Cognitive Training by Animated Pedagogical Agents (TAPA) Development of a Tele-Medical System for Memory Improvement in Children with Epilepsy

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Keywords: HCI, Animated Pedagogical Agents, Virtual Characters, System Adaptivity, User Modelling, User-Interface Evaluation, Universal Design Concepts, Meta-Communication, Meta-Memory Training, Assistive Technologies, Telemedicine

Abstract: Recent psychological research demonstrates, that children with cognitive disorders can clearly benefit by special training of meta-memory strategies. Though up to now this kind of memory training requires a specialized coach who performs an individual motivational support.
In the consequence we started to develop a tele-medical Training system that is primarily based on the concept of Animated Pedagogical Agents (TAPA). These agents that inhabit interactive training environments can exhibit lifelike behaviours and are able to impart and coach memory strategies in a very suitable way to children. In addition to provide problem-solving advice in response to children's activities, these agents may also be able to play a powerful motivational role. The TAPA-System realizes furthermore a web-based use for an economical, prolonged and controlled intervention in large numbers of neuropaediatric patients. The user interface adaptivity to the individual child is based on nontrivial inferences from input information.

Introduction

The increasing number of chronic diseases in childhood in the last decades is a well-known observation in paediatric research. This development is less caused by a naturally increasing morbidity than the paradoxical result of the progress in medical care [21]. For the price of a remaining chronic disease many patients are saved today from former fatal diseases by new successful therapy methods. In chronic diseases with a progressing character e.g. cystic fibrosis, neuromuscular diseases or HIV-infections improved therapy reached a stepwise prolongation of life expectancy. Other chronic diseases as there are e.g. asthma bronchiale, haemophilia, epilepsy or juvenile arthritis are characterized by a continuous but symptom lacking course with sudden precarious crisis.
Recent research in clinical and neuropsychology focussed on frequent occurring disorders of cognitive development as one of the most problematic secondary symptoms in the consequence of chronic diseases [13]. Especially affected are patients with a neurological disease as for example childhood epilepsy. Cognitive disturbances like memory dysfunctions

or delay of memory development are very often accompanied with seizure diseases [4, 10]. In up to 70% of the affected children mild to severe cognitive disturbances especially memory deficits can be diagnosed [5, 29].

Since these impairments have partially very negative consequences on the educational, professional and sociopsychological development of the affected children several studies conclude a high need for intervention[1, 9].

But there is still no concrete psychological, pedagogical nor medical intervention concept that is used for a concerted support of epileptic patients or patients with other chronic cerebral risks. In fact recent research showed that children with cognitive disorders could clearly benefit by a special training of meta-memory strategies [8, 22, 23], but in long term these results can be obtained only with a high time and personnel effort for each individual children. Partially this might be the reason why meta-memory trainings have not been used in the clinical practice yet.

In this regard the here introduced TAPA that is based on the concepts of Animated Pedagogical Agents (APA) and adaptive user interfaces opens up new perspectives in realizing individual intervention for memory improvement in children.

The APA paradigm has been developed in the recent years and is one of the current main research areas in Human-Computer-Interaction (HCI). APA's have life-like, animated personas and represent a type of autonomous agents [11]:

> They can be employed to attract the user's focus of attention [2] and are capable of pursuing goals in complex environments and adapting their behaviour as needed in response to unexpected events. Their typical environment is an educational simulation, together with the learner and other interacting agents. APA's may seek to achieve pedagogical goals (e.g. to help a student to learn about a topic), communicative goals (e.g. to acknowledge a learner's action), and task goals (e.g. to help the learner solve some particular problems). They can respond to the learner with a human-like combination of verbal communication and non-verbal gestures such as gaze, pointing, body stance, and head nods. And finally they are able to convey emotions such as surprise, approval, or disappointment.

HCI research showed that - taken these capabilities together - APA's can interact with learners in a manner that is close to face-to-face collaborative learning [12, 20, 31].

Some well known APA examples of the ongoing development and research in HCI are:

- *Steve*, a 3D animated agent, can interact with learners in individual and team scenarios [25, 26, 27, 28].
- *PPP Persona* is able to generate tutorial presentations of Web-based learning materials [3].
- *Cosmo* is able to generate critiques and explanations using a combination of speech and emotive gestures. Early empirical results show that this agent can enhance the learning experience and improve its effectiveness [15, 16, 17, 18, 19].
- *Adele* was designed to run on desktop platforms with conventional interfaces, in order to broaden the applicability of pedagogical agent technology. Adele runs in a student's Web browser and is designed to integrate into Web-based electronic learning materials of web-based courses [25, 26, 27, 28].

Project's Purpose

The project's purpose is to develop and evaluate a tele-medical intervention system with the following characteristics:

- Performing an agent-interface with a high suitability for children using a variety of input devices as well as virtual reality techniques.
- Integration of diagnostic and training module allowing precise assessment of the cognitive starting point as well as performance changes during the training. A continuous diagnostic is important to realize an individual adaptation of the task difficulty to the child's abilities and to keep the motivational level.
- General consideration of the motivational and emotional situation of the child while training with the system is necessary to achieve the expected training effect. To receive information about the current motivational situation as valid as possible different input techniques are used and crosschecked. The system should be able to realize an individual influencing of the child's motivation by reactively changing the agents behaviour and task presentation within an adaptive system environment.
- Finally the whole TAPA-system is aimed for a web-based use with an individual and autonomous training at home, which is necessary to obtain a prolonged effect in large numbers of affected children.

Meta-Memory Training

Meta-Memory means to know about the own memory functioning. Under positive conditions children develop in the age between 8 and 10 years some kind of knowledge about their memory and how it works [8, 22]. An essential requirement for this is a minimum breadth of "world knowledge" that enables the child to realize similarities and dissimilarities between objects. The initially immature idea of the own knowledge structure makes children invent and use memory strategies, e.g. they sort objects mentally before they learn them (strategy of categorical ordering). But even in younger children simple memory strategies are employed unconsciously, e.g.: they rehearse words or terms when they want to prevent forgetting them.
It is not a higher cognitive capability that enables adults for better memory performance than children, it is the result of a functioning meta-memory and efficient use of different memory strategies.
Children with cognitive disorder or development delay often have the risk of not developing these strategies [30]. Especially in children with learning disabilities clear delays and even lacks of the meta-memory development can be observed. From that point it was exiting to find that these children can benefit from an instructional coaching and are able to catch up with their contemporary playmates [7, 22, 23].
The here developed TAPA is based on four main training components and considers the last research result. All steps will be introduced, explained and supervised by animated pedagogical agents.

1. Impart and support of specific memory strategies (e.g. categorical ordering)
2. Impart and support of meta-memory knowledge and self-controlling strategies (e.g. stop-check-and-study = memory monitoring strategy)
3. Attention and concentration training
4. Impart and support of effective learning and performance behaviour as well as of positive perception of self-efficacy to support stabilization of personal identity (see below)

Some previous studies [7, 23] examining meta-memory training effectiveness had to note two problems: a) trainings with only few sessions had just short time effects and b) effects were limited to the trained kind of tasks and could not easily transferred to every-day context.

That's why in TAPA strategies and tasks are strictly orientated towards every-day contents with respect to the referring age. Pre-analyses of the children's every-day content are performed by interviewing children, parents, teachers and siblings.
Another step to optimize TAPA consists in special transfer training units. The childish user is confronted explicitly with the task to use the new learned strategy in different contexts.
Last but not least TAPA is to improve the children's perceiving of their self-efficacy. Due to repeated and continuous feedback by animated agents the child can learn to estimate its own performance more realistically.

Animated Pedagogical Agents

The paradigm of Animated Pedagogical Agents has been developed in the recent years. These lifelike autonomous characters inhabit learning environments and make rich, face-to-face learning interactions possible. Children seem to develop an immediate and deep affinity to such characters:

- The agents abilities open up exciting new possibilities, e.g. agents can demonstrate complex tasks, employ locomotion and gesture to focus children's attention on the most important aspect of a task at hand, and convey emotional responses to the tutorial situation. They offer new possibilities for broadening the bandwidth of tutorial communication and the learning environments' ability to engage and motivate children.
- To design the most effective agent trainer for children with cognitive disorder, it is essential to consider that children perceive an agent as personality with affective dimensions such as encouragement, believability, utility and clarity.

Therefore the following aspects have to be considered in the development of the agents' characters and behaviours [15]:

Clearness – in language and behaviour
Autonomous activity – even during actually passive situations
Transparency – what is the goal and why
Affection – emotional expression in facial play, gestures and body language
Believable – reasonable and real behaviour
Keeping charge - if user's progress stagnates, suggestion of something new
Reinforcement – user's performance is rewarded consecutively
Repair questions – providing misunderstanding
Responsiveness – every user's action will be responded

Basics of meaningful Agent – User Interaction

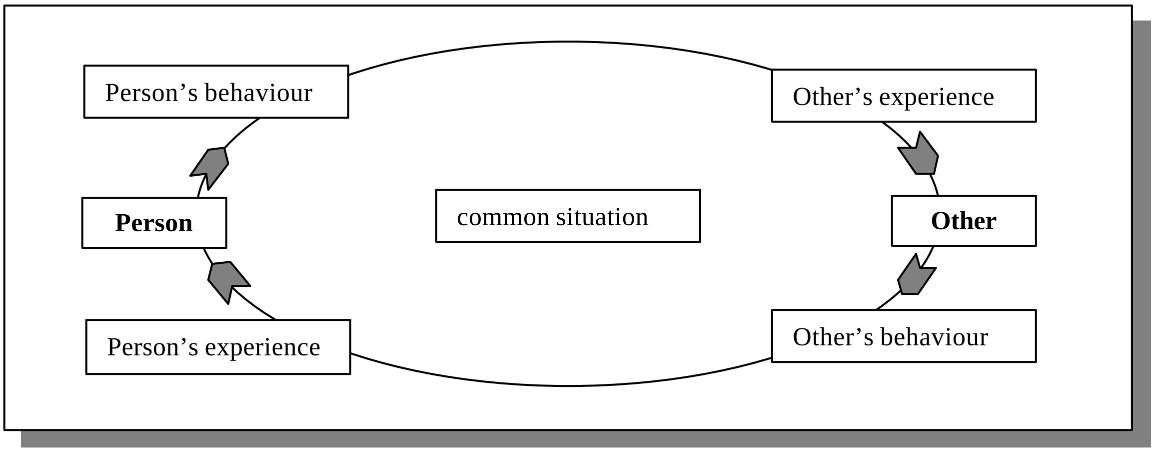
Social psychology refers to reactive behaviour characterized like this by analytical concepts about the interactive stabilization of personal identity through motivationally supportive *enfolding of empathy* [24]. If these concepts can be operationalized, they can serve as a framework for effective agent design as well as for evaluating the motivational efficacy of child-agent interaction.

In this regard basic concepts of the so-called "Interpersonal Perception Method" (IPM) may be applicable, which for long has proven be useful in psycho-therapeutical diagnostics of interpersonal relationships [14]. The two basic IPM-assumptions are:

1. Behaviour is a function of experience.

2. Experience as well as behaviour always has a relationship to someone else or something else other than oneself.

Accordingly the most basic scheme to explain individual behaviour comprises two individuals – or, in our case, an individual and a virtual entity, i.e. the animated pedagogical agent – and a situation common to both of them. Additionally, this scheme has not only to reveal indications about interaction between the corresponding entities but also indications about their inter-experiences:



Box 1

According to this scheme Person's behaviour with regard to the generalized Other is partially a function of how Person experiences Other. How Person experiences Other is also partially a function of Other's behaviour with regard to Person. In turn Other's behaviour with regard to Person is partially a function of how Other experiences Person; and this experience is again partially a function of Other's behaviour with regard to Person.

The following is important: If Person's experience about Other deviates largely from Other's self-image, Other will most likely misunderstand Person's behaviour directed towards him/her. In so far interactive misunderstanding is always a result of failed empathy – i.e. failed attempts to experience Other in as complete as possible congruence with his/her self-image. Therefore, for purposes of user modelling, evaluation of the individual benefit of agent intervention or even user-interface adaptivity in general, it is methodologically sufficient, to investigate certain perspectives of interactive experiences. Revelations about successful or failed enfolding of empathy can then be derived form the reciprocity or non-reciprocity of interactively interrelated perspectives.

Three different perspectives of interactive experiences can be distinguished:

- direct perspective:
  self-experience of Person or generalized Other; formalized by the term…

  P(x) or **O(x)**
- metaperspective:
  experiences about the reciprocal views of what Person thinks about Other, vice versa; formalized by the terms…

  PO(x) or **OP(x)**
- meta – metaperspective:
  experience based feelings of Person about what Other thinks about him/her; formalized by the terms…

  POP(x) or **OPO(x)**

According to these formalisms…

understanding can be defined as a logical conjunction between metaperspective of Person and direct perspective of generalized Other (**P** supposes **O** to have a certain view **x** and **O** indeed has view **x**), formalized…

PO(x) and **O(x)**

being understood can be defined as a logical conjunction between meta – metaperspective of Person and metaperspective of generalized Other (**P** supposes **O** to suppose he/she would have a certain view **x** and **O** indeed supposes **P** to have view **x**), formalized…

POP(x) and **OP(x)**

(*subjective) feeling to be understood* can be defined as a logical conjunction between the own direct perspective of Person with its own meta – metaperspective (**P** has a certain view **x** and supposes **O** to suppose that he/she indeed has view **x**), formalized…

P(x) and **POP(x)**

Finally, successful enfolding of empathy can be derived from a conjunction chain between direct and meta-metaperspective of Person and metaperspective of generalized Other, formalized by…

P(x) and **POP(x)** and **OP(x)**

…because logically **P(x)** can be defined as a unique "superview" **x',** so that follows…

P(x) and **POP(x)** and **OP(x)** → **PO(x')** and **O(x')**

In natural language: If **P** has a certain view **x** and supposes **O** to know that he/she has view **x** and **O** indeed supposes **P** to have view **x** then **P** and **O** understand each other with regard to the direct perspective of **P** (which then can formally be defined as view **x'**).

Moreover the above formalization clarifies the two-dimensionality of empathy, which's constituents by the conjunction **P(x)** and **POP(x)** is the *subjective feeling to be understood* and by the conjunction **POP(x)** and **OP(x)** is *being understood* objectively. Pathologies in the sense of failed enfolding of empathy or - more naturally speaking – misunderstandings between Person and generalized Other which may also be related to deficient efficacy of child-agent interaction have therefore to take into account both these dimensions.

In the course of the TAPA project, possible interactive pathologies will further be derived from the presented logical framework and accordingly be used for evaluating child-agent interaction.

Adaptivity

Adaptivity is a basic requirement for the functioning of TAPA. Regarding the system's ability to adapt to the individual needs three user-modelling aspects can be differentiated:

- Providing the system with the necessary background knowledge about the user in general: When starting with a first session the system needs information about chronological and developmental age (if possible via other cognitive assessment), information about seizure type, focus, frequency, information about sex, school form and class and many other information (about prior knowledge of the topic, learning style, motivation) all this may be entered by the doctor or any other responsible person. This first input makes TAPA adapt the agents' basic behaviour as well as the type and difficulties of the tasks.

- In a second step the system has to adapt the task difficulty to the maximum limit of the child abilities by analysing continuously the child's performance.
- The third aspect is one of the project's most challenging. TAPA needs a technical interface that can receive enough information about the changing motivational status of the child for to let the agents react in a motivating way. If the system cannot receive precise and valid information about the emotional and motivational changes on the user's side any attempt to coach individually and interactively will fail.

It is especially aggravating that there is a conflict between the need for a maximum of detailed and comprehensive information regarding the user's motivational status and limited indications from user-protocols due to the practical limitation of input techniques within the envisioned web-based application scenario. Precise but expensive techniques like eye-tracker or facial recognition devices can be available at best in some selected places e.g. in another care centre but not at the PC in the patient's home.

To ensure still the highest possible validity of information it therefore becomes necessary to perform experimental pre-studies that use all the different input devices as well as behaviour observation through experts simultaneously. Then all data can be cross-checked and analysed statistically. The more expensive and supposingly more valid techniques will be statistically compared with the web capable and ones adjusting the respective probabilities of α- and β-mistake (*$p[\alpha]$= probability that change of motivation is measured although there was no change; $p[\beta]$= probability that change of motivation is not measured although there was a change*).

It would be furthermore important to employ a universal and powerful communication method between adaptivity functions and the different input devices. For example adaptive behaviour of the agent should be based on the amount of data that is derived from input devices and does exist in an adaptivity database with a defined adaptivity language. A module should be developed for every input device to write the adaptivity instructions into the adaptivity database. This procedure will add more flexibility for the usage of the system and independency of used input devices.

We intend to use the following input devices for the experimental pre-studies: touch-screen function, voice recognition, mouse, keyboard, power measuring joystick, eye tracker, facial recognition techniques, several virtual panel boards for the child to quote e.g. its actual motivation.

Moreover, the child's quoting about its actual motivation on virtual panel boards shall additionally be combined with meta-communicative (form-filling-) requests about the experienced reciprocity or non-reciprocity of the interactively interrelated perspectives mentioned above, thus revealing directed needs to modify the animated

Meta-Communication Example:

Subsequently to the agent's (**A**) request the child (**C**) has mistakenly quoted an increasing of motivation (**m**) via virtual panel board (>**AC[m?]** and **C[m?]**). Actually the child wanted to express it's wish for a funnier next task that way. With respect to the child's low performance in the respective last task the agent would begin the following dialogue to avoid the risk of **CAC[m?]** and **AC[m?]**:

A: "I see you found the last task very funny. But I would like to know more about that. Was the last task funnier as the ones before? Please answer with Yes or No!"
C: "No."
A: "Ah, so you meant that the last task was as funny as the ones before? Yes or No?"
C: "No."
A: "Oh, so you actually wanted to say that the last task wasn't that funny than the last ones?"
C: "Yes."
A: "O.K. Now I understand. You didn't like the last task and you wanted to say the next one should become funnier? Yes or No?"
C: "Yes."

With the agent's repair questions the situations now looks like that: **C[m?]** and **CAC[m?]** and **AC[m?]→CA[m?']** and **A[m?']**.
Result: The agent has to do some motivational work.
Furthermore the agent knows that he has to explain again and more precisely how the child has to use the virtual motivation panel board.

agents behaviour towards a more successful enfolding of empathy (see Box 2).

Box 2

We are developing and using the following methods and technologies to achieve the above mentioned goals [6].

- Wide and shallow, explicit and sophisticated learner modelling with respect to knowledge, beliefs and goals
- Definition of stereo types
- Domain modelling
- Conception of communication between agent and other components of the system
- Development of Bayesian networks with an influence diagram containing chance, decision and value nodes
- Machine learning techniques
- Logical inference
- Handler of noise and uncertainty

Evaluation

Evaluation of TAPA will be performed at first in preliminary studies that consist of repeated testing of prototype scenarios with parallel behaviour observation through experts. This first evaluation step helps to analyse communicational functionality as well as validity and is necessary for optimising of meta-communication.
Main Evaluation involves a pre-/post-test design with at least n = 100 cognitive impaired children. The necessary evaluation criteria for the diagnostic module are committed to concurrent validity, precision, reliability and predictive accuracy of diagnostic module via comparison with conventional memory tests.
Training efficiency, ecological validity and individual benefit of intervention module will be performed within the pre-/post-test design and via alternative examination of every-day memory performance including a comparison to efficacy-studies on human trainers.
Next to these effectivity criteria the users' acceptance and subjective perceiving of TAPA should be evaluated.

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