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MENTALLY CHALLENGED AS DESIGN PRINCIPLES AND MODELS FOR THEIR APPLICATIONS

Abstract

Tablet computers have become a common part of our life style. Since 2012, inspired by the success of touch devices in special education, we have established and led the IT therapy program for the mentally challenged. In this paper we also present one of our final study with 12 participants. Based on our findings from our studies we have finally proposed 14 design principles (an extension and redefinition of a previously proposed 10 simple design principles) which should be generally respected in design and development of every "usable/accessible" application for the mentally challenged. Some of these principles are applicable as design patterns or models in software development and some were already implemented in our framework which we used to develop new more usable applications.

1. INTRODUCTION

In last five years we have witnessed huge expansion of touch screen devices in our common life style. Beside touch smart phones, tablet computers are also emerging and have become the common part of our everyday technology. One of tablet computer emerging area is the branch of special education. In this area tablet computers have quickly become the part of assistive and education techno-logy. Thanks to a massive usage of touch technology in this area, the usage of tablet computers in special education is called "*the revolution of special pedagogy*", see (Rihova, 2013; Rihova & Jelinkova, 2013; Shah, 2011).

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Based on the success of these touch devices achieved in special education, we started a research project called "*computer therapy*" in 2012. One of the first main aims was to investigate and also offer the advantages of touch devices designs for daily life (outside the school walls) of mentally challenged individuals by creating a therapy like program with use of touch devices and applications. But as we started we figured out that there are many uncovered usability and accessibility issues even on existing, working applications used on touch devices in special education needs (SEN). Consequently we have pointed out that in order to be able to solve these issues we need multi-disciplinary approach, not only separated health, social, pedagogical, or IT approach. Hence on the turn of 2012/2013 we proposed first simple design principles based on our computer therapy project approach. These principles define how software (SW) should be designed, developed and deployed (used in practice) to bring maximal outcome in therapy for the mentally disabled.

Our therapy program was managed by corresponding author personally (7 hours per working day) in Czech home for mentally disabled. As part of this therapy we have conducted a series of long-term studies based on usability testing. During all three years more than 30 mentally challenged individuals have participated directly and another 10 indirectly in this long-term study. With respect to the scope of this long-term study, here we present one of our final sub-study with 12 participants.

Moreover we have also designed, developed and deployed new applications for the mentally disabled according to proposed design principles and their domain models (applying the model driven engineering methodology – MDE). These developed applications were consequently tested in our therapy environment of mentally challenged and the first positive results were already published in international journals and conferences (Fiala & Koci, 2014, 2015; Vejtasa, 2014).

In this paper, we first present a detailed description of later conducted usability testing and consequently we present the identified flaws of present day tablet computer app designs. Subsequently, based on these flaws, we recall proposed design principles which have been previously presented in a simplified version. The main content of this paper presents the extension and revision of these design principles (some also applicable as design patterns) and, furthermore, we demonstrate (see below our MDE development demo example) the way these principles can handle some of the identified flaws.

Although we operate here with some methods of human computer interaction, these methods are only auxiliary and the main contribution of this paper is in the scope of software engineering (where the proposed design principles have its place). Mentally disabled users are in the centre of our research, thus it is clear to call this summary of present research as "*Mentally challenged as design principles and models for their applications*".

1.1. Definitions

In our research "*computer therapy*" (abbreviated as *i-CT*) stands for research in software engineering and HCI which leads to a proposal of design principles, models for a development of applications for mentally disabled. Moreover, it stands for the therapy-like program (based on special education therapy) established for usability testing of developed apps (according to these principles). In our "*i-CT*" abbreviation, the letter *i* denotes the reference to an intelligent and intuitive touch device like iPad, *C* stands for computer and *T* for therapy term.

The human computer interaction metrics like usability, accessibility, usefulness, etc. are understood in terms of Nielson definitions (Nielsen, 1994). Other abbreviations like UML or MDE (model driven engineering), OCL (object constraint language) are standard terms used in software engineering.

1.2. Related Work and Research Bases

In spite of a wide scope of present research in human computer interaction, there still exists practical usability issues (e.g. section 3.1), or (Budiu & Nielsen, 2011; Fiala & Koci, 2014; Nielsen & Budiu, 2013) which should be discussed and handled. This also holds for the specific HCI area focused on SEN. One of the possible solutions is the proposed "*guideline*" for design and development in order to avoid inappropriate usability issues as a result. This can also be achieved by proposal of specific design principles.

The need and merits of design principles in the role of "*guideline*" for proper design and development is generally known and respected. Besides general software engineering design principles e.g. GRASP or SOLID in (Larman, 2005; Martin, 2000; Marinescu & Lanza, 2006) there is also the need of more specific design principles in specific fields. In the specific field of HCI the usage and benefits of design principles have also been proposed and discussed (Burgstahler, 2008; Karwowski, Soares & Stanton, 2011). Naturally, most of these HCI design principles are oriented on user interface (UI) which is the key part in human computer interaction (Pearson, Buchanan, & Thimbleby, 2010; Stephanidis, 2009).

In relation to the interaction with the disabled, there also appeared attempts to propose design principles for disabled individuals in the past. But before the boom of tablet computers (Hager, 2010; Shah, 2011), most of them were focused on interaction with classical PC or specific devices, see (Vanderheiden & Jordan, 2006). After the boom of touch devices in 2010, there appeared more works discussing the design principles focused on touch screen platforms but these were more oriented on intellectually capable individuals (Budiu & Nielsen, 2011; Pearson, Buchanan, & Thimbleby, 2010). On the other hand new research outcomes focused on design principles for interaction of the disabled

with a tablet computer were also proposed in previous years. In these contributions we mostly find works oriented on specific subgroup of disabled users for example autism (Signore, Balasi, & Yuan, 2014) or oriented on a very general group of disabled users in an effort to handle most of disabilities (Buhler & Pelka, 2014) or focused on design principles for one specific app for example in (Dobosz, Dobosz, & Fiolka, 2014; Signore, Balasi, & Yuan, 2014).

Beside the benefits of these efforts we understand the need of their further extension which is naturally invoked by daily needs of the mentally disabled (mostly observable in special education/therapy). Thus we put the mentally challenged individuals as the centre of our research. This leads us to specific conditions which should be met in the proposed design principles.

In comparison, the primary focus in our case is not only oriented on user interface (UI), but is closer to classical software engineering design principles. Although all of proposed principles are not primarily addressing UI, it finally has a fundamental impact to end-user usability and accessibility. In this research we come from our critical review of existing apps, from conducted long term usability testing and identified flaws. These flaws highlights the fact, that some of uncovered usability issues have its cause in inappropriate basic software engineering design and development. Therefore inappropriate basic software engineering design and development can have a fundamental influence on final app usability. As a result, our research basis puts some research specific constraints, which requires that all research criteria should be met. As we can recognise from related work discussion, our practical oriented research goals lead us to following specific criteria on design principles:

- Design principles are oriented on usability (HCI) issues (humans are in the centre of design), but are not strictly focused on UI elements.
- End-users are specifically mentally challenged individuals, but cover a wide range of mental disabilities with combined, attached impairments.
- Design principles are not focused on one group of specific apps design (e.g. apps for alternative and augmentative communication – AAC), but cover a range of common apps used in special education/therapy.
- Instead of PC platform, design principles are oriented on apps for platforms of touch devices (tablet computers and smart phones, multiplatform).
- Design principles are not defined as general plain text claims only, but in spite of its generality can be applied in real specific situations and can be represented formally by model representations (e.g. in UML with extension of OCL), which is common in SW design and development, e.g. see (Jacobson, Booch, & Rumbaugh, 1999).

These 5 research criteria create very specific conditions in our research. On the other hand, the need of "*guideline*" (e.g. represented by design principles) for special education is growing rapidly with growing success of touch, mobile

devices in this area which led to "*the revolution of special education*" in 2012, see (Rihova, 2013; Rihova & Jelinkova, 2013; Shah, 2011). Although such design principles may look very specific, they stand for "*guideline*" for a specific education app design, which is being expected and seems to be still unfilled, see (Fiala & Koci, 2015). Hence we have already proposed the first version of design principles for these mentally disabled (Fiala & Koci, 2014).

On the other hand, it is obvious, that our first version of proposed design principles cannot be final and calls for further correction and extension. Therefore, we have conducted further usability testing, critical reviews, semi-structured interviews with mentally challenged individuals to find out the most common usability issues, which should be handled in priority. Hence we still continue in this urgent work and extend original design principles by reflecting our latest long term usability testing and identified apps design flaws. Thus, in summary, our original design principles were modified, extended and several new ones were added too (increasing from 10 to 14).

It is expected that some of the proposed principles may already be known or applicable in other situations, conditions or fields that we assume in a HCI context with SEN. Therefore our contribution novelty is not based on each principle novelty and originality, but is expressed by such a set of design principles which leads to recovery from identified usability issues we are facing today in SEN.

2. RESEARCH METHODS AND RESOURCES

In this research we generally put the focus on being involved in this testing process to "*put our hands on and get it dirty*". In order to identify flaws in present apps on touch devices we have firstly established the therapy program (called simply computer therapy) for the mentally disabled as the research ground for prepared usability testing with mentally disabled individuals.

This therapy program was based on the special education cognitive play therapy methodology and was also supervised by Czech experts in special education (Rihova & Jelinkova, 2013). The therapy has also adopted the principles of *i-CT* proposed previously. The therapy (located in a Czech home for the mentally challenged with attached disorders) was provided personally by the corresponding author of this paper for 7 hours per working day during three years, 2012–2014.

2.1. User Group Definition

During this daily therapy we have conducted the series of usability testing (real user-based testing). More than 30 mentally challenged individuals have participated directly and another 10 indirectly by supervision of their key assistants.

With the respect to the whole scope of this three year long-term study, here we just present one of our later testing (conducted in 2014) with consequent flaws identification observed at the conducted usability study (one of the series) in a group of 12 users (age from 20 to 50).

Tested users were mentally challenged (moderate mental disability) with associated combined disorders including physical defects, learning disabilities (LD), Attention Deficit Hyperactivity Disorder (ADHD), Down syndrome and cerebral palsy. They did not have any experience in using a PC, because they were not able to use it due to its complexity (keyboard, mouse, classical OS concept of files and folders). Some of these participants used to visit a class in a special school several years ago, but there was no driven continuity in obtained competences development. All of them had a low vocabulary and some of them had a low ability to speak. Some participants were able to count to 10 (addition and subtraction only), but counting over 10 was unreachable, and some of them were not able to count at all. There was no knowledge of any foreign language at all.

2.2. Hardware and Software Resources

In this case of usability testing users were working with tablet computers. This group of users covered users with different main specific needs, therefore several and different applications (covering user's specific educational needs – SEN) were tested in this study. A tablet computer platform (Apple iOS) was selected with respect to required user's SEN in applications on a selected platform. Finally, the following HW and SW resources were employed:

- *Apple iPad* 4th generation, 10" display, OS: iOS 7.
- *Niki Talk, C.P.A., Kabosil, VOXkom* (apps for alternative and augmenttative communication – AAC).
- *Touch the Sound, Sound Touch 2, Match it up, Little Finder, My little suitcase* (education in vocabulary).
- *Pocket pond, Fluidity, Gaze HD, Plasma globe, Tiny piano, I can xylo, Music sparkle, Guitar free, iAm Guitar, Magic Piano, Doodle Buddy, Draw 4 free, Kids paint, Let's Create!*
- *Pottery HD Lite, 123D Sculpt, 123D Creature* (training, motivation, play therapy apps).
- *BitsBoard, ABC Chiffres, ABCD for children, My first words* (reading and writing apps).
- *Add testic, Sub testic, Free Clock, Czech money, Missy math stage 1* (education in little math).

2.3. Task Scenarios and Usability Testing

The 12 individuals were grouped into smaller groups according to their disability and abilities, development in specific needs which was the object of their therapy. Each group is described by its own case of study and scenario.

2.3.1. Scenario for group in augmentative and alternative communication (1)

The group contained 3 individuals with moderate intellectual disability and some physical movement defects. Touch screen platform was usable in some tasks, thus we have supported these individuals with AAC apps as their main task for alternative communication focused on basic daily phrases.

2.3.2. Scenario for group in vocabulary development (2)

Group consisted of 4 individuals with moderate intellectual disability with further disorders (ADHD, Down syndrome). These individuals were able to speak but had a very limited vocabulary. Therefore, we have focused on vocabulary development through proper apps on touch screen platform as listed in previous section. The participant's task was to learn new words from a given vocabulary setup in available applications.

2.3.3. Scenario for group in reading, writing and math skills (3)

Group consisted of 5 individuals with moderate intellectual disability. All of them used to visit a class in a special school several years ago, but there was no further driven continuity in obtained competences development. Their speech was limited, but they could express whole sentences and they had some ability in reading and writing. They also had some experience in a little math (up to 10 addition and subtraction). Therefore, we operated with apps (as listed in section 2.2) for reading, writing and math development to extend their original skills in this area. The participant's task was reading and writing of known words from given a vocabulary setup in application and little math training.

2.3.4. Usability testing description

Primary goal of this usability testing (testing with real users) was not the identification of the best applications (usability comparison among available apps), but the identification of their flaws observed through a set of available apps for each specific group. At the beginning (preparation phase – 2 hours per week during one month) each participant was introduced to iPad through training, motivation, play therapy apps (see section 2.2) which were used during the daily therapy program.

Afterwards (testing phase – 2 hours per week during 6 month) each participant was asked to perform his specific tasks described in his scenario. Each participant used several applications for his tasks (see section 2.2) and whenever the user was not able to complete his task (partially or totally), the participant was interviewed via a semi-structure interview to describe the reason as much as possible. During this long term testing the participant's reasons were progressively corrected and checked by a therapy assistant (whether stated cause is truly reasonable). At the end of usability testing all unreachable states which should be reached in a user task and which also passed through reasonable progressive correction and checking, were marked as identified flaws. As a final output we have observed the list of identified flaws of application designs which are described in the following section.

3. RESEARCH METHODS AND RESOURCES

3.1. Identified Flaws of Mobile, Touch Platform Applications

In this section we summarise the list of the most common identified flaws observed during conducted long term usability testing and inspection cognitive walkthrough as described in the previous section. In spite of different tasks completion during usability testing performance, we can track common issues which are consequently grouped in a joint flaw categories as follows:

1. **Protection, security lacking** – apps setting is mostly without any access restrictions, setting is not protected and can be improperly changed by users. Moreover, any individual can use the app for unlimited time if not guided properly (this may lead to improper addiction or habits). On the other hand, the app can be switched on or off easily which allows an individual to escape from education/therapy program inappropriately.
2. **Accessibility lacking due to price inaccessibility** – some required applications are not accessible due to their application price, thus disabled individuals cannot use or access these apps as needed.
3. **Internationalization and localization lacking** – missing the option of national (e.g. Czech) user interface, control.
4. **Individual SEN lacking** – missing user accounts, profiles, account protection.
5. **Presence of non-perceptible affordances** – some parts of user interface (affordances) are not perceptible, not as intuitive as needed (i.e. scrolling is difficult to discover, some elements, pictures, lines, buttons were designed too small to be controlled correctly even on 10" tablet computer – phenomenon of fat finger).

Tab. 1. The incidence of each case of identified flaw at each tested mentally challenged end-user (own study)

			The occurrences of app design flaws according to their category*							
Scenario number	**End-user**	**Gender**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	Maria	F	x	x	x	x	x		x	x
	John	M	x	x	x	x	x	x	x	x
	Bob	M	x	x	x	x	x		x	x
2	Michal	M	x	x			x	x	x	
	Tom	M	x	x	x	x	x		x	
	Peter	M	x	x			x	x	x	x
	Robin	M	x	x	x		x	x	x	x
	David	M	x	x	x	x	x	x	x	
3	Otto	M	x	x		x	x	x	x	x
	Joseph	M	x	x	x	x	x	x	x	x
	Gabriela	F	x	x	x	x	x	x	x	x
	Helen	F	x	x			x	x	x	x
Flaw frequency in %			100	100	66,7	66,7	100	75	100	75

* Each flaw occurrence was marked according to usability testing method, see section 2.3.4.

6. **App customization lacking** – low or difficult app customization/modifications in app setting (for example in the case of AAC app, it is not possible to change existing pictograms in some categories).
7. **Platform isolation, dependency** – app is available for one platform only (e.g. Apple).
8. **Works online only** – app or its partial functionality is accessible only as a web-app, it could not be fully used outside the range of Wi-Fi connection.

As we can see in Tab. 1, each flaw occurred for more than 50% of all users. Even when one instance occurs such a flaw can be a logical reason to think about the usability improvement for mentally challenged users, but there appeared much more than one incidence only.

3.2. Extending the Computer Therapy Design Principles

Here we present the extension of the previous simple 10 principles to 14 design principles according to the latest testing and flaws identifications. Each principle is described by its problem description and its prescription – the proposed solution. First, previously published positive results (Fiala & Koci, 2014) led us to this revision and extension of the first version of design principles.

For comparison, the first basic 10 design principles were extended by principles marked as no. II, XII, XIII and XIV in this paper.

Furthermore each of the original design principles was also revised by defining descriptive and prescriptive parts and thus making clear and simple redefinition with use case examples corresponding with UML representation

(each design principle is possible to express at least by one domain model e.g. in the UML with OCL representation, see section 3.3). The reference to a specific identified flaw is marked in brackets (expresses which principle handles one of the specific identified flaws, as listed in section 3.1).

I. The principle of platform independence (multiplatform). [7]
Problem: mentally challenged individuals cannot care about variety of platform producers, or why this is not working on my device, or why this is not compatible. They simply need their app working on their device.
Solution: designed and developed app (i.e. application for AAC) should be supported on multiple platforms (i.e. mobile touch platforms with operating systems like iOS, Android or Windows), to launch with a similar look and feel behaviour as much as possible.

II. The principle of "*online*" independence. [8]
Problem: life-style of mentally disabled is in contrast with world-wide trend of cloud solutions and "*Internet of Things*". Mentally challenged individual needs a robust, stable app everywhere and anytime. They cannot handle or care about the reasons of non-working web service/app or whether my location has some available connection with optimum throughput.
Solution: SW – applications should be developed as native or hybrid rather than web applications to support accessibility and usability independent on an internet connection, which cannot be properly accessible in every life-style situation of the mentally disabled as needed.

III. The principle of multidisciplinary attitude.
Problem: mentally disabled individual is usually very dependent (during the whole life) on services of social care, health care and continuous education which is in contrast with a common, intellectually capable individual.
Solution: the design and development of app should meet the requirements concluded from specific educational needs (SEN), demands from social, health care, all confronted with ICT constraints. The whole application should reflect the real objects situations from these four areas at least.

IV. The principle of free, open accessibility (OA). [2]
Problem: in general, working life of a mentally disabled person is not financially fruitful enough to cover all their expenses and, therefore, if the required app is not accessible due to its cost, then unfortunately there is no accessibility and usability too.
Solution: final app should be distributed as freeware or available at low accessible cost, SW should prefer availability under open public licence (including codes for further open development by community of experts).

V. The principle of proper SW techniques.
Problem: it is uneasy (even in cases of multidisciplinary attitude) to map properly the complexity of the world of mentally disabled reflecting all their needs and limitations. Thus we can always create only the representation at a certain level of inaccuracy.
Solution: SW design and development techniques should use such methods to map the "*real world of mentally disabled*" as precise as possible and needed. SW techniques of real world object mapping like OOP should be included with related modern IT standards. This includes the proper choice of SW architecture, for example, MVC architecture, see (Veit & Herrmann, 2003).

VI. The principle of SEN purpose priority. [4]
Problem: there are many needs in the life of the mentally challenged, but for purposes of special education and therapy (in terms of special pedagogy) there are key needs – SEN, as also noted in "*The principle of multi-disciplinary attitude*".
Solution: to guarantee the app's purpose for education and therapy, SEN should be primarily reflected and implemented as the main app's purpose. Consequently the final app should be accessible and usable primarily in the scope of this SEN purpose (i.e. categories and its word/pictogram cards in an application for AAC).

VII. The principle of "*beyond the school walls*".
Problem: the education and therapies of mentally challenged are not restricted by school walls only in their common daily practise but are continuing in collaboration and interconnection with other provided services (e.g. parts of social, health services).
Solution: app should be designed, developed as usable in the school environment (i.e. integrated in common school, or in special education) and out of school education, free time activities, games, see (Fiala & Koci, 2014), common daily life environment, including the sector of social-health services, in summary usable in conditions where disabled individual lives or moves.

VIII. The principle of individual content (educational/therapy). [4]
Problem: besides the need for a multidisciplinary attitude (described in "*The principle of multidisciplinary attitude*") there is the need for an individual educational/therapy attitude which reflects specific/individual educational needs (individual content) of each mentally challenged individual.
Solution: app should offer the customisation for individual education/therapy content (e.g. customisable set of pictograms/categories in the case of AAC application). Individual content should also reflect individual plans (i.e. respecting individual limitation, health condition, activities, and hobbies).

This customisation should be protected from unwanted changes caused by accidental touches and this protection is further handled by "*The principle of safety and protection*" below.

IX. The principle of continuity.
Problem: the instant, continuous education/therapy program is important in the life of the mentally challenged individual (in case of over school individuals we talk about free time pedagogy and therapy programs which can be offered continuously). Only this way the learned, obtained competences can sustain and possibly increase too.
Solution: a designed and developed application should be prepared for long term and everyday intensive usage. This includes the support for a variety of educational content for each individual and offering future app support (e.g. available in a form of unknown issues, bugs reporting or user's suggestions reporting for further app development).

X. The principle of usability and affordances amplification. [5]
Problem: generally each control or other action element in user interface should suggest its usage (affordances). In the case of mentally challenged individuals, this rule should be multiplied (amplified) by the degree of intelligence deficiency or deficiency in perception abilities. A similar situation occurs in the focus on user interface element's practical usability. A user interface element may be usable (touchable) for an intellectually capable individual, but not usable (touchable) for a mentally challenged individual with worse perception or deficiency in soft motoric functions.
Solution: each element of user interface should be formed well enough (size, shape, colour, sound response) to suggest its usage, even for the mentally disabled e.g. using simplified and amplified principles of "*Design of everyday things*", see (Norman, 2013). Size of elements should be large enough to avoid "*thick finger effect*" and distances among elements should allow freer place to avoid of multiple action-button touches. Furthermore, all gestures should be intuitive, simply based on common-known, real world gestures (real world of mentally challenged).

XI. The principle of assistive mode. [1]
Problem: in special education/therapies many of the given tasks are dependent on the assistance of a special tutor or a social/health care worker. The need for assistance may still be necessary even in cases of tasks realised on a touch device (e.g. tablet computer). Besides the assistive mode required in real time task completion, the assistive mode is also required for a proper app, educational content customisation, setting before the education/therapy is started.

Solution: besides an end-user account, each app should offer other types of accounts. The first is an assistive account for setting and modification (i.e. personalisation of education content: adding or removing functions, time lock or screen lock) according to individual needs (i.e. for teachers, instructors, assistance). It should be possible to simply switch between these accounts, even during real time task completion work with the mentally disabled.

XII. The principle of administration mode. [1]

Problem: in common special education/therapy one educational tool (including tablet computer with specific educational app.) is used by many special tutors for several mentally challenged users. Meanwhile, some demands of special tutors and some SEN of their users may be very similar, while some of them may differ. This leads to demand of further administration.

Solution: besides the assistive mode – account described in the previous principle of assistive mode there is a need of administration mode (account) to guarantee the control over multiple special tutor's accounts. The administrator can operate over app permissions (restrictions, see below), even over the special tutor's accounts. Moreover, the administrator should be able to make a copy of accounts (assistance, special tutor, and end-user) and pass its setting, customisation to new created profile or replace some of the existing profiles.

XIII. The principle of internationalization and localization. [3]

Problem: for the most ofmoderate intellectually challenged users it is almost impossible to understand and use other foreign languages.

Solution: to guarantee the usability and accessibility for intellectually challenged users, the app should fully support individual internationalization and localization.

XIV. The principle of safety and protection. [1]

Problem: improper usage of electronic data (e.g. games) may lead to addiction even in cases of an intellectually capable individual. Furthermore, some data available in apps or available through such apps or internet browsing may include or lead to "*inappropriate explicit content*". Moreover, in spite of the application of "*the principle of online independence*" (app online independence) the tablet computer can still be connected to the internet or there might be some inappropriate apps installed on the device. Therefore, the question of safety and protection still remains uncovered. In contrast, intellectually disabled users are not able to recognise the risks of such apps, content and thus should be protected as much as possible.

Solution: an app should offer safety usage in terms of the prevention and protection from abusive or addictive practices which an intellectually disabled individual cannot recognise or prevent. This includes the prevention from inappropriate explicit content e.g. violence, hate or addictive practices like internet pornography, see (Kleponis, 2012). The application should allow time and content restrictions (blocking the escape from an app, e.g. "*kiosk mode*"), which are customisable in administration mode.

Although some of the proposed principles may appear as standalone, in this proposal all 14 design principles create one aggregate and are interconnected, one principle assumes the presence of others. Hence all principles are assumed to be applied in each app development for mentally challenged users (special education and therapies). If a principle application cannot be handled (e.g. due to technical issues), we assume its maximal application (apply the principle as far as possible) to support at least part of the principle.

3.3. *i-CT* design principles as domain models in MDE for apps development

In software engineering common practices (developmental methodologies) we transit through developmental cycles where formal software modelling is usually required. This formal representation is usually expressed by diagrams in UML. One of common developmental methodologies is the model driven engineering (MDE) and domain driven design (DDD), see (Evans, 2004) and (Schmidt, 2006). In these developmental methodologies we operate a with domain model representations which are used for further code generation in the implementation phase. By application of MDE and DDD methodologies, *i-CT* design principles represented in UML domain models also serve as the enhancement of software developmental process (apps for mentally challenged). Hence proposed design principles are not only represented as abstract plain text claims, but they are also expressed by an UML with OCL extension and thus create domain models which are directly applicable in further software developmental process.

In detail, obtained domain models are used for code generation of a common framework which is consequently used for each specific app development (development driven by framework). Thus, by utilization of domain models in UML the SW developmental process of certain apps are enhanced by automation of this process. In result, a specific demanded app for the mentally challenged is developed and deployed faster. Thus, the practical accessibility is also increased in terms of HCI.

The first version *i-CT* design principles have already been expressed in UML, OCL domain model representations which were used for the first framework generation and this framework was consequently utilised for development of the first 3 apps for mentally challenged, (see the next section for detail).

The same process is now expected with an updated, revised new version *i-CT* design principles which are presented in this paper. But this process completion in now in progress, (see chapter 4 "*On-going and future work*"). For demonstration purposes here we can present two of the proposed designed principles in formal UML representation, specifically in a class diagram. Following figure 1 describes a domain model in UML class diagram representing the principle of assistive and principle of administrative modes (no. XI and XII).

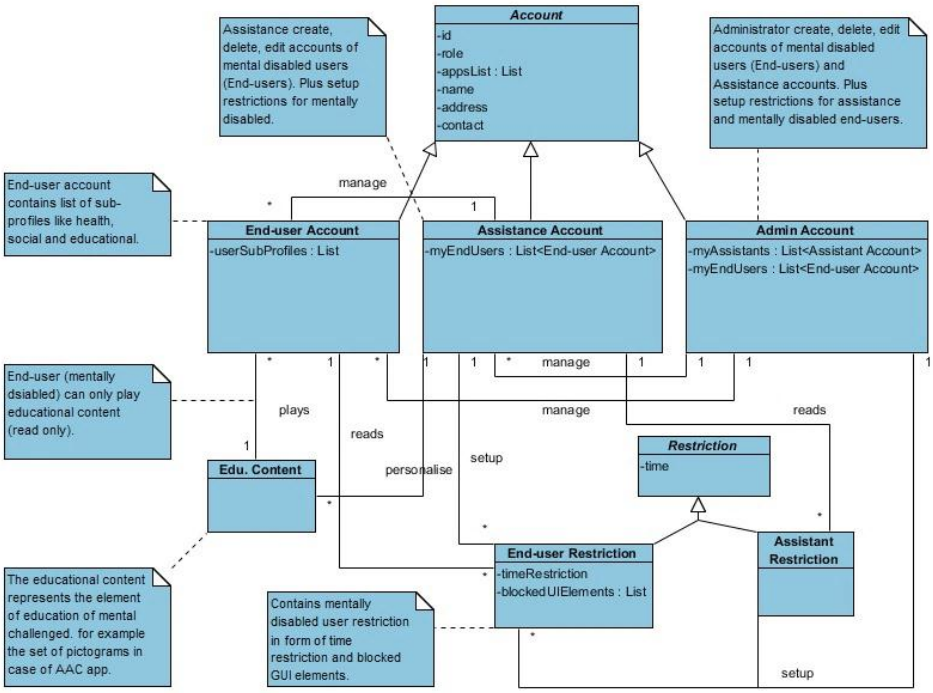

Fig. 1. The draft of possible realization of the principle of assistive and administrative mode in the UML domain class diagram (own study).

As we can see the design principle no. XI and XII sets specific constraints, conditions in object oriented design, and thus generate the stub of the domain model. In the case of class diagrams this leads to a generation of specific classes, associations among end-user account, assistance account, administration account, educational content (education content) and restrictions, where associations among classes have specific constraints and properties.

Moreover, each core class prescribes the list of methods (operations) which should be handled in the implementation process. Even in this simple example, it is obvious that by respecting these examples of design principles of assistive and administration mode represented in UML, we eliminate an inappropriate

design which may lead to one of identified flaws in the result and thus to a significant reduction in end-user usability and accessibility (as justified in principles description). On the other hand it is obvious that for each of proposed design principle there exists one or more proper domain model representations. Hence we assume at least one of proper model representation which is released collectively with the implementation of our proposed revised design principles in*i-CT*framework and its superstructure apps (see section 4 "*On-going and future work*").

3.4. Demo Example: Mentally Challenged as Models for Their Applications

As we have noted in the introduction, this research is significantly interconnected with practical work and implementation. Since 2013 we have started the development of first open source framework (called *i-CT framework*) which implements models of the first 10 design principles in UML to a practical framework. In 2014 the first version of *i-CT* framework (version 1.1.0) was released, see (Fiala, Koci & Vejtasa, 2014).

Presently we are extending our original first framework by the application of the revised, proposed 14 design *i-CT* principles at present and consequently, we are also preparing the design of new apps (see section 4 "*On-going and future work*" below). We cannot demonstrate the whole positive impact of these extended, revised design *i-CT* principles here. Therefore, to provide some demonstration of the positive impact of these *i-CT* principles to usability issues, we recall previously released applications. These apps were built based on first framework version generated from domain models obtained from the first 10 design principles according to MDE and DDD methodologies. A list of these first apps is below:

- *EasyTalk*: application for alternative, augmentative communication (AAC).
- *SignToLanguage*: application for training and testing of sign to language.
- *YesNoCommunication*: application for elementary AAC.

Each of the developed applications was verified previously during usability testing in comparison present similar applications at present. Each of them had provided higher usability and accessibility in comparison with the corresponding apps. Here we recall a closer one of the developed app, called *EasyTalk* (the AAC application). This app simply demonstrates the way the accessibility and usability is also increased if *i-CT* design principles (even the first proposed version) are properly adopted and respected in software engineering process.

The common goal of any proper AAC app is to compensate and reduce the speech disability (Beukelman & Mirenda, 2005). In case of mentally challenged individual with speech disability, AAC often represents the only way to communicate. Hence the usability and accessibility of such AAC application is critically important.

In recent years the usage of AAC apps on tablet computers have proven significant results when working with the intellectually disabled, see (Bradshaw, 2013; Fiala & Koci, 2015).

Fig. 2. *Easy-Talk* application desktop is accessible in several languages including Czech – in comparison with other AAC apps, this desktop is also customizable by different visual styles andits control panel contains more functionality for AAC expression (own study)

Tab. 2. AAC application *EasyTalk* in HCI factors comparison with other present applications (own study)

AAC apps	Important AAC application functionality related to HCI factors*								
	Assist. support **(XI)****	User accounts **(VIII)****	Multi-platform **(I)****	Editable content **(VIII)****	Sentence history **(VI)****	Canvas **(VI)****	Text input **(VI)****	Free distr. **(IV)****	Open source **(IV)****
Easy-Talk	YES	YES	YES	YES	YES	YES	YES	YES	YES
Klabosil	NO	NO	NO	YES	YES	NO	NO	YES	NO
Niki Talk	NO	NO	YES	YES	NO	YES	YES	NO	NO
C.P.A.	YES	YES	YES	YES	NO	NO	NO	YES	NO
Grid Player	NO	NO	NO	YES	NO	NO	NO	NO	NO

* HCI factors were based on comparison of two designs, one with supported functionality available in *EasyTalk* app and partial or missing functionality available in other AAC app.

** Roman numbers in brackets denote design principles which were used to improve the functionality in *EasyTalk*.

Unfortunately many of these apps include HCI factors (e.g. as noted in Table 2) which lead to inappropriate usability issues, see (Fiala & Koci, 2015; Vejtasa, 2014). Therefore, we have previously implemented the above mentioned *EasyTalk* app to handle some of these issues and also through a proper software development strategy based on the described utilisation of *i-CT* design principles. For *EasyTalk* app illustration see Figure 2.

The first positive outcomes demonstrating the comparison of *EasyTalk* app with present similar AAC apps were already published in (Fiala & Koci, 2015; Vejtasa, 2014).Table 2 recalls an observed comparison of *EasyTalk* app with other present AAC apps used for special education and therapy (the key of comparison are HCI factors).From the recalled observed data and *EasyTalk* app usability testing we can see that implementation of *EasyTalk* app according to proper software development strategy based on noted utilization of *i-CT* design principles had finally led to an improvement of usability in comparison with other similar present AAC apps.

If we consider the first *i-CT* design principles and proposed extension and revision of *i-CT* design principles as presented in this paper, it is clear to claim that based on the provided justification the analogous utilisation of presented 14 extended *i-CT* design principles into SW development process will also lead to an improvement of usability and accessibility in specific apps (at least in the cases of previously developed specific apps). On the other hand, the full evidence can be done only through implementation and testing of specific apps and its consequent comparison with similar apps, which is now in progress.

4. ON-GOING AND FUTURE WORK

As noted in section 3.4, based on the first version of the design principles, the framework and several applications for special education/therapy of mentally disabled were already developed.

By revision and extension of these design principles as proposed in this paper, the previously developed framework should be revised and extended, too. The same holds for the previously developed apps based on this framework. This is the task of the present on-going work. At present, we are extending previously developed apps and new apps (e.g. app for real time sign language translation and other apps for communication) were also added. For all developed apps and framework hold the same as previously, all software is licensed as freeware under public domain (open source) to underline the accessibility factor.

The domain model (mostly based on UML with OCL) package, including the possible model representations as domain diagrams of each principle, is going to be included within the new framework release. Once the framework and apps will be finalised, we are going to conduct further usability testing to observe the full evidence of usability improvement of developed apps in comparison with present and similar comparable apps.

5. CONCLUSION

The usability and accessibility of ICT resources are key factors for each mentally challenged individual. This importance was further increased by the new possibilities of touch devices (tablet computers, smartphones) which were observed in special education and therapies (Hayhoe, 2012; Isasi, Basterretxea & Zorrilla, 2013; Jowett, Moore & Anderson, 2012). In spite of many positive HCI factors of the touch devices for mentally disabled, there still remain usability and accessibility issues which should be discussed and handled (Fiala & Koci, 2014; Nielsen & Budiu, 2013). Hence, since 2012 we have started a daily "*tablet computer*" special therapy program for the mentally challenged (simply called "*computer therapy*" program) to identify the main usability issues and to consequently verify the proposed solution. Based on the first identified usability flaws we have proposed the first version of *i-CT* design principles which were further expressed as domain models and used in MDE for the generation of the practical framework which was consequently applied to development of practical apps for special education. During the long term usability testing, these first apps have provided the evidence of improvement in usability and accessibility. Thus we have enhanced the SW development process itself and have overcome insufficient functionality referring to specific HCI factors see (Fiala & Koci, 2014, 2015; Vejtasa, 2014). This improvement was achieved due to a proper developmental strategy obtained through the proposed *i-CT* design principles applied into a software development process by the usage of MDE and DDD methodologies. In this paper we also presented one of our final usability testing which has led to the identification of further usability issues. Based on this identification and evidence we have revised the first version of *i-CT* design principles by:

- Redefinition of each principle (in the form of clear problem description and prescription to provide clear and specific requirements usable simply in SW life cycle e.g. MDE).
- Extension of these principles by 4 new principles (reflecting noted flaws).
- Expressing principles in UML with OCL representation (to inject the proposed principles into the design model directly).

The goal of this paper was to present important usability issues (identified flaws) observed during our testing and propose the proper design principles to handle such issues and furthermore, to demonstrate its positive improvement in usability and accessibility in apps for mentally disabled. The demonstration of the positive contribution was provided based on justification and a comparison with a previously proposed first version of *i-CT* design principles which have proven the improvement in usability and accessibility in specific apps. As noted in section 1.2 and 2, our practical oriented research goals led us

to noted specific criteria on design principles. Although this criteria seems to be strictly specific, it addresses the field of special education, therapy which awaits for solutions of practical usability issues. Hence here we continue in this effort and present further results of conducted usability testing (identified flaws) and propose the revision and extension of the previous first version of design principles for the mentally disabled. As we have started and continued this research in close connection to mentally challenged, it is clear to summarize this contribution by the title "*Mentally challenged as design principles and models for their applications*".

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