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Developing Brain Computer Interface for Motor Imagery Mental Commands

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***Abstract* — In this study we propose how to design and develop brain computer interface for motor imagery (MI) where the training is based on action observation of a robot's body parts and MI activities in terms of electroencephalogram (EEG) signals are featured and classified by Support Vector Machines. As the classification process is binary, most relevant features under study are based on statistical changes. The portable brain-aware device Emotiv EPOC is used to track and transmit EEG signals while the human is focusing and following positional directions, which are translated into navigation commands for the robot. The designed by us EEG-based portable Brain-Computer Interface (BCI) measures and features the brain electrical activity for an observation/execution matching system. The electrodes in the parietal lobe, the area involved in transforming visual information into motor commands, together with "smart artifacts" induced in the raw EEG signals are used for classifying the type of the mental command.**

***Keywords* — Brain-computer interface, Motor imagery, Human-robot interaction, Pedagogical rehabilitation for children with SEN, SVM.**

I. INTRODUCTION

Our past experience in spatial orientation with children with Special Educational Needs (SEN) has shown that their basic skill is far below expected, which in turn means they need a different and task engagement approach for repetitions using their mind power and learning by imitation [1]. The Mirror Neuron System (MNS) [2] is believed to provide a basic mechanism for social behaviors such as action recognition and imitation. Thus, exploiting socially assistive robots for repetition by imitation we design brain-robotic scenarios how to create habits for orientation in space.

All human behaviors involve motor functions, from walking to simple picking up a glass of water, where the brain has not only to contract the muscles but has to estimate, execute and plan other factors, such as the volume of the water, the shape of the glass, the trajectory, etc. In this study we used the electroencephalogram (EEG) signals correlated with all mental activities underlying the motor imagery (MI) to identify observation/execution matching. Motor imagery is defined as the cognitive process of imagining the movement of your own body part without actually moving that body part [3]. Since self-cognition is difficult for children with SEN, to obtain consistency in mind training and, consequently, use of this training in terms of mental commands, we propose a new model for training – a Brain-Computer Interface (BCI) training by action observation for imagining the movements of the robot's body part.

Novel approaches in HCI include the use of information technologies and, specifically, the use of brain aware devices and Brain-Computer Interface which bypasses the conventional channels of communication, i.e. muscles, and provides direct communication and control between the human brain and the physical devices. BCI translates different patterns of brain activity into commands in real time [4]. Recently, portable, non-invasive and affordable EEG commercial devices for "gaming" or "well-being sustainability" have emerged [5]. They record the brain activity and measure the change in brain pulse voltage by electrodes on the scalp. We use low resolution devices "EPOC" or "INSIGHT" (Fig.1.) by EMOTIV bioinformatics company [6]. The electrode locations (INSIGHT ones are discriminated by red circles) are shown on Fig.1.a according to the 10-20 international EEG system (Fig.1.b), recommended by the International Federation of Societies for Electro-encephalography and Clinical Neurophysiology [7]. Although both devices have low resolution and are with a few electrodes, they provide high-quality output neural signals [8]. More electrodes are positioned around the frontal and prefrontal lobes and they pick up signals from facial muscles and the eyes. The frontal sensors induce noise in EEG signals - however we also use these signals to classify which muscle groups are responsible for the artifacts. These so-called "smart artifacts" induced in pure EEG signals are diverted and classified to map the activation in different muscle groups and eye movement into events and we used them for detecting the motor imagery activities.

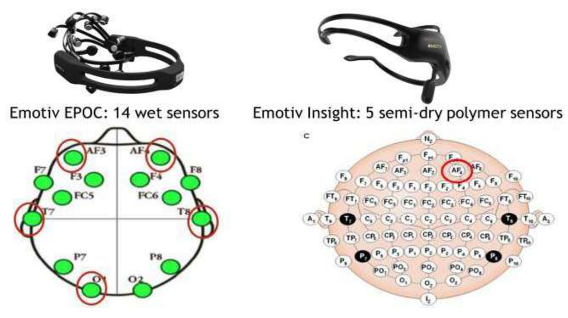

Fig. 1. EMOTIV BCI technologies and electrode locations according to the 10-20 international EEG system.

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In the current study we have developed a BCI to be used in pedagogical scenarios, mediated by socially assistive robots. BCI measures and features in real time the brain electrical activity behind the mental commands for spatial orientation by motor imagery of the robot head, arms or legs. The robots are controlled by BCI and this integration of both technologies engages the spatial orientation of children with SEN by action observation and reinforces their attention. First, they have to create personally a mental command for each direction. Creating "Mental Commands" is a process to train the BCI system to recognize human background mental state from imagining the consequences of the command. In order to recruit and facilitate the imagination during the training phase, we bound the mental commands to different robot movements by analogy to the Emotiv EPOC Control Center [9] that supports animations of a 3D cube (or a car) during the training for PUSH, PULL, LIFT, DROP, LEFT, etc. This induces artifacts form eye movements and we use these "smart artifacts" complementary to the pure EEG signals placed on the temporal, parietal and occipital lobes. The BCI-Robot framework, developed in the frame of the CybSPEED project [10], contains EMOTIV brain headset for tracking, processing and translating EEG data into mental commands, as it is illustrated on Fig.2.

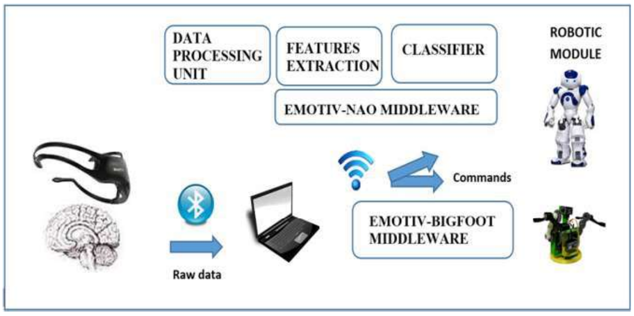

Fig. 2. BCI-Robot wireless framework for training and control

A research protocol, describing how the motor imagery mental commands, can be tracked by physiological (neural data) observations and how data will be recorded and used, was submitted to the Ethics Committee for Scientific Research (ECSR) of the Institute of Robotics, Bulgarian Academy of Sciences (IR-BAS) and approved in October, 2018.

The paper is organized as follows: Section II presents related work about neuroscience implications for motor imagery and a review for signal processing techniques for motor imagery BCI. Section III presents the used materials and methods. Section IV presents the classification results and the conclusion follows.

II. Related Works

A. Neuroscience implications for the motor imagery

A neuropsychological interpretation how the brain structures participate in mental simulation of motor behavior can be found in [11]. According to the anatomy of movement all human behaviors involve motor functions, from walking to simple picking up a glass of water, where the brain has to contract the muscles and their sequence for grasping the glass, however also has to estimate and execute the force needed to pick up the glass. Planning of other factors, like the volume of water and the material the glass is made from, also influence the brain calculations. Therefore, many anatomical regions need to be involved in motor tasks and the main regions of the motor cortex involved in the planning, control, and execution of voluntary movements are shown on Fig.3. The motor cortex is an area of the frontal lobe located in the posterior precentral gyrus immediately anterior to the central sulcus.

The primary motor cortex (PMC) is a brain area located in the frontal lobe and its role is to generate brain impulses that control the execution of movement by activating skeletal muscles. Left hemisphere controls the right side of the body and vice versa. Other regions of the cortex involved in motor function are the premotor cortex, posterior parietal cortex and the supplementary motor area (SMA). *The posterior parietal cortex is involved in transforming visual information into motor commands.*

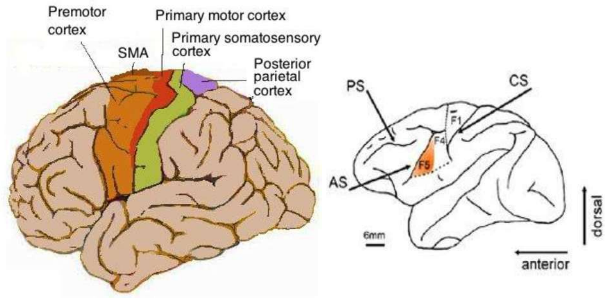

Fig. 3. Main regions of the motor cortex (adapted from Wikipedia). https://en.wikipedia.org/wiki/Motor_cortex, accessed January, 2020.

A 'motor' theory of social development and its relation to mirror neurons (MNs) is first proposed by Rizzolatti [2]. A set of F5 neurons ("mirror neurons", n = 92) became active both when one is performing a given action and when one is observing a similar action performed by an experimenter. Many research efforts have been involved in motor theories of cognitive and social development in humans by providing a potential neural mechanism underlying an action observation/execution matching system [12, 13, 14]. It has been proposed that this system plays a fundamental role in the development of complex social and cognitive behaviors such as imitation and action recognition.

Children with ASD often exhibit early difficulties with action imitation possibly due to low-level sensory or motor impairments [12]. EEG activation displays differences in the pre-motor cortex and supplementary motor area between normal individuals and individuals with high and low traits of autism [14]. Children with ASD exhibit greater beta-ERD than their control peers but post-movement beta rebound (PMBR) is absent [12]. Typically developing adolescents exhibited adult-like patterns of motor signals, e.g., event-related beta and mu desynchronization (ERD) before and during the movement and a post-movement beta rebound (PMBR) after the movement. In contrast, those with ASD exhibited stronger

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beta and mu-ERD and reduced PMBR. Behavioral performance was similar between groups despite differences in motor cortical oscillations.

B. Review for signal processing techniques for motor imagery brain computer interfaces

Motor Imagery Brain Computer Interface provides a non-muscular channel for communication to those, who are suffering from neuronal disorders [15]. An example for a system with BCI for MI has been reported to be effective for stroke rehabilitation [3]. Authors in [15] discuss existing challenges in the domain of motor imagery brain-computer interface and suggest possible research directions. The designing of an accurate and reliable MI-BCI system requires the extraction of informative and discriminative features. Common Spatial Pattern (CSP) has been potent and is widely used in BCI for extracting features in motor imagery tasks. The classifiers translate these features into device commands. Many classification algorithms have been devised, among those Support Vector Machine (SVM) and Linear Discriminate Analysis (LDA) have been widely used. In recent studies deep neural networks for classification of motor imagery tasks are used. The research paper [15] provides a comprehensive review of dominant feature extraction methods and classification algorithms in BCI for motor imagery tasks.

More studies, using EEG signals and features of motor imagery to identify different imagery activities can be found in [16], where the authors propose similar to our approach: Emotiv EPOC is used to extract EEG features about MI based on electroencephalogram signals. They use only AF3, AF4, FC5 and FC6 to capture EEG signals. A feature vector of EEG signals is transferred by a Wavelet transform. The four classified actions are analyzed through SVM algorithm with the Gauss kernel function. However, we consider that these 4 electrodes are not enough to identify neural activities underlying the MI by action observation, because more electrodes need to be analyzed in the parietal lobe, the area involved in transforming visual information into motor commands. We studied the electrodes positioned at the posterior parietal cortex and supplementary motor area during action observation and our feature extraction involves the neural activities underlying the "Observation–execution matching system".

III. MATERIALS AND METHODS

A. Hypothesis and relevance of the materials and methods

Our hypothesis is the following: 1) Spatial orientation of children with SEN will be increased by practicing navigation skills by imitation, mediated by socially assistive robots in an entertaining and playful environment. 2) A non-intrusive monitoring and assessment by BCI will provide EEG evidence for the presence of an "observation–execution matching system" in these children.

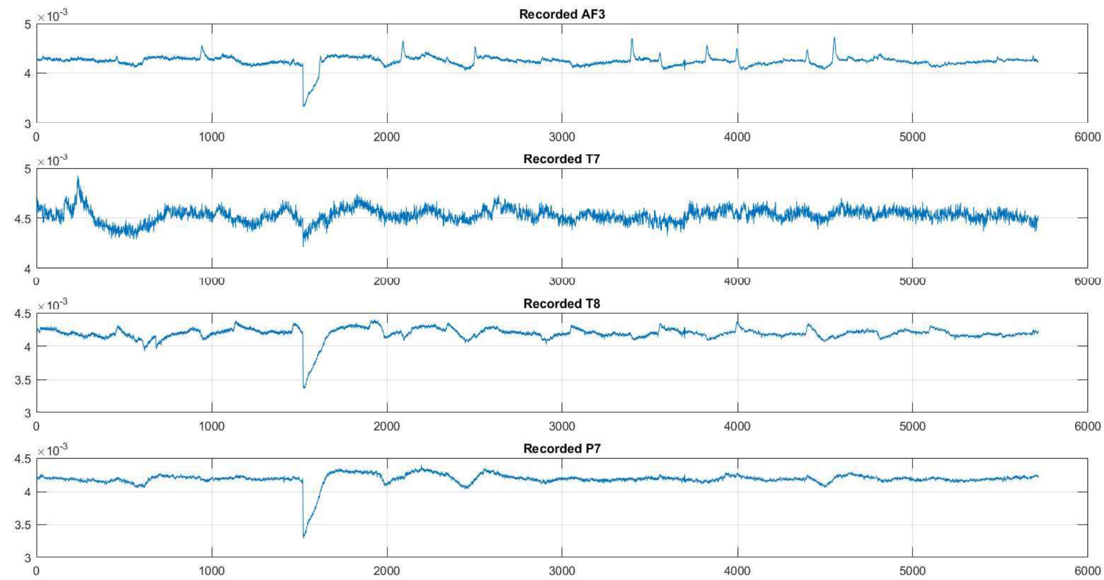

Fig. 4. Some representative signals of the recording sequence : Rest-Right-Left- Right- Right- Right- Left- Left- Left- Right-Left

Materials: Assistive robots: humanoid robot NAO or non-humanoid Arduino-based robot, especially designed to not scare the kids. The intelligent sensors used for measuring the EEG correlated to motor imagery – the brain-aware headset EMOTIV EPOC. This headset is harmless wearable device complying with the requirements of the Low Voltage Directive 2006/95/EC, the EMC Directive 2004/108/EC, the R&TTE Directive 1999/5/EC, and carries the CE and C-Tick marks accordingly [12].

B. Methods

The experimental conditions for testing the proposed brain-robotic intervention scenarios are described in detail in a research protocol. During the training and testing that are involved in the classification and detection of the left / right eye imagery movements, the human made a set of left and right looks, and the corresponding EEG signal is recorded in training and testing sessions.

To better understand the association between EEG activities and the eye movement responses, several factors have been intensively investigated, which are as follows: *1) number of electrodes; 2) types and numbers of features; 3) types of classifier.*

After a series of recording and analysis sessions of the obtained signals, we noticed that MI and artifacts, induced from the movement of the eyes, did not affect all EEG data: Only AF3, AF4 and P7 signals (see Fig.4) are capable to provide reliable information for a classification task.

B.1. Signal preprocessing and features extraction

Since the recorded EEG data is very noisy, it was first preprocessed to make it smoother and to minimize the influence of the artifacts. A median filter of order 5 is then used to eliminate outlier values. The average value of each signal must then be eliminated in order to highlight only the ocular changes.

Before extracting the left and right eye patterns, a separate recording of each pattern is required to allow its identification (Fig.5). The two signals are differentiable by their phase oppositions.

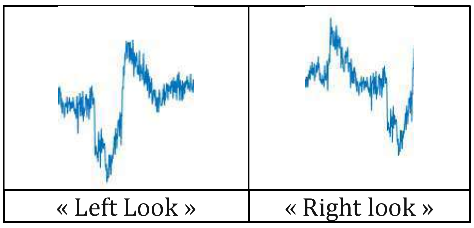

Fig. 5. Patterns representing left and right looks: Case of the P7 signal

To reflect the real case of an interactive class between the robot and the students, the recording is asynchronous. Pattern detection and its extraction from the recorded signal are then achieved through a visual inspection and analysis. The choice of features aims to describe one or more characteristics of the eye movement activity and will be used by a learning algorithm to establish a model for the Left Look-Right Look classes. Since the classification process is binary, the most relevant features under study are essentially based on the temporal, statistical and power changes. They are calculated and organized as follows:

TABLE I. LIST OF USED FEATURES

Feature	Designation	Role
mn	Mean value	measures the distribution of the pattern over time
vr	Variance	measure of the dispersion of values
sk	Skewness	the asymmetry measurement of the pattern
kr	Kurtosis	measure of the "tailedness" of the pattern
rms	Root mean square	quadratic mean
apwr	Average power	the power related to the pattern

Following this calculation approach, the original elements are neither redundant, nor correlated. This will allow a better understanding of the information, contained in each vector of functionalities, obtained without any additional processing.

For the recording sequence, shown in Fig. 4, the values of the calculated features for each pattern are represented in the following tables:

TABLE 2. CALCULATED FEATURES FOR EACH RIGHT PATTERN: CASE OF THE RECORDING REPRESENTED BY THE SIGNAL P7 IN FIGURE 4.

Features\Pattern	Right1	Right2	Right3	Right4	Right5
mn	*0.004*	*0.004*	*0.004*	*0.004*	*0.004*
vr	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
sk	*0.12*	*-0.04*	*1.11*	*0.27*	*1.47*
kr	*2.19*	*2.67*	*5.90*	*2.65*	*6.33*
rms	*0.004*	*0.004*	*0.004*	*0.004*	*0.004*
apwr	*1,7e-05*	*1,8e-05*	*1,6e-05*	*1,8e-05*	*1,8e-05*

TABLE 3. CALCULATED FEATURES FOR EACH LEFT PATTERN: CASE OF THE RECORDING REPRESENTED BY THE SIGNAL T8 IN FIGURE 4.

Features\Pattern	Left1	Left 2	Left 3	Left 4	Left 5
mn	*0.004*	*0.004*	*0.004*	*0.004*	*0.004*
vr	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
sk	*0.68*	*-0.13*	*1.64*	*0.86*	*0.54*
kr	*3.42*	*2.07*	*8.52*	*4.82*	*2.91*
rms	*0.004*	*0.004*	*0.004*	*0.004*	*0.004*
apwr	*1,8e-05*	*1,7e-05*	*1,8e-05*	*1,8e-05*	*1,8e-05*

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According to the calculated values, the characteristics that have a large discriminatory effect are skewness and kurtosis.

B.2. Classification algorithm

The classifier used in this study is based on the supervised approach developed in the 1990s based on Vladimir Vapnik's theoretical considerations on the development of a statistical theory of learning - Support Vector Machines (SVM) [17].

B.2.1. Basic Theory of SVM

Given a training set of instance-label pairs (x_i,y_i); $i = 1,\ldots,l$ where $x_i \in R^n$ and $y_i \in \{1,-1\}^l$. The SVM [17] are used to find a hyperplane Wx+b=0 to separate the data with the maximum margin. They require the solution of the following optimization problem:

$$\text{minimize } M = \frac{1}{2}W^T W$$

Subject to

$$y_i(\ W^T \emptyset(x_i) + b) \geq 1 \tag{1}$$

Using a soft-margin instead of a hard-margin, we obtain the primal problem for SVMs:

$$\text{minimize } \frac{1}{2}W^T W + C\sum_{i=1}^{n} \xi_i \tag{2}$$

Subject to

$$y_i(\ W^T \emptyset(x_i) + b) \geq 1 - \xi_i\ ;\ \xi_i \geq 0 \tag{3}$$

where:

- $\{\xi_i\}$ are slack variables which allow for penalized constraint violation through the penalty function $F(\xi)$ defined by Equation 14:

$$F(\xi) = \sum_{i=1}^{n} \xi_i \tag{4}$$

- C is the parameter controlling the trade-off between a large margin and less constrained violation
- $\emptyset(\ldots)$ represents the mapping from the input space to the feature space. However researchers prefer to use a kernel function K(.,.) given by the following expression: $K(x_i,x_j) = \emptyset(x_i)^T \emptyset(x_j)$. Practically, the most commonly used kernel functions are:
    - Linear: $K(x_i,x_j) = x_i^T x_j$
    - Polynomial: $K(x_i,x_j) = (\gamma x_i^T x_j + r)^d$, $\gamma > 0$
    - Exponential Radial basis function (ERBF): $K(x_i,x_j) = \exp(-\gamma \|x_i - x_j\|^2)$, $\gamma > 0$
    - Sigmoid: $K(x_i,x_j) = \tanh(\gamma x_i^T x_j + r)$

Here, γ, r and d are kernel parameters. Furthermore, a practical use and implementation of the SVM classifier is presented in [19].

B.2.2. Optimization of the classifier

We set the classifier parameters based on binary classification. Beyond the fundamental principle of parsimony in research, the SVM approach leaves, in practice, a number of options and settings to the user such as: the choice of the tuning parameter, and the choice of kernel type.

The kernel function:

The adopted kernel is the Exponential Radial Basis Function (ERBF) as it represents the best way to follow the non-linear decision surfaces.

For maximum robustness, instead of the basic equation, we use a structure that takes into account the number of learning elements [18]. The kernel function expression is given by (5).

$$k(x,y) = \exp\left(-\frac{\|x-y\|^2}{m\sigma^2}\right) \tag{5}$$

- m is the dimension of the observation vectors;
- σ represents the width of the Gaussian function. It is the main parameter that affects the complexity of decision surfaces. Optimization of the classifier involves determination of that parameter in order to maximize the performance and the feasible value is σ=0.5 [18].

Controlling parameters

As already mentioned, this coefficient controls the tradeoff between maximizing the margin of a class's separation and minimization of classification errors on the training set. It's a balancing parameter to set a priori, in order to make floppy the margin's SVM. The best practical results are usually obtained [19] using an adaptive value "C_{dat}" of that penalty parameter based on the number of « m » learning elements. Thus, C_{dat} is obtained according to the equation (6) wherein the kernel function $k(x_i,x_i)$ is defined by Equation (5).

$$C_{dat} = \frac{1}{\frac{1}{m}\sum_{i=1}^{m} k(x_i,x_i)} \tag{6}$$

IV. Classification Results

The recordings were made for several people and a database was built for training and testing of the classification model. In this last phase, a cross validation method was applied. With this approach, the generality of the established classification systems is tested and verified when the system has trained the characteristics of the studied EEG signals.

The procedure consists of starting the supervised learning process with the first database and later launching the test phase with the second and vice versa. The result of this test is given as a confusion matrix in the table below.

TABLE V. AVERAGE SVM BINARY CLASSIFICATION RESULTS (Left look vs. Right look)

SVM classifier : *« ERBF Kernel », σ=0.5 and C=Cdat*		*Estimated Patterns*	
		Left	***Right***
Real Patterns	***Left***	***65%***	*35%*
	Right	*38%*	***62%***

Although the overall result is correct, a binary classification based on supervised learning often leads to better precision: two reasons are possible:
1) The signal had to be cleaned well before the classification process.
2) Among the characteristics chosen, some calculated values have a low class separation power.

However, the use of the SVM classifier and its correct configuration made it possible to clearly distinguish the patterns under study.

In the future we intend to apply the proposed model for training and controlling social robots by mental commands correlated with the attention and emotional knowledge of children with special educational needs, in order to extend our past experiments [20]. We plan to test another brain-aware device – the Open BCI [21].

CONCLUSION

A new EEG-based brain-computer interface has been proposed for controlling body parts of a humanoid robot NAO or non-humanoid Arduino-based robot by motor imagery. To obtain consistency in BCI training and consequently use of personalized mental commands we propose a model for BCI training by action observation. The experimental results show that the BCI classification system for motor imagery that extracts features and translate those features into navigation robot commands is general enough to establish and classify other mental commands based on EEG signals.

ACKNOWLEDGMENTS

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6

Acquiring Digital Skills and New Qualifications by Introducing Modern Technologies in Education

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***Abstract*—The paper discusses the need to improve the digital skills of children in schools. EU statistics are provided to illustrate this need. Three directions for introducing the new technologies are considered – in special, non-formal and formal education. The authors' research experience in both special and non-formal education is presented. The state of the art in introducing emerging technologies in formal education is analysed. Different innovative technologies like humanoid and non-humanoid robots, drones, virtual, augmented and mixed reality are considered and their potential to contribute to the learning process is discussed[1].**

Keywords—New technologies, special, formal and non-formal education, STEAM education

I. Introduction

The European Commission has placed at the top of its political agenda the objective of stimulating children acquisition of digital skills, enticing them to follow Science, Technology, Engineering, and Mathematics (STEM) education and careers [1]. There is no doubt that good education is a prerequisite for a better future and the skills acquired at school are a guarantee that no one will be excluded or marginalized. The main goal is children to be creators instead of observers and consumers and the new technologies provide a great opportunity for moving in that direction.

According to the official EU statistics 44% (169 million) of the EU citizens between 16 and 74 years do not have basic digital skills, 22% of EU citizens have a low level of digital skills, and 16% of young people do not have digital skills [1]. Almost every job now involves a range of digital skills, yet employers report a shortage in skilled new starters. 21st century employees need to be able to work with sophisticated machines and IT solutions as part of their everyday activities, from car mechanics to doctors and nurses. Today, 40% of the companies have difficulties finding information and communication technology (ICT) specialists and the prediction is that there will be 500,000 unfilled vacancies for ICT professionals by 2020. In the near future 95% of all jobs will require digital skills. Therefore improving the digital skills at school is a great challenge.

Rapid development of modern technologies will enhance the education by making learning interesting and interactive. New technological realities require a new approach to education and skills. This includes the ability to handle software and complex machines, training teachers with digital skills, providing teaching materials and equipment, Internet access, etc. All this means modernizing the education system by educational innovations in all types of education – formal, non-formal, informal and special.

Formal education is organized, guided by a formal curriculum and leads to a formally recognized credential such as a school diploma or a degree. *Non-formal education* includes various structured learning situations which are not necessarily part of a formal curriculum. This type of education may be led by a qualified teacher or by a leader with more experience as a scientist. Though it doesn't result in a formal degree or diploma, non-formal education is highly enriching and builds an individual's skills and capacities. *Special education* is a form of learning provided to students with special educational needs (SEN), such as students with learning difficulties.

Emerging technologies in schools cannot be a luxury, a privilege for children from families with better opportunities. These have to be for all, part of a school program - accessible for every single child. Several new technologies can contribute to introducing modern methods in education – Humanoid and Non-humanoid Robots, Raspbery Pi, Virtual, Added and Mixed Reality, Motion Sensing Devices, etc. Further in the paper we will mark them with

[1] The paper was presented by the first author at the Symposium „Robotic and ICT assisted wellbeing" of „26th IEEE International Conference on Software, Telecommunications and Computer Networks" (SoftCOM 2018), Supetar, Split, Croatia, 13.09.2018-15.09.2018.

R&ICT (Robotic and Information and Communication Technologies). An important question is how to introduce and use them in the educational process in order to achieve maximum efficiency in compliance with all ethical norms.

In the paper the specificities of the three above-mentioned types of education are discussed from both authors personal experience and from the literature. Different innovative technologies like humanoid and non-humanoid robots, drones, virtual, augmented and mixed reality are considered from the point of view of their capability to contribute to the learning process.

II. II. APPLICATION OF R&ICT IN SPECIAL, NON-FORMAL AND FORMAL EDUCATION

Due to their nature, special and non-formal education require individual and group-specific approaches that imply corresponding targeted methods, while formal education requires a uniform methodology for all pupils. There are many investigations and applications of R&ICT in special and non-formal education in the literature. But research and pilot investigations about the necessity and the methodology of application of most popular R&ICT in formal education is still insufficient. For example, the reported outcomes on the use of robots are, in most of the cases descriptive, since they are based on reports of educators regarding individual initiatives, involving a small sample of participants and not integrated into official classroom activities [4]. Now the robotics in education may be characterized only as a current trend, not as a systematic practice.

The paper presents the analysis and the derived recommendations about application of R&ICT in special and non-formal education based on our own experience from participation in several research projects. For further analysis of specificities, directions and challenges of the application of R&ICT in formal education, results from the literature are analysed. The analysis of the specificities, directions and challenges of the application of two of the most popular and promising technologies in formal education – robots and VR – is based on the results from the literature.

II.1. R&ICT in Special Education

Numerous investigations are being conducted on using R&ICT with children with SEN, but most of them focusing on mild to medium cases of autism, attention deficit disorder, or hyperactivity [2], [3], [4], [5], [6]. It is proven in the literature that the most promising way to use R&ICT solutions in education of children with SEN is to focus on the entertaining role of the technologies in special education, empowering the child to be in control of complex technological devices under the guidance of the teacher.

From our previous and current studies in the frame of the finished METEMSS project [7] and current CybSPEED project [8] based on how children with SEN express themselves verbally and emotionally in play-learning environment supported by modern technologies, we revealed that positive emotions during the play with humanoid [9] and non-humanoid [10] robots can unlock learning skills quite unexpectedly. The play-like activities have been assisted by innovative human-robot interfaces for transmission of intentions and control, based on 3D motion-sensing devices. We used Kinect enabled serious motion-sensing games and the redesign of computer games into motion-sensing serious games for children with limited physical skills. The novel method was developed for Kinect–robot teleoperation based on fuzzy depth data processing and motion retargeting where Wireless Kinect-NAO Framework (WKNF) was proposed for teleoperation [6].

We proposed guidelines how to design supportive educational game-based environment for these children and how to help them getting used to modern technologies and be prepared for the digital age. Humanoid (NAO), semi-humanoid (Minion doll with a robotic hand) and non-humanoid (Big Foot robot, developed at Institute of Robotics - Bulgarian Academy of Sciences (IR-BAS) via 3D technology) robots were used in our experiments.

The children involved in METEMSS have been diagnosed with the following disorders: intellectual disability, autistic spectrum disorders, cerebral palsy or multiple disabilities. In the current MSCA, RISE CybSPEED [8] project entitled "Cyber-Physical systems for pedagogical rehabilitation in special education" a new type of Cyber–Physical System (CPS) has been proposed. We implement robot-based games and creative activities which, on the one hand, allowed the children to learn skills by moving, role playing, and self-expressing and to assist teachers in their assessment of learners by new modalities for children-robot interaction, on the other.

Children are attracted by robots spontaneously and this facilitates the assessment process by high-tech technologies. For example, humanoid robot NAO [9] has the potential for being used as a playful tool for improving the listening and speaking skills of children with SEN by involving a series of tasks developed and deployed on NAO. Video observations help assess children listening, understanding of the verbal language and speaking skills. Ongoing research on integrating intelligent sensors like Emotiv sensor [11] and MS Kinect v2 [12] to NAO sessions will enhance the listening and speaking assessment of these children.

Assessment of learning for children with SEN can be seen as a 'qualitative' type of measurement procedures

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modified and adjusted to meet the needs of the individual child.

Here we will not discuss in detail the studies, the experiments and the results obtained, but will summarize some of the observations and recommendations of using R&ICT in special education:

- Progress in learning a motor or cognitive skill is important, but is secondary to the therapeutic process. The most important in special education is the entertaining role of the technology and the emotional involvement of children;
- By empowering the child to be in control of complex technological devices and giving instructions in a 'natural' manner – speech and gestures - the child learns how to react to environments. This is expected to result in better adaptation to the outside world and the social environment of each individual child;
- The R&ICT device has the ability to initiate the discourse with the child in its functioning as an educational assistant to the teacher;
- Before processing the work with R&ICT, a profile of each child has to be created including personal information and information about child motor skills, cognitive skills, social skills, etc.;
- Analysis of the feasibility of different technological solutions for every child should be made depending of the individual SEN;
- Detailed description of R&ICT devices to be used and the respective activities for each child have to be determined in advance. It is very important not to bore them, or tire them, or be too demanding because their emotionality is very fragile and emotional outbursts are possible;
- The task of working with the child requires patience and multiple repetitions and is very tiring for the therapist;
- Strict observance of all ethical norms and principles relating to processing personal data is mandatory;
- Written permission from parents for conducting the experiments is obligatory;
- The use of R&ICT allows detailed measurements and monitoring to be made. In combination with the expertise of the therapist and the parents, it can produce satisfactory results in the educational process.

Still many challenges have to be solved during the process of application of R&ICT in special education. One of them is that teachers needed to be given more methodological support, equipment and training in order to improve their skills in quantitative observation and to develop more individualized methods for work with children with SEN.

II.2. R&ICT in Non-Formal Education

There is no doubt that non-formal education meets better the individual needs of pupils. When the new R&ICT technologies are included the results can be impressive. Recently, new approach to work with motivated students is used, namely engagement in science through an innovative approach of teaching and learning.

The authors of this paper have experience from the Robo-Academy project [13] with a main goal - training and promotion innovations and high-tech developments among young people from the specialized technological schools in the field R&ICT in Bulgaria by combining expertise of professional scientists, the pedagogical skills of teachers and the creativity of talented students. After the launch of the project many discussions and workshops between creative young people and teachers and mentors were carried out in the Institute of Robotics at BAS. Modern technologies such as 3D printing, humanoid robot NAO, non-humanoid Walking robot, humanoid arm, MS Kinect sensor, Emotive, Raspberry pi, Arduino and others are included in the educational process. After that specific R&ICT projects for groups of students were formulated. The projects are:

- Integration of brain-computer interface and humanoid robot - Brain-computer interface translates non-invasive EEG brain signals into robot commands. Two innovative technologies are integrated – EMOTIV and NAO robot.
- Development of 3D printed robotized hand for gestures - original humanoid hand, printed on 3D printer, capable to perform gestures, controlled by sensor glove. Possible application - special education;
- Programming of humanoid robot NAO for educational goals – programming NAO by using Python language in the Choregraphe software;
- Design of mobile sonar with wireless control - design of mobile sonar for measuring by using Arduino. Possible applications - for measuring in a dangerous and overheated places; that has time limit between charging;
- Design of robot with six legs – 3D printing robot with 6 legs with optimal energy consumption;
- 3D printed Leonardo Da Vinci's Mechanisms.

After the projects was launched, practical exercises in specific R&ICT under consideration were held - 3D printers in robot prototyping, how to create details of 3D robot models - FDM technology, software suitable for creating 3D robot models, sensors, programming robot NAO, using MS Kinect sensor, Motion Capture Devices, Emotive for tracking EEG signals, Raspberry pi, Humanoid arm etc.

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The implementation of the projects include designing 3D models and prototypes, choosing sensors, creation of specific robot and automated systems, programming, control, making experiments and discussions of results.

The results were presented in front of a larger audience of students, to stimulate them to follow STEM education and careers. All lectures and exercises were adapted to students according to their age. Project teams participated at several regional and national exhibitions and conferences, at which the project results were presented and demonstrated. The students also participated in a number of radio and TV interviews to popularize the scientific approach in non-formal education.

The following conclusions and recommendations can be made for the use of R&ICT in non-formal education at this stage:

- Initial discussions and workshops with students are obligatory in order to establish their interests and level of competence;
- Choice of a set of R&ICT to be used in the projects can be made according to individual skills and capacities of the participating students;
- Careful creation of Working groups and Mentors is necessary;
- This is project – based learning and all project stages must be respected – project description, project implementation, project communication and dissemination of the results;

Non-formal education with the use of new technologies contributes to improving skills like team working, skills for project-based working and learning, improving creation potential, programming, making experiments, making presentations, communication skills and for better professional orientation of young people.

II.3. R&ICT in Formal Education

Present day R&ICT education is focused mainly on the support of additional education of children and is restricted to the sphere of extracurricular activities. We are not talking about computers, interactive boards, laptops and online learning plans, proliferating in schools, but for robots, virtual reality and other technologies with high potential to be used effectively in mass education. The reasons for their restricted use are obvious – robots and new devices are expensive, cannot be delivered to all schools, there are no developed methodologies and teaching capacity in every school.

Our research interest is now targeted to introducing robots and emerging technologies in mass education. The questions of interest are whether it is necessary, whether it is possible and how to accelerate the process of introducing R&ICT in mass education. Project RONNI [14] aimed at promotion of application of R&ICT in mass education in order to overcome the learning difficulties and raise the educational level of the young generation of the citizens for a better future. New innovative teaching strategies and methodologies, transferable across the region, will be proposed to support effective learning, including humanoid and nonhumanoid robots, VR, flying robots, etc. The team made a survey "Assessment of enhanced R&ICT for education" in order to determine specific target group preferences – children, parents or experts.

Two general approaches for introducing R&ICT in mass education have been identified to now:

The first approach is a traditional approach by following all mandatory steps of introducing a new subject in curricula and its assessment, complying with all existing standards. This process is accompanied by a number of difficulties, is time consuming and is more applicable for the technically oriented schools [15]. **The second approach** can be used to achieve mass R&ICT education, namely to design R&ICT - enhanced learning content, not only in existing STEAM subjects, by connecting it with the regular curriculum for all graders in the school. This approach is more flexible and is adequate to the emerging technologies. Examples of the second approach are given in the literature [16].

The two approaches are analysed below in the context of concrete technologies with high potential to be used effectively in the mass education in the near future, namely – Educational Robotics and Virtual Reality.

a) Educational Robotics

Restriction of robotics classes to the sphere of extracurricular activities exists and courses in robotics are included in the educational program only in specialized technical schools. Paid robotics courses, organized by external firms, are becoming more and more popular to fill up the existing gap in schools. The directions and methods of teaching robotics in schools are currently not sufficiently defined. At the same time robots have already become an integral part of society. Knowledge of the foundations of robotics has to become a basic element of youth education and to enter the content of the school curriculum. Educational robotics can be considered as a new educational technology with three components of training: *(a)* robotics as an object of study; *(b)* designing and programming of robots; *(c)* robotics as a means of teaching, development and upbringing of students.

A three component educational process, applicable mainly to technical schools and illustrating the first approach, is considered in [15].

1st component: *Robotics as an object of study* - history of robotics and its development prospects, the place and role of robotic systems in modern society; foundations of philosophy and methodology of robotics; modern robotic

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solutions; robot properties as a "sense of touch", "sense of smell", "sense of sight", "hearing sense", "speech", "memory", "nervous system", artificial intelligence; robots communication, etc.

2nd component: *Designing and programming of robots* - robots and their systems - sensors, actuators, control, robotic demonstrations and experiments, creation of a virtual model of robot, 3D printing of robots, performing tasks with concrete objective by using constructed robot, etc. Different type of robots are available on the market for this purpose - Lego education WeDo, Lego Mindstorms, EV3 [4]. Experimental results show that these robots are stable and reliable and are welcomed by the majority of young people.

3rd component: *Robot as a means of teaching, development and upbringing* - educational functions of robots in combination with others technologies. There are many examples in the literature for using humanoid robots as a teacher [16], [17], [18], [19]. By now the most of these robots are used for foreign language learning. In Denmark, for example, a humanoid robot NAO is used as an educational tool [20].

Reviews of recently published scientific literature on the use of robotics in schools are given in [21] in order to: *(a)* identify the potential contribution of the incorporation of robotics as educational tool in schools; *(b)* present a synthesis of the available empirical evidence on the educational effectiveness of robotics as an educational tool in schools, and *(c)* define future research perspectives concerning educational robotics. After systematically searching online bibliographic databases, ten relevant articles are located and included in the study. The articles reviewed suggest that educational robotics usually acts as an element that enhances learning. However, this is not always the case, as there are studies that have reported situations, in which there was no improvement in learning.

In [22] authors present a constructionist approach to introducing robotics in the early childhood classroom. This approach asserts that people learn better when they are engaged in designing and building their own personally meaningful artifacts and sharing them with others in a community, i.e. the moto is “learning by designing”. They introduce a methodology for teaching pre-service teachers to integrate technology in the classroom and describe four different experiences in which pre-service teachers designed and integrated robotic projects done with LEGO Mindstorms and ROBOLAB to engage their young students in exploring and learning new concepts and ways of thinking.

In [23] several promising instructional models for teaching engineering in P-12 classrooms are presented as examples of how engineering can be integrated into the curriculum. While the introduction of engineering education into P-12 classrooms presents a number of opportunities for STEM learning, it also raises issues regarding teacher knowledge and professional development, and institutional challenges such as curricular standards and high-stakes assessments.

b) Virtual Reality, Augmented Reality and Mixed Reality

The second considered technology with high potential to be used effectively in the mass education which is already used in many schools is Virtual reality. VR technology is an ideal example of using the second mentioned approach because it can be implemented in all subjects. Using this approach includes materials for instructors that facilitate the selection of themes, goals of education, related subjects and curriculum, compliance with STEAM learning, overall plans, evaluation criteria, evaluation plans, and instruction/learning course plans in each session, and materials for students for introduction of themes, thought-sharing, thought-representing, thought supporting, and thought-reflecting activities.

Virtual reality (VR) can be referred to as immersive multimedia or computer-simulated reality. It replicates an environment that simulates a physical presence in places in the real world or an imagined world, allowing the user to interact in that world.

Augmented reality (AR) is a live, direct or indirect view of a physical, real-world environment whose elements are *augmented* by computer-generated sensory input such as sound, video, graphics or GPS data.

Mixed Reality (MR) brings a new dimension to students - physical interaction. MR content allows students to physically interact with a huge range of exciting 3D models - holding a human heart in your hands, getting up close and personal with a black widow spider, or stepping inside a medieval house. MR allows you to manipulate and view the model exactly as if you were holding it.

By using VR, AR and MR pupils in mass education can interact with the teacher, each other and with the virtual objects within this 3D environment and thus create experience by interesting, entertaining and engaging learning [24]. VR technology is an ideal example of using the second mentioned approach because it can be implemented in all school subjects.

Oculus VR glasses can be used in all subjects - geography, history, chemistry, engineering, mathematics, arts and culture, zoology, astronomy, anatomy, biology, architecture, design, languages learning, etc. combining a *virtual reality headset* with a *motion sensing device* allowing to create a mixed reality that might be used for different educational applications in mass and special schools [24]. Learning means that a strong memory trace is created to keep the learned material. Adding more modalities, like touch and audio, strengthens the memory traces. Several VR platforms are already on the market. In order to work

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properly, each platform should have the following elements:

- Playlist or Catalog with sample of VR and AR lessons, all aligned to the national curriculum for each class, which is continuously renewed;
- Videos are all sequenced simultaneously, so every student can see the video at the same point, allowing teachers to describe and comment it;
- Kids can use VR, but the teachers have to be careful [26];
- Real-time tracking of headset movement and orientation, providing valuable feedback to teachers and possibility for continuous control by the teacher and to have a view of exactly where each student is looking in their headset;
- Option for automatically lock into the selected activity from the playlist.

Conclusions

Three directions for introducing the new technologies are considered in the paper – in special, non-formal and formal education. The authors' research experience in both special and non-formal education is discussed and conclusions are derived based on previous and current research, revealing the big and unexplored yet potential of R&ICT. The introducing of emerging technologies in formal education has specificities to be accounted for in future schools enhancing pupils digital knowledge. Different innovative technologies like humanoid and non-humanoid robots, drones, virtual, augmented and mixed reality can contribute to the learning process if used in a competent and creative manner, which is set as future direction for research.

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Complexity Science for Evolving Software Ecosystems

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***Abstract*—**The innovation necessary to create economic growth, drive societal change and address challenges related to profitable growth relies on technologies that are software – centric. The competitive environment and market dynamics are totally different. This evolving software ecosystem is still struggling with the growing pains that the current economic conditions present both as a catalyst for change and an opportunity to mature. Software ecosystem is typically a set of projects and products that co-evolve within the same organizational, social and technical concerns. Economic principles govern the choices more than the technology. Promoting Human Talent in Software, Creating Innovative Capacity and Shaping the future Internet and Mobile platforms are the core challenges in seizing the emerging opportunities. The production of systems with specific demands on Reliability, Availability, Maintenance, and Performance [RAMP] is one of the greatest challenges of software engineering at all phases of the development cycle. RAMP requirements for the ecosystem are left unspecified, specified at a later stage, or at best vaguely specified. Also, often times either it is difficult or prohibitively expensive to test for some of the RAMP specifications such as maintainability, reliability, and high availability. The difficulties multiply rapidly due to the absence of a clear set of rules, design principle or practices for the RAMP specifications. Acceptable Software Systems are not adequate. Even wrong Software Works. The concepts of **complexity** and **chaos** are becoming quite frequent in the evolving software ecosystems. This paper positions the emerging **Complexity Science** as a viable method.

***Keywords*—**Complexity Science, Cybernetics, Dynamical Systems, Software Aesthetics, Systems Thinking, Web Intelligence

I. INTRODUCTION

"We have seen the enemy and he is us" aptly summarizes the deliberations at the 1968 NATO Conference on Software Engineering.

Some of the basic lessons learnt are given below:

1. The hardware environment of a software system is not a constraint, but rather a primary driving force of software architecture and design.
2. At a high level, every software system can be modeled with four types of design elements: data structures and primitive operations, external (hardware) interfaces, system algorithms, and data flow and sequence of actions.
3. None of the design languages and modeling tools currently in use is adequate for developing and representing an entire software system.

"Engineering, medicine, business, architecture and painting are concerned not with the necessary but with the contingent - not with how things are but with how they might be - in short, with design."

- Herbert Simon, 1996

The lack of first principles of software development results in "the software crisis." The NATO Conference suggested some initial principles given below.

- Software artifacts are "machines"
  - Deterministic, cause and effect, formally describable
- People are potential "machines"
  - After installation of proper formalisms (education/training)
  - With appropriate management discipline
- Systems are Cartesian
- Model = machine
  - Possible to define a formal syntax and grammar capable of unambiguous description of the implemented machine.

Software began to be seen as Art, Science, Discipline and Psychology. Over the past five decades, Software Engineering which began with

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the above principles ushered in many more concepts, principles, tools and techniques.

Some Characteristics of Large Software are given below.

- High degree of Uncertainty due to the dynamic nature of the parameters.
- Computing done by a Network of Computers, Sensors and other Gadgets with mobility whose behavior is difficult to predict.
- It is usually not practical to test the system under realistic conditions before deploying.
- Human intervention in debugging and modification while the Software is in use is prohibitively expensive.
- Stiff deadlines and stringent Quality of Service Parameters.
- There is a very high degree of heterogeneity.
- Compelling need to make assumptions, presumptions based on both "Imagination & Information".

The demand for increased variety of applications resulted in the industry examine new channels for supplying customers and new approaches to designing applications based on their core products. The dominant technology in many modern technical products is software. Software often provides the cohesiveness, control, and functionality that enable products to deliver solutions to customers. Software also provides the flexibility needed to workaround limitations or problems encountered when integrating other items into the system. Software is easy to change but extremely difficult to change correctly. The industry took to models based on collaboration between business competitors for developing Software with **Robustness, Productivity and Niche Creation as the crux.** Multi-stakeholders became imperative. Developing Large Software gave way to building services and a set of interacting components. Systems thinking is necessary for composing **Adaptive Software Systems**.

System can be **abstract or concrete**; **elementary or composite**; **linear or nonlinear**; **simple or complicated**; **complex or chaotic**. Complex systems are highly composite ones, built up from very large numbers of mutually interacting subsystems whose repeated interactions result in rich, collective behavior that feeds back into the behavior of the individual parts. Chaotic systems can have very few interacting subsystems, but they interact in such a way as to produce very intricate dynamics. Software systems consist primarily of a set of rules about behavior and also include the mechanism necessary to follow those rules as the system responds to states of the world. The production of such software systems with specific demands on Reliability, Availability, Maintenance, and Performance [RAMP] is one of the greatest challenges of software engineering at all phases of the development cycle.

A complex adaptive system is an ensemble of independent components that interact to create an ecosystem. The interactions are defined by the exchange of information and the actions of the components are based on some system of internal rules. These systems self-organize in nonlinear ways to produce emergent results that exhibit characteristics of both order and chaos. They evolve over time.

"Process" and "Frameworks for Quality" greatly enhanced the visibility of many core challenges. However, the domain knowledge remains a serious hurdle as software systems became pervasive all too soon.

1.1 Fringes of Science

In the philosophy of science, the question of where to properly draw a boundary between science and non-science, when the objective actually is objectivity, is called the demarcation problem. Compounding this issue is that proponents of some fringe theories use both proper scientific evidence and outlandish claims to support their arguments.

Software Development has been replete with the usage of Metaphors to connote the context. The following metaphors have found use in practice.

- **Diaphor –** poetry
  – "what if … was like …"
- **Epiphor –** prose
  – "an atom can be visualized as a small planetary system with electrons (planets) orbiting a central nucleus (sun), the orbits corresponding to …"

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- **Lexical usage**
  – "Both the human brain and the electronic computer are instances of physical symbol systems, hence the brain IS a kind of computer."
- **Paraphor**
  – When a metaphor becomes a paradigm
    - Kuhn's notion of paradigm
    - Lexical use of metaphor

  – Metaphor becomes part of cultural perspective

  – Values associated with paraphor become the values of the culture
    - 'Rational' is good – emotional is bad
    - Control is essential – chaos is evil
    - Efficiency is a virtue – waste is a vice

The process based on these approaches does not manage bounds, directs, nudges and confines. It relies on emergent order rather than an imposed order. The components are not based on tasks and are highly interactive and unpredictable. Unfortunately, it needs a major error to bring out the functioning of the software. Unacceptable risks are not recognized. There are unnecessary components developed and some required one not developed. The success rate tends to be dismal.

Cyber – Physical Systems [1,2,3] is a quest for a consistently applied software systems engineering approach to build and deliver the "new order" of software-dependent systems based on Complexity Science.

II. Complexity

Complex is a special attribute given to many kinds of systems. It is used often, somewhat incorrectly, as a synonym of difficult. Difficult is an object which, with adequate computational power, can be predictable deterministically or stochastically. Complex is an object which is not predictable because of logical impossibility or because its predictability would require computational power far beyond any physical feasibility. Complexity, usually, is in reference to some observing system, it is subjective, and thus it is observed irreducible complexity.

Human systems are affected by several sources of complexity and may be put into three classes given below.

1. **Systems belonging to the first class are not predictable at all.** This class of systems has two types of complexity given below.

   a. **Logical Complexity:** directly deriving from self-reference, Gödel's incompleteness theorems
   b. **Relational Complexity:** resulting in a sort of indeterminacy principle occurring in social systems.

2. **Systems belonging to the second class are predictable only through an infinite computational capacity.** This class of systems has three types of complexity given below.

   a. **Gnosiological Complexity:** consists of the variety of possible perceptions
   b. **Semiotic Complexity:** represents the infinite possible interpretations of signs and facts
   c. **Chaotic Complexity:** characterizes phenomena of nonlinear dynamic systems.

3. **Systems belonging to the third class are predictable only through a trans-computational capacity.** Computational complexity that coincides with the mathematical concept of intractability belongs to this class. What appeared as complexity in the computer program was to a considerable extent complexity of the environment to which the program was seeking to adapt its behavior. Formal systems are merely complicated.

Presently only a limited complexity of systems in third class is studied and used in developing evolving software systems. The "essential" software engineering problems mentioned below have strained the domain knowledge of Computer Science and Engineering.

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- **Changeability:** adapting themselves to unanticipated changes
- **Conformity:** working out everything the computer needs to "know"
  - Devoid of intuition, commonsense reasoning
- **Complexity:** integrating multiple already- complex programs
- **Invisibility:** communicating their likely behavior to humans

"Web Intelligence" and related technologies support the software systems through the Information Dependent functionalities such as:

- Integration of Change
- Unclear Goals and Objectives
- Internal and External Communications
- Knowledge Management
- Working as Teams
- Learning Technology
- Work Processes and Flows
- Customer Needs
- Developing Managerial Skills
- Managing Competition and Market Forces

This paper proposes Software Aesthetics and Cybernetics as two solutions for building the Cyber – Physical Systems founded on the Complexity Science.

III. SOFTWARE AESTHETICS

The Nature of Software [5] is as follows.

- Software is utilitarian.
- Software is mutable.
- Software is hidden.
- Software is beautiful.
- Software is complex.
- Software is insidious.
- Software is slavish.
- Software is logical.
- Software is abstract.
- Software is mediatory.
- Software is buggy.
- Software is transformable.
- Software is dictatorial.
- Software is pervasive.

There is no objective reality. All reality considered is socially constructed. Hence Software development is also a moral and social process within the ambit of an exploration of the constructed reality.

Aesthetics is an integral part of society, our interaction with hardware, and of software representation. Increasing pervasiveness of computing results in a corresponding concern for design aesthetics. All designs need strong aesthetic foundations, and a requirement to balance form and function. Software can be represented within the virtuality continuum facilitating effective, efficient and joyous interaction.

The goal of software aesthetics is not simply to create casual, ambient, peripheral, or otherwise fun objects. Instead, the goal is to explore the full range of interaction potential between software in the periphery and in-depth software analysis.

There is a basic difference between engineering problem solving and actually creating beyond what the problem calls for. It is interesting that people with design experience are able to see the nuances of what makes something appropriate in design. Software Aesthetics begins with the subjective or qualitative aspects such as:

- Source code that is more clearly organized
- More effective unit tests
- Better documentation
- More efficient
- More robust
- More usable user interface
- More attractive user interface
- More accessible
- More internationalized
- Presenting a unified whole
- Make users feel good
- Inspire confidence

These aspects need to be blended with the Software Metrics that are quantitative and specific to a chosen framework or a Maturity Model.

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Complexity Science specifies aspects of aesthetics as:

- Cooperation
- Appropriate form
- System minimality - It is as small as it can be.
- Component singularity
- Functional locality
- Readability
- Simplicity

Formal proofs need an Unconventional Computing Model [6, 7].

IV. CYBERNETICS

Complexity Science warrants:

- Systems Thinking
- Creativity
- Open Systems
- Incrementalism
- Testing with External Intelligence
- Excellence
- Anticipating Needs
- Managing Resistance to Change
- Challenging Everything
- Risk Taking

A good formalism such as Cybernetics gives a space for complexity science to define the Cyber – Physical System in between the Comprising and Comfort Zone of Experimentation and Chaos or Anarchy. Unlike several engineering disciplines that have clear and well grounded rules specifications for experimentation, software engineering makes “Grounding Practice” as difficult as deciding on practice. Hence, formalism such as Cybernetics is necessary to outline pertinent verification and validation of evolving software ecosystems.

Cybernetics is an interdisciplinary approach for exploring regulatory systems - their structures, constraints, and possibilities **Cybernetics** includes the study of feedback, black boxes and derived concepts such as communication and control in living organisms, machines and organizations including self-organization. It is underpinned by the notion of **circularity** and feedback between a system and its environment.

Cybernetics is not merely a thrust for optimization on time and space. It is about the principle of circularity that factors the human paradox to a maximum possible extent.

The language of a deterministic world view applied to computing gradually changes to systemic view unpredictability of the interactions among the large number of components. Figure 1 [3] below is the basis for the evolving software ecosystem that functions on the emerging complexity science.

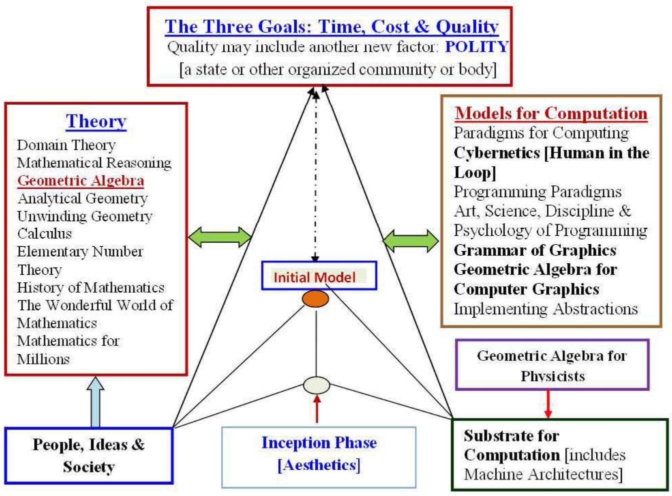

Fig 1. Proposed Block Schematic for Software Behavior in Cyber – Physical Systems

V. CONCLUSIONS

Chaos theory seeks an understanding of simple systems that may change in a sudden, unexpected, or irregular way. **Complexity** theory focuses on **complex** systems involving numerous interacting parts, which often give rise to unexpected order. Complexity Science for evolving Software Ecosystems is based on:

- Interconnected and interdependent elements and dimensions
- Feedback processes promote and inhibit change within systems
- System characteristics and behaviors emerge from simple rules of interaction
- Nonlinearity
- Sensitivity to initial conditions
- Phase space – the ‘space of the possible’

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- Attractors, chaos and the 'edge of chaos'
- Adaptive agents
- Self-organization
- Co-evolution

This paper presents Software Aesthetics and Cybernetics as two solutions that make Complexity Science viable for evolving software ecosystems.

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Can Social Robots Actually be Used in Special Education? Designing an Easy to Use and Customizable Game for Robot Therapy for Children with Autism

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***Abstract*— Using social robots in therapy for children with autism spectrum disorder (ASD) has proven to have positive effects on diminishing ASD-related symptoms. Yet, the uptake of these robots in social therapies is low, due to high workload and different priorities of the therapists. The aim of this research was to increase the usage of robots in therapy for children in autism, by introducing a robot-supervised activity which requires low effort from the therapists. As a result, this paper features the design of a boardgame that is supervised by a NAO robot. The game includes elements of Pivotal Response Treatment (PRT). Within the game, through different assignments, the children can develop their social skills in a fun and playful way. The game is designed from the perspective of non-technically skilled experts, like occupational therapists. Differently from existing efforts that mainly focus on end-user programming, we propose design solutions to make it easy for these professionals to use the robot. A user confrontation shows that this proposed robot-supervised game allows the therapists to fully focus on the therapy and the development of the children. Guidelines of how to design robot-based therapy–ready games are proposed.**

***Keywords*—Robots for Children with ASD, Tangible games with robots, Uptakes of robots in therapies.**

I. Introduction

The use of social robots can be very diverse and has multiple different possibilities, such as being used in educational or therapeutic context, or being used to enhance the social interaction and wellbeing of a person [4] [6][16][20]. Enriching educational and health-related applications of robots with social rewards is especially important because both health and education should be personal and reassuring for people. Several good developments in this direction exist [3][4][14][15][23], however most remain restricted to the research environment and are not yet implemented in the everyday practice of therapists and educators.

This research is inspired by the challenge which occupational therapists at the institution for children care, Levvel[1], were facing. They were convinced to purchase a ZORA robot (which is a NAO robot equipped with an additional software layer from the ZoraBots company) to use in their therapy for children with autism spectrum disorder (ASD), but unfortunately, they stopped using this robot. This is actually a common problem - the companies see an opportunity to sell robots if they develop a software that makes the robot a bit easier to use, and they apply a strong marketing strategy to sell the robot. However, research on how to successfully introduce the robots in practice is lacking behind. The major efforts in this direction are to develop end-user interfaces that are thoroughly tested and re-designed, such as [2][11][17][18][25]. We take a complimentary approach to use design methods to create existing technical solutions to fit better in the daily practices of the therapists. This proposed approach needs to deal with the implementation challenges of robots, such as the busy schedules of the therapists and being occupied with many children and tasks, which previously caused them to stop using the robot.

Next to the above-mentioned challenges there is also a lack of products (add-ons) which therapists can use in combination with a social robot, so the robot can engage in embodied interaction, and not be solely used as a conversational partner. There are many studies which have shown that the application of robots in different domains is useful yet, when searching for products, it seems like all designs, which are previously made, are solely for a specific research purpose. Therefore, our aim was to develop easy to reproduce products and robot behaviors to increase the potential use of the robot in therapy for children with ASD. The activity should support both the therapists in their training routines and the children in the development of their social skills. This should be an additional tool which complements the training provided by the therapists and supports them to use the social robot.

To answer these requirements, we designed the robot-supervised game: Robot & Me. This game has been designed through a collaborative design process together with the occupational therapists of Levvel. Robot & Me is an easy-to-use, robot-supervised game which allows children with ASD to train their social skills and does not require additional effort from the therapists (e.g. controlling the robot). This means that the therapists can fully focus on the training of the children [19]. The robot will guide the players through the game, by introducing the game and explaining the different assignments. A social therapist will mediate between the children to encourage social interaction, to

[1] At the time of the experiments the institution was called De Bascule Duivendrecht, the Netherlands.

support the training of social skills, such as understanding emotions and asking questions, in a fun and playful way.

II. Related Work

A. Autism Spectrum Disorder

Autism spectrum disorder (ASD) is a developmental disorder which affects the social interaction, behavior flexibility and communication abilities of a person [10][24]. Behavioral therapies are the most effective practices to help people with autism to improve these skills. Pivotal Response Treatment (PRT) is a therapy in which the focus lays with different key areas (pivots) [22]. These key areas are: motivation, response to multiple cues, self-management and initiation of social interaction [5][23][28], and if trained, improvements are seen across other areas of social skills, communication, behavior and learning. PRT therapy requires high levels of personalization to each child and is most successful when provided at a young age [27].

B. Social robots and ASD

Social robots are being used in multiple application areas, but one of the most promising remains to be training of persons with ASD [13]. There are multiple reasons of why it is interesting to investigate the possibilities of implementing social robots in therapy for children with autism. At first, contrary to people, robots are predictable, and they mostly do not have dynamic facial expressions and eye movements. This may decrease the threshold of the interaction with the robot compared to humans [9] and makes robots appealing to children with ASD [5]. Using humanoid robots rather than social robots with other embodiment can be more helpful in social skills training for children with ASD, because these robots resemble humans, and can bring to generalization of the learned skills to real-life social interactions [2]. The study of Robins et al. showed that the usage of a social robot Kaspar over a longer period of time, helped children with ASD to develop their social skills [26]. Newer studies performed randomized controlled trials that proved that the use of robotics in PRT is an effective treatment component in diminishing ASD-related symptoms and improving general clinical functioning in young children with ASD [5][23][28]. Based on the potential of these findings, we can conclude that there is a need to integrate the use of social robots in therapy for children with ASD in the routines of the therapists.

C. The robot platform and programming

The social robot used in this project is the humanoid-robot NAO (Figure 1), with software that can be controlled with the custom-provided Choregraphe programming environment, enhanced by an additional software layer build by ZoraBots Company. The ZORA software layer is targeted on healthcare applications and provides a tool for healthcare personnel that is intended to easily program and control the robot [21][29]. Several other more advanced software solutions that aim easy use of robots by end-users, as well as some advanced end-user development tools such as TiViPE software, have been successfully used in health applications [2][3][5][28] and as an end-user programming tool [7][8]. Other software solutions exist that aim to make the robots more accessible to end-users, see for instance [11][18][25]. With the current study we aim also to help companies who develop software for end-users by providing a process and content that the ad-hoc developed software can be useful in practice and be used independently by therapists.

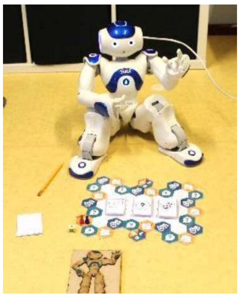

Figure 1. The set-up of the Robot & Me game including the NAO robot.

D. Social robots and therapy design

Many studies focus on the design of social robots [1] [9][13], yet all of these studies propose new ways to design robots or to design new robots to use in different application areas e.g. therapy for children with ASD [9]. Other research utilizes existing artefacts in combination with the robot, to facilitate therapy [3]. There has been little focus on designing add-ons for robot interaction. We argue that the usage of social robots can be enhanced when introducing designs that make the interaction with the robots more embodied, and thus engaging for children, since it will provide opportunities for natural and tangible interaction.

III. Robot & Me Design

The aim of the research described in this paper is to increase the usage of social robots for the specific context of PRT therapy, by designing add-ons and interactions aiming to enrich the human-robot interaction, without increasing the programming complexity of the robot. We designed the Robot & Me game, which is supervised by a NAO robot, equipped with ZORA software, and allows social therapists to provide a tool that helps children with ASD to develop their social skills in a fun and playful way.

First, we defined and observed several challenges which the social therapists experienced when working with the NAO robot. The most important one is inability to work with the robot, due to being non-technically skilled and being occupied by other activities and therefore not being able or interested to dive into the controls of the robot. The biggest disadvantage the therapist saw in the use of a robot with the ZORA software was that two persons were needed to perform an activity with the robot and the children. As most activities require the use of a text-to-speech module to make the robot talk, one person was needed to control the robot and another person was needed to guide the children. Therefore, the main objective of the design should be the ease of use of the robot, allowing the therapists to use the robot more often during therapy.

A. *Robot & Me game*

Robot & Me is a multi-player game consisting of a board game and a puzzle which will provide an opportunity for the children to learn about turn-taking and working together [3][12]. The game is played between a child and the robot and possibly other children or caregivers/therapists and consists of a gameboard and a puzzle. The goal of the game is for the players to collect all the pieces of the robot puzzle (Figure 2), each piece of the puzzle is obtained after completing an assignment from the gameboard shown in Figure 3.

Each space on the gameboard (Figure 3) relates to an assignment named Asking, Acting or Drawing. The design of all assignments is inspired by the PRT therapy. Table 1 shows the instructions for each assignment, as given by the NAO robot, and its relation to ASD therapy.

Figure 2. Two different version of the robot puzzle.

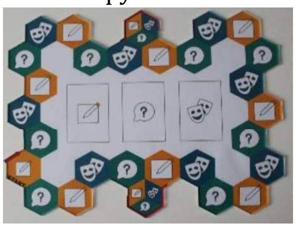

Figure 3. The gameboard. Every icon represents a category of the assignment.

After rolling the dice and moving the pawn accordingly, the player will get an assignment card which corresponds to the space the player has landed on. The player will scan the QR-code on the back of the assignment card (Figure 5), which will initiate the robot to explain the assignment. Once the therapist decides that the assignment has been executed well (depending on the skills of the child) the therapist will press one of the sensors of the robot. The robot will finalize the assignment with a compliment and a (funny) remark and the player will get to choose a puzzle piece. Once the puzzle is finished, the game ends.

Figure 4 shows a flowchart of the game. Color coding shows which actor takes each action at different moments in the scenario.

Table 1. Categories of the assignments of the game, their instructions and relation to the provided therapy.

Assignment	Instructions	Relation to Therapy
Asking	*Can you ask the other player something about...? (e.g. family, school, sports etc.)*	Develop self-initiation and learn to ask questions to someone else [22].
Acting	*How do you express yourself when you are...? (happy, sad, angry etc.)*	Learning to understand emotions and how you and others react [22].
Drawing	*Draw the word on the assignment card, the other player has to guess what you are drawing by asking questions.*	Developing self-initiation and asking questions [22].

B. *Ease of Use*

To ensure that using the robot would not be complicated for the therapists, we focused on the ease of use of the design. We will discuss in the following paragraphs how this has been taken into account.

1) *Ease of use for social therapists*

As observed by De Haas et al. [19] due to the occupation of the occupational therapists and the presence of multiple children during the therapy, the therapists do not have the time to both focus on the development of the child and to control the robot at the same time. While De Haas focused on increasing the autonomy of the robot, we explored how a good design can optimize and simplify the interaction. For instance, in order to limit the use of text-to-speech interaction, which is slow and prone to typing errors, we chose to work with QR-codes, which are used nowadays in many applications, such as internet banking and others, so most adults and even children are acquainted with their use. The different interactions of the robot that include speech and movement combinations, can be pre-programmed, and downloaded as a QR-code. Each QR-code is presented on a card that can be scanned either by the child or by the therapist (Figure 5). The robot scans the code and will perform the interaction which links to the code. This allows the therapists to focus on the children, rather than on controlling the robot. An example interaction is described in Table 2.

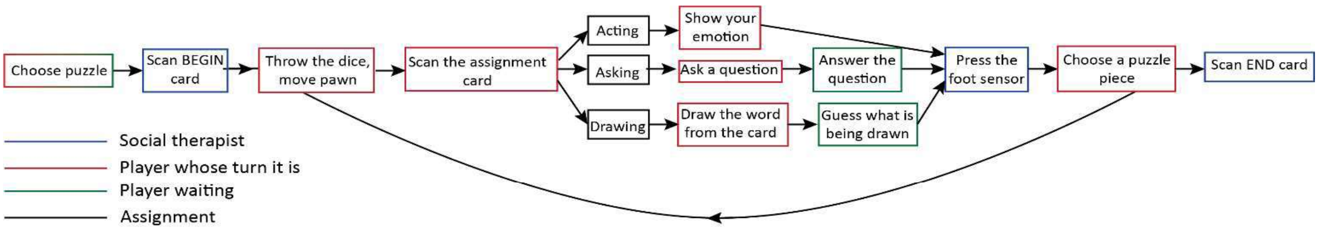

Figure 4. Flowchart of Robot & Me game. The color coding depicts the terms of the different actors. The interaction can be extended to multiple players.

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Table 2. An example assignment in the category Acting. The behavior is pre-programmed in the ZORA software. The animation behavior uses pre-programmed actions from the ZORA software, such as being angry. The action 'Emotion animation' allows NAO to use its hands while talking, which makes it more natural. The audio is what NAO says with a consistent speech tempo and volume.

Behavior NAO	Action NAO	Audio NAO	Relation to the game
Speech	Emotion animation	You have the assignment Acting. How do you act when you are angry?	Explain assig-nment
Wait	Wait behind left- or right foot sensor	-	-
Speech	Emotion animation	Well done! I can be angry at times as well. When I'm angry I act like this.	Compliment and react to assignment
Animation	Sitting	*'Emotions – Negative Angry 1'*	-
Speech	Emotion animation	You may get a puzzle piece. The next player may take its turn.	Finalize assignment

2) Design for flexible use

To allow the therapists to fit the game into the therapy of different children, the game was designed to be flexible in several ways. The gameboard was designed to only have a beginning and no finish (Figure 3), therefore the duration of the game is flexible, depending on the number of puzzles which will be completed. Other puzzles can be used with the game, that can be related to the child's interest. Next to this, to adapt the game to the specific needs of the child(ren), the therapist can choose to vary the number of players (e.g. play in teams, act as a player in one-on-one training or have multiple children in the game), shift the focus of the assignment and/or add extra challenges to the assignments (e.g. start a conversation based on the assignment or let the other players react to the assignment as well). Additionally, a guide on how to add and change the assignments was provided to the therapists, allowing them to adapt the game to the wishes and needs of an individual child.

IV. Pilot Tests and Outcomes

The game was piloted in several settings. Here we will discuss the outcomes of the tests and the proposed design guidelines for designing add-ons for robots.

A. Explorative testing with social therapists

The game was firstly played with three occupational therapists, a snapshot of the test is shown in Figure 5. The aim of this test was for the therapists to get familiar with the game, to understand how they are supposed to interact with the robot and to provide an informed opinion whether the children would understand and enjoy the interaction. The occupational therapists reported that the working of the game was easy to understand and to execute. They shared their predictions of how the children would react to the game and to the actions and utterances of the robot. This sparked new ideas for the therapists of how to start using the robot.

B. Confrontation with the children

The Robot & Me game was also played with the children at Levvel (Figure 6). This play session was the first time for the children to see and interact with the robot. This also generated a lot of enthusiasm for the children as they had never seen a robot before and were intrigued by its abilities. What was seen during the game was that the children understood what was expected of them. They were able to scan the QR-codes and execute the assignments. The therapist who was present noticed that all children liked playing the game, even the children from whom she was not sure at first whether they would like to play it.

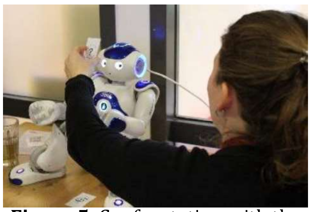

Figure 5. Confrontation with the therapists. One of the therapists scanning the QR-code.

Figure 6. Confrontation with the children.

C. Design guidelines for add-ons for robots

This research provides an example of how to easily increase the usability of the robot by designing add-ons for existing robots and not by increasing the autonomy of the robot and therefore the programming complexity. These add-ons should be designed with a clear purpose and for a defined target group in order to ensure that the design will fit the purpose. In our case, a game that is flexible to personalization and easy to reproduce. Here we will discuss some guidelines to design add-ons to support robot-human interaction.

1) Using the strengths of the robot

When designing an add-on for a robot, one first has to explore the existing features and how these can be used for the designated purpose. In our case we used the ability of the robot to scan QR-codes and response to touch of its sensors. By scanning the QR-codes we were able to avoid having to use text-to-speech teleoperation by the therapists, so they can devote their attention to the training of the children, rather than controlling the robot. The usage of touch sensors allowed us the pause the behavior of the robot and to continue when touching one of these sensors. This allowed us to only use one QR-code per assignment and integrating all elements of the assignment (explanation of the assignment, compliment, and finishing the assignment, see Table 2) in one behavior. This also reduced the number of actions needed to control the robot during the game.

2) Fitting the activity to the context

The add-on should fit the intended activity which it should support or substitute. In our case, the game supports social skill training for children with ASD. Through collaboration between the designer and the social therapists, the whole game was designed for specific

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purposes, which are listed in Table 1. All assignments relate to the PRT therapy which is used at this institution. Since the game is made for multiple players, the children will have to collaborate to collect all of the puzzle pieces and they will learn to wait for their turn, which is not related to this therapeutic method but an important skill for these children. The presence of the therapist also encourages a more in-depth discussion with the children about the execution of the assignment.

3) Long-term use

The users of the activity will continuously change. Eventually, new therapists will come to work at the facility, as well as interns can be employed. Additionally, different children will be subjected to therapy, all with their own level of development and set of challenges to learn skills. To ensure that the activity will fit each user, a way to adapt the game should be introduced. For the Robot & Me game, a handbook was written containing information about the interaction with the NAO robot, equipped with the particular software, and a manual of how to control the robot and how to adapt the game. This is an additional way to supporting the social therapists and encouraging the use of the robot during therapy.

V. Discussion

We presented a design-based approach to reduce the ease of use and increase the flexibility towards personalization of social robots in therapy settings. The add-ons and interaction design guidelines that aim to ease the uptake of robots in everyday practice of occupational therapists were proposed. The Robot & Me game was developed, and user confrontations showed that it is fully experiential and can easily be played with both occupational therapists and children diagnosed with ASD and this concept can easily be reused with other robots that have QR scanning function and in different facilities for training children with ASD.

By motivating children to play games that are especially designed to target specific skills, they may willingly work on developing their social skills by executing the different engaging assignments. The ease of use of such a game can also motivate the therapists to invest time and use the robot during therapy, despite their busy schedules. Further research should test the usability and the engagement with the game by different children and caregivers. Next to the proposed design approach to ease the uptake of social robots in everyday practice, we believe that increasing the autonomy of the robots and making robot programming more user friendly remains the main road towards the actual use of these robots in practice.

VI. Conclusion

Robot & Me is designed to be an addition to the social skills therapy provided for children with ASD. The game has been designed in collaboration with social therapists from the facility. Their previous experience with the NAO robot equipped with ZORA software was taken as baseline for this project, and may differ with other software and programming interfaces, as reported in [3][7][8][11]. The aim of this research was to propose a design method to increase the usability and the user experience with social robots with the available technology and end-user programming tools.

We have developed a single game that does not require a lot of preparation or additional tasks from the therapists. The game can be used in different contexts and number of players, so it provides an example of how to use readily existing features of the robot to create novel games and interactions.

We can conclude that designing add-ons to existing robots is an easy way towards successful enrichment of the interaction with the robot as an additional dimension to the development of robot autonomy.

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