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Role-Playing Computer Game to Improve Speech Ability of Down Syndrome Children

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ABSTRACT

Down syndrome individuals are known to have difficulties in speech, both in pronunciation of words and making sentences, due to the innate physical impairment of their mouth muscles and their cognitive and intelligence limitations. An interesting finding by other researchers shows that the vocabulary acquisition rates of these individuals fall between the range of average to slow, and they hardly use good grammar, although they seem to have good understanding of casual conversation. However, most research efforts have been dedicated to enhancing their words recognition ability and computer applications have been developed for reading therapy, whereas the syntax and expressive language training are rarely focused. In this paper, we propose the use of role playing computer game featuring state-of-the-art speech recognition technology as an attempt to improve the speech accuracy of down syndrome children in terms of grammar. The challenges involved the input received in coordinating the speech accuracy. We provide systematic review on some of the base elements to consider while developing the game for the mildly-impaired down syndrome individuals, which includes speech recognition technology, cognitive psychology, instructional design models, system development life cycle, and multimedia in special education.

Key words : Down Syndrome, Multimedia Applications, Serious Game, Speech Training.

1. INTRODUCTION

Language learning can be quite challenging for children with down syndrome [1]-[3], and their language development is usually delayed. It is suggested that these children usually are worse in grammar than the children without down syndrome, and they have difficulties to express themselves in words which makes it very hard for them to communicate with others [1], [4]-[7]. To help children develop their language skills, with and without down syndrome, multimedia assistive software is widely used [8]. This is because by integrating multimedia elements in the instructional design (ID) can significantly enhance the learning experience for children [9]. Without reinventing the wheel, multimedia presentation method should consistently be used in courseware or other systems that provide speech training so that the children are not bored and discouraged with the practice. Whilst there are many multimedia applications to assist language learning for down syndrome children, many of them rarely scratch the grammar quotient of the down syndrome children. On top of that, the study published in [10] shows that the applications developed for down syndrome children language learning only cover three out of four essential language skills, including reading, writing (typing), and hearing. Still, speaking being one of the fundamental skills in language learning is ignored.

We found that even until today, the grammar illiteracy problem among the down syndrome children still prevails in Malaysia, because the practice by down syndrome children to speaking sort sentences is always neglected by educators. Hence, we propose in this paper the adoption of role-playing computer game (RPG) with speech recognition enabled for their speech practicing which employs multimedia and gaming elements that help to hook and engage the students in learning, as well as to utilise their visual memory to provide more effective learning, since the visual memory has more influence on grammar quotient of the down syndrome children [11].

Other than enhancing students' engagement, RPG is suitable to be used for language learning in special education because it does not have winners or losers in the traditional sense of the terms [12], which is important to build confidence for the down syndrome children to keep on trying and learning [13]. The study [12] also points out that RPG can adopt almost any settings be it detective, fantasy, western, etc., which is useful for the development of language learning application based in different context. Many other reasons why RPGs should be considered as a tool for language learning have been addressed by [14].

Speech interaction is seen in digital games and can be tracked back to year 1960s, parallel to the development of voice recognition technology and has become ubiquitous in the 1980s [15]. As the speech recognition technology advanced, the accuracy of Automatic Speech Recognition (ASR) system now compares favourably with humans though not reaching the human parity [16]-[18]. Although speech recognition in gaming industry is still rarely seen in both serious and conventional games due to the limitation of the underlying technology of speech recognition, a result of the delay in speech recognition during the transcription of utterance into text which makes it unsuitable to be used for fast-paced games, the technology could still be integrated in courseware or learning system that caters for down syndrome children, which is slower in terms of interactivity between users and computer that ensures the core of learning, be it the knowledge or skill, can be conveyed thoroughly. A recent study by [19] developed the "HATLE" courseware, which integrates speech recognition in pronunciation learning for children with down syndrome shows the feasibility of speech recognition for speech therapy and education.

The rest of this paper reviews and analyses the previous research that have been conducted on different aspects of work that are aligned with our study, including their findings and contributions that provide justifications for our research. The deficiencies of the current techniques are also presented.

2. SPEECH REGCONITION TECHNOLOGY

Speech recognition refers to a technology that covert human speech into words or symbol [20], [49]. The review of speech recognition technology in this study addresses the Google speech recognition system and its recent accuracy achievement on children's speech recognition since it is vital to note that the recognition engine performs differently when matching speeches with different voice frequencies and fundamentals that are remarkably different between adults and children. Google ASR is reviewed because it is currently available for public use with Webkit website browsers at no extra costs, while being one of the most research-active ASR systems that accounts for children's voice recognition. Moreover, a study compared several ASR engines for children's speech recognition found that Google ASR always out-perform other engines [20]. A paper published by Google Inc. in 2015 [21] found that training on a large amount of selected data aided by a neural network classifier showed best results in children's speech matching, after experimented with pitch features, spectral smoothing and vocal tract length normalization (VTLN), and applied improved acoustic modelling for the recognition of children' speech.

From the experimental results in [21], adding both adult and child utterances to the training set shows improvement to the children's speech recognition. The results showed that their best achievement for children's speech recognition is about 10 percent word error rate (WER) under clean or noisy environments. However, the measuring details for the experiment is unclear, wherein no information regarding the utterance patterns, such as the grammatical structure, was given. The study in [20] suggests that the semantical correctness plays a significant role in the ASR engine's recognition rates. At 95% confident interval (CI), the recognition for fixed grammar and template grammar tests returned WER lower than 50%, while the engines recognised almost no sentence correctly for the open grammar test. From which, we deduce that using speech recognition technology in game-based educational application that provides fixed sentences for the children to utter is viable, since research efforts have been exerted constantly in this area.

3. COGNITIVE PSYCHOLOGY

To develop multimedia applications for the down syndrome children, it must be noted that the cognitive psychology of these children is different from children without down syndrome. The review of cognitive psychology in this study focuses on the working memory of the down syndrome children, which is the one mechanism that contributes to acquisition and processing of language [22], [51] so that the method of context presentation that is suitable to be used by these children can be understood and efficient language learning application, RPG in this case, can be produced.

Deficit of verbal working memory among down syndrome children may contribute to the delay in their language development [11], [23]. Working memory involves the temporary storage and manipulation of information for complex cognitive activities [24]. As mentioned in Baddeley's paper, the working memory can be further divided into phonological loop (verbal memory), visuospatial sketchpad (vision memory), episodic buffer and central executive. For information gaining such as learning a language, phonological loop and visuospatial sketchpad are involved before the information being processed by the episodic buffer and central executive. The study [24] also suggests that children with good immediate verbal memory are proved to be better at language learning than those with short spans, measured by both vocabulary and acquisition of syntax or grammar. Unfortunately, it is also agreed by other researchers that the verbal abilities in the down syndrome population are usually lower than visuospatial abilities [11], [23], [25]. Therefore, visuospatial sketchpad must be emphasized as an alternative approach for the acquisition of syntax.

Visuospatial sketchpad can be divided into three subsystems: visual, spatial-sequential and spatial-simultaneous [25], [26],

[27]. Visual memory is the ability of the brain to remember what is presented to the eyes, spatial-sequential memory is the brain's ability to remember the presented visual details in correct sequence, whereas spatial-simultaneous is the brain's ability to remember two or more visual details presented at the same time. Although must be emphasized, it is important to note that visuospatial component of working memory is selectively impaired in individuals with down syndrome [28]. To examine the performance of individuals with down syndrome on specific visuospatial memory components, the study [25] compared 34 children without down syndrome with 34 down syndrome children on four visuospatial working memory tasks: in two of these are spatial-sequential, and in another two spatial-simultaneous. The results showed that down syndrome children performed better in spatial-sequential working memory than spatial-simultaneous working memory. They concluded that it might be the brain's processing speed that affect the performance of individuals with down syndrome on spatial simultaneous tasks, that is, lower ability to move quickly between different points to include details in their working memory. Spatial-simultaneous working memory of the down syndrome children could be improved with substantial memory trainings lead by their parents [28].

By understanding that down syndrome children are slower in brain's processing speed, the feasibility of using RPG for speech practice is further justified. This is because the events in the RPG are always triggered by other events, and for a speech practising RPG, it is the sentences uttered that will trigger an event. In other words, the down syndrome children can see the sequence of their daily situations and remember to use corresponding sentences through RPG. With the guiding sentences to be spoken display on the gaming screen that reflect real-life situations, the down syndrome children could remember to use the sentences and grammar that associate with the game. On the other hand, the options enabled to be chosen in the RPG allow the parents to lead their children in spatial-simultaneous working memory training. For instance, two or more actions are presented in simultaneous fashion to be chosen from. With more practices, the down syndrome children could become more familiarized with choices in their daily lives and they can recall the sentences to say.

4. DESIGN AND DEVELOPMENT

A. *Instructional Design Model*

According to [29], all ID models practically contains the core elements of the ADDIE process, wherein ADDIE is an acronym for analyse, design, develop, implement, and evaluate. However, despite being the core of all ID models, it has been criticised for being outdated, ineffective and inefficient in leading to the best instructional solutions [30]. This section briefly describes three popular ID models apart from ADDIE framework that have either been based or with potential for special education, which are ASSURE model as adopted by [31], Keller's ARCS model as adopted by [13], and Gerlach-Ely model as adopted by [32] for its flexibility to include media [33].

The ARCS Model was developed by Keller for diagnosing problems associated with learning motivation based on the correlation between performance and learning motivation [34]. The four elements of this model are attention, relevance, confidence and satisfaction, which are said to be effective at enhancing motivation of down syndrome children [13]. According to [34], Keller's primary ARCS Model is based on the interaction between instructional materials and learners. Attention refers to the learner's response in perceiving the provided instructional materials. Relevance helps learners associate their prior experiences with the instructional materials being presented. Confidence stresses to provide meaningful experiences during the learning process to build positive expectation in the learners towards the learning task. Satisfaction is achieved when learners are can use their newly acquired knowledge or skills and receive feedback that leads to positive attitudes towards the learning task. Keller's ARCS model of motivation is more of the aims to achieve rather than being a model. The development of the RPG for down syndrome children should have the attributes of the ARCS model, which may be achieved by proper game planning and design.

The ASSURE Model is said to be the most suitable and most convenient model for integrating the theories of education technology and research with practice, as it focuses on instruction goals achievement by selecting and making the best multimedia tools, as well as by encouraging the learners to interact and participate [35], [36]. ASSURE is the acronym for analyse learners, state objectives, select media and materials, utilise media and materials, require learner participation, and evaluate and revise. The study [36] shows that a computer game activity design using ASSURE and ARCS models has positive effect on learners' attitude. When developing an RPG for educational purpose, we recommend a slight modification of the model to be used in hybrid with the Gerlach and Ely Model so that the usability of the game is equally emphasized.

Gerlach and Ely model is a resource-focused model. Using this model together with an instruction-focused model such as ASSURE, could overcome the weaknesses of both models, as demonstrated by [37] with hybrid Gerlach-Ely and Kemp models to offer better delivery of knowledge or skills. Gerlach and Ely is recommended to be used for smooth integration of instructional design with the game development as it provides clear stages to designing the instruction. Unlike the two models mentioned above that are sequential processes, Gerlach and Ely Model follows a more flexible sequential pattern that incorporates a parallel process in its second phase.

The phases of this model comprise of three parts - design, develop and evaluate. As the Gerlach and Ely Model focuses more on the instructional materials and resources without identifying the instructional problems [37], it is rarely seen to be implemented alone, but in a hybrid system. The Gerlach and Ely Model is commonly represented as in Figure 1.

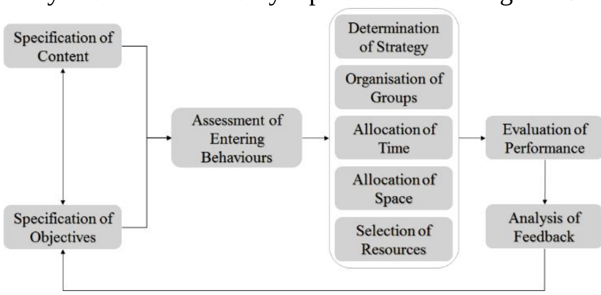

Figure 1: Gerlach and Ely Model

B. System Development Life Cycle

This section introduces and compares some popular SDLC models, including Waterfall, Spiral, V-Model and Agile models to contrast their usability for the RPG development. Several studies have discussed the advantages and disadvantages of these models [38]-[41], which we simplified in Table 1.

Table 1: Advantages and disadvantages of Models

Model	Advantages	Disadvantages
Waterfall	• Simple to implement • Phases do not overlap, more efficient management • Works very well for small projects	• No evaluation on each phase: high risk and uncertainty • Very rigid project scope • User approval and project usability can only be determined at the end of cycle
Spiral	• High amount of risk analysis • Efficient for large projects • Software is produced early in the life cycle	• Does not work well with smaller projects • Costly due to repeated processes
V	• Easy to use • Planning and designing happen before coding • Requirement changes are possible at any phase	• Very rigid and low flexibility • No early prototypes are produced • Requirements documents and test documentation needs to be updated when changes happen • Not suitable for short term projects
Agile	• Incorporate changes easily • Continuous inputs from clients • Costs changes can be handled well	• Not suitable for large projects. • Vague planning date. • Experienced programmers needed to make decision. • Team involvement is highly essential

5. MULTIMEDIA IN SPECIAL EDUCATION

The review of multimedia for special education in this section is to outline the factors to be considered while developing the application so that it does not cause confusion or distraction to the students. We then present and comment on the user interfaces of two educational applications developed for learners with special needs, represented by a Malay reading application for down syndrome children: MEL-SindD [13], and a Cantonese application for individuals with intellectual impairment: Dragon Case Training Workshop II (龍情訓練坊2) [42], to highlight the common issues that are usually neglected by developers. Research suggests that courseware designed for down syndrome children must be able to catch and maintain their attention to increase their motivation [9], [10,]. Inclusion of multi-interactions techniques and different types of activities are preferable. Generally, most of the existing design methods focus on visual and auditory approaches, which involve graphics, text and sounds [10]. Moreover, educational applications designed for down syndrome learners, including courseware and games, must take their learning capabilities into account, which include the intelligent, visual and auditory impairments [43]. Therefore, the interface of the courseware, including the font size and images, must be ideal for them to use, and the application must equip with clear voice delivery and the appropriate voice intonation [50].

A. Comments on current application's interface

As a courseware developed for down syndrome children, we find that the interface is not user-friendly because it is not self-explanatory and does not have the mechanism that cues the learners of their progress.

Figure 2: MEL-SindD's user interface

The graphical illustrations in Figure 2 appear to be convoluted but no text annotation was provided. Children with down syndrome cannot be expected to comprehend these images without extra help. We suspect that it is a factor that diminishes the confidence of the learners. On the other hand, although the texts are outlined and large enough for the visually-impaired learners [44], their colours do not contrast with the background, which makes it difficult for the visually impaired learners to differentiate the important information from the background. The study [44] suggests that the combination of font colour and background colour must be highly contrast, such as yellow and dark green or black and white.

Although not intended for down syndrome children, the design limitations of the application in Figure 3 are commonly seen and could be improved.

Figure 3: Dragon Case Training Workshop II's user interface

Firstly, the colour of the header characters does not contrast with the background, making it very difficult for the users to read. The graphics in one screen is minimized, which is recommended [44], but the size of graphics is not emphasized. There could be interaction between learners and the application where the graphics enlarge while being selected. Without any form of animation involved in the application making it looks dull and uninteresting. The main text and the menu text could be outlined for easier reading. The navigation icons are too small to look at, which causes the learners to strain their eyes. The icons are also confusing, which are clearly not suitable for the intellectually impaired learners. The size of the important graphics on the applications developed especially for down syndrome children must be large and easy to understand.

B. Recommendation for RPG interface development

As a courseware developed for down syndrome children, we find that the interface is not user-friendly because it is not self-explanatory and These days, designers can choose to design an RPG in 2-dimensional (2D) or 3-dimensional (3D) display. The users' preference for either presentation also varies from person to person. Nevertheless, no other advantages of 3D presentation have been specified to be more beneficial for the down syndrome children apart from better looking. instead, it creates unnecessary cognitive load on the users [45], [46]. Apart from better looking, no other advantages have been specified to be more beneficial for the down syndrome children, instead, it creates unnecessary cognitive load on the programme users [45], [46]. From the perspective of spatial-memory impacts, research has found no different in subject's performance on the memory tasks [47]. As a learning-centred RPG, the main purpose of the game is to provide a more effective way to convey knowledge, by omitting any known obstacles that may hinder the learning process. An overall comparison of learning gain using 2D and 3D representation shows that 2D model delivered better learning outcomes [48]. Thus, we recommend the adoption of 2D for the interface design rather than 3D to minimize the cognitive skills requirements on the down syndrome learners.

6. CONCLUSION

As a conclusion, the reason for the proposal of using RPG in speech practising is that we did not see the urge for the down syndrome children to initiate learning with the educational courseware. Instead, children like to play games. With the proposed method, we aimed to provide speech training to the down syndrome children without them realising that they are in fact learning from the game. The method we proposed could encourage enthusiasm in the children to speak more often without being asked and pushed by others. Amongst the many genres of computer games, RPG is the most suitable to be used for speech practising not only because it allows a variety of situational settings in story-telling mode that reflect the real-life situations relatable to the children, but it allows the children to play at their own pace, rather than the pace of a pre-set timer.

There are constrains and challenges to the proposed method, one of which is the limitation of current speech recognition technology to recognise children's speech. Google ASR engines is said to be the most accurate for the task so far. In this paper, we highlighted cognitive psychology of the down syndrome children to contrast the importance of proper instructional and game planning and design, so that the multimedia elements chosen for the game development do not become a hindering factor for the conveyance of knowledge or skill to the children. The literatures reviewed addressed the part of visuospatial working memory that should be emphasised for down syndrome language learning since it has been confirmed that their visual memory is also impaired, only less severely than their verbal memory.

From the review of previous studies, we had found that the devoid of knowledge lies between the working memory and multimedia content suitable for down syndrome children. It is not known whether 2D visualisation or 3D visualisation is easier to be processed and digested by the memory impaired individuals. 2D visualisation is recommended in this paper because it induces less cognitive burden on the learner. 2D representation is also less resource thirsty and thus, can be implemented and accessed easily from lower end computers. The literatures also lack focus on bringing contextual information to language learning, which could enhance grammar quotient of down syndrome individuals. Finally, the literatures reviewed suggest that speech recognition accuracy is now comparable to human parity and therefore could be used in digital games even for language learning. In addition, these literatures highlight the effects of working memory impairment to language learning and give the direction to focus when teaching language to the down syndrome children. The general standards and the models for instructional design and system development should also be considered when developing multimedia application or games for individuals with down syndrome.

7. FUTURE SCOPE

This study has paved the way for further research in using RPG games to advance in this area.

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