasive Robots Acceptance Model (PRAM): Roles of social responses within the acceptance model of persuasive robots. *International Journal of Social Robotics*, 1-18. https://doi.org/10.1007/s12369-019-00611-1

Hamzah, M. S. J., Shamsuddin, S., Miskam, M. A., Yussof, H., & Hashim, K. S. (2014). Development of interaction scenarios based on pre-school curriculum in robotic intervention for children with autism. *Procedia Computer Science*, *42*, 214-221. https://doi.org/10.1016/j.procs.2014.11.054

Huijnen, C. A., Lexis, M. A., Jansens, R., & De Witte, L. P. (2016). Mapping robots to therapy and educational objectives for children with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *46*(6), 2100-2114. https://doi.org/10.1007/s10803-016-2740-6

Katmada, A., Mavridis, A., Apostolidis, H., & Tsiatsos, T. (2015). Developing an adaptive serious game based on students' bio-feedback. *2015 6th International Conference on Information, Intelligence, Systems and Applications (IISA), Corfu, 2015,* (pp. 1-6). https://doi.org/10.1109/IISA.2015.7387975

Kim, E. S., Berkovits, L. D., Bernier, E. P., Leyzberg, D., Shic, F., Paul, R., & Scassellati, B. (2013). Social robots as embedded reinforcers of social behavior in children with autism. *Journal of Autism and Developmental Disorders*, *43*(5), 1038-1049. https://doi.org/10.1007/s10803-012-1645-2

Lekova, A., Stancheva, V., Krastev, A., Dimitrova, M., & Wagatsuma, H. (2015). Redesign of computer games towards serious motion-sensing games for children with limited physical skills: A developer perspective. *Proceedings of the ICT Innovations 2015*.

Mukherjee, S., Paramkusam, D., & Dwivedy, S. K. (2015). Inverse kinematics of a NAO humanoid robot using kinect to track and imitate human motion. *2015 International Conference on Robotics, Automation, Control and Embedded Systems (RACE), Chennai, 2015* (pp. 1-7). https://doi.org/10.1109/RACE.2015.7097245

Ozaeta, L., Graña, M., Dimitrova, M., & Krastev, A. (2018). Child oriented storytelling with NAO robot in hospital environment: preliminary application results. *Problems of Engineering Cybernetics and Robotics*, *69*, 21-29.

Pliasa, S., & Fachantidis, N. (2019). Can a robot be an efficient mediator in promoting dyadic activities among children with Autism Spectrum Disorders and children of Typical Development? *BCI'19: Proceedings of the 9th Balkan Conference on Informatics* (pp. 1-6). https://doi.org/10.1145/3351556.3351592

Tanaka, F., Isshiki, K., Takahashi, F., Uekusa, M., Sei, R., & Hayashi, K. (2015). Pepper learns together with children: Development of an educational application. *2015 IEEE-RAS 15th International Conference on Humanoid Robots (Humanoids)*, Seoul, 2015, (pp. 270-275). https://doi.org/10.1109/HUMANOIDS.2015.7363546

Toh, L. P. E., Causo, A., Tzuo, P. W., Chen, I. M., & Yeo, S. H. (2016). A review on the use of robots in education and young children. *Journal of Educational Technology & Society*, *19*(2), 148-163. http://www.jstor.org/stable/jeductechsoci.19.2.148

Van den Berk-Smeekens, I., Van Dongen-Boomsma, M., De Korte, M. W., Den Boer, J. C., Oosterling, I. J., Peters-Scheffer, N. C., Buitelaar, J. K., Barakova, E. I., Lourens, T., Staal, W. G. & Glennon, J. C. (2020). Adherence and acceptability of a robot-assisted Pivotal Response Treatment protocol for children with autism spectrum disorder. *Scientific Reports*, *10*(1), 1-11. https://doi.org/10.1038/s41598-020-65048-3

Wainer, J., Dautenhahn, K., Robins, B., & Amirabdollahian, F. (2014). A pilot study with a novel setup for collaborative play of the humanoid robot KASPAR with children with autism. *International Journal of Social Robotics*, *6*(1), 45-65. https://doi.org/10.1007/s12369-013-0195-x