Research Paper: Mobile Speech Therapy Application Using Speech Processing for Intellectually Disabled Children

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ABSTRACT

Introduction: Smart phones and mobile devices are among the most important inventions of modern technology. Their physical and potential capabilities offer a wide variety of opportunities to software programmers for developing new applications. Of these applications, educational games can efficiently promote the learning goals. The speech therapy applications are educational games which can be more effective if they use interactive games running on mobile devices.

Materials and Methods: In this research, a mobile speech therapy application is designed to help children with Down Syndrome (DS) to improve their speaking skills. The application helps the children memorize the words and checks their pronunciation with an offline speech processing algorithm. The speech therapy application was tested on 5 children with different severity of DS. The application was assessed from two aspects of ease of use and efficiency by a Likert-type 5 item questionnaire under supervision of an expert. Also paired samples t test was performed to compare the efficiency of mobile application with the traditional speech therapy methods.

Results: According to the paired samples t test results, the decision measure was 0.020 (less than 0.05), which shows that mobile application of speech therapy prefers to the traditional method.

Conclusion: The results show that the application is effective and easy enough for children with Down Syndrome to use. Also the comparing assessment with the traditional teaching method show that using mobile application as a means of education will improve learning efficiency.

1. Introduction

Today, a lot of various digital products with special features are in the market. Mobile phones and tablets are the most common digital products which have many beneficial capabilities. Touch screens of the new gener-ation of mobile devices, is one of their most important ca-pabilities. It looks like a simple feature, but it come handy in developing applications for the children with intellectu-al disability such as Down Syndrome (DS). These children can easily interact with the appropriate applications just by touching the screen. DS is a genetic disorder that delays children's growth and usually leads to mental problems.

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DS affects children's abilities in different ways; however, they can still learn and improve their skills. In other words, they could achieve their aims but at a different speed compared to normal children. Most of the children with DS suffer from speech disorders and because speaking and diction-making skills are the foundation of social and cognitive growth, their disabilities affect all aspects of their lives. Speaking problems may also cause depression in these children. Therefore one of the most important supportive plans for these children is to improve their speaking skills.

Because using mobile phones is significantly increasing, their applications have become more and more important. Mobile applications are categorized under different groups such as medical, educational, game, utility, and location-based. Educational applications with some games will engage the user to learn more. During the last decade, learning games have become part of modern education. Nowadays learning games have emerged as a new educational means [1]. Since governments, teachers, and parents have realized the psychic necessity of playing and learning games, the educational games have become a successful way to teach and learn. The game is an interactive stream that instructs the children in a narrative form the goals, rules, compatibility, problem solving, and interaction. The games process both a deep biological process and an important evolutionary performance in the learning process [2].

The educational games are categorized under 13 groups; facts, skills, judgment, behaviors, theories, reasoning, processing, procedures, creativity, language, systems, observation, and communication. In language learning games, the learning process includes imitation methods, frequent drills, and engagement [2]. As a result, the speech therapy applications may decrease the speaking problems of children with DS. Game's user interface compatibility with the real conditions, considering all or the most of educational concepts, having quick reactions to the user, focusing on special educational targets on each step of playing time and saving the player's progress in the playing process will make a learning game efficient [3].

Most of the children with DS are unable to control their speaking organs and have problems in tongue, lips, chap and mouth coordination. They suffer from problems in consecution of words, speech clarity and phonemes declaration, and speech fluency [4]. Final consonant deletion and cluster reduction are the common speech disorders among these children [5]. Some speech disorders originate from auditory discrimination and short term memory [6]. The solution is to teach the performance of each sound to the child by emphasizing that changing the sounds will change the meaning of the words [7] [8]. In some speech disorders, the errors will increase as the word's complexity or length increases, or when the speech duration protracts. If there are some words containing sibilant sounds or affricates, the speech problems will appear [9]. People, who suffer from auditory processing disorder, can hear the vocal signals but their auditory nervous system does not process it [10]. The solution is periodic auditory exercises [11]. The DS children act contradictory in word pronunciation; they repeat more than half of the words differently [12]. It is also obvious when they pronounce fricatives; i.e., they pronounce them differently each time [13]. Most of DS children have delay in saying their basic words and their vocabulary expands slower than normal children. Limited vocabulary may lead to difficulty in remembering words and names. The improvement method is word naming exercise [14]. DS children's speaking and language skills grow slower than their nonverbal skills. Speaking skills are the base of cognitive growth that affects all other aspects of growth [4].

Language learning process should express the meaning of the words in different sentences and clauses [15]. Also, multiple-meaning words recognition is necessary in verbal and written communication. Children may face these words in different social environments [16]. According to the research studies, the best method for teaching words is to apply both explicit and implicit train of perceptual and explanatory operations [17, 18]. Realizing the concepts is a part of the speech therapy. Because concepts are the foundation of scientific education and their realization is necessary to success in academic carrier and achieving high level thinking [19]. Therefore the children should know the basic concepts to realize fundamental contents of different topics [20]. Description ability is a common subject in scientific environments. Children use lots of adjectives in descriptions; therefore those who have speech disorder or speech deferment may get into trouble when they want to describe their intents clearly [21].

Here we are going to review some speech therapy applications appropriate for the English-speaking children. Each of the applications try to solve some of the speaking problems of the children. As some of the speech problems are common between the children with Down Syndrome and the other intellectually disabled children, the applications may be useful for several intellectual disabilities. These applications run in Android or iOS mobile devices, too.

Some of speech therapy applications try to resolve vocabulary and pronunciation problems. The objective of "Apraxia Rainbow Bee" game is language actuation skill improvement of children with apraxia. This game has three levels of complexity and let the therapist to stimulate the lexical, visual, and auditory actuations [22]. The "Auditory Workout" game is designed for 4 to 10 children who have auditory processing disorder. This game focuses on auditory attention improvement, auditory process of verbal commands, and auditory memory of verbal commands [23]. "Articulation Games" let the child to practice pronunciation of more than 40 English phonemes according to correct articulation. It shows the game results in the plots and diagrams [24]. "Phonological Processes app" is for children older than 4 years who suffer from speech disorder. It provides a linguistic approach for the treatment of auditory discrimination problem in a pair of words [25]. "The Fun with R" app game allows children to practice pronunciation of the hardest phoneme "R". The application does it by changing the position of "R" in different words [26]. The game "Word Retrieval" is suitable for people who have problems in finding words. This app helps them to organize their vocabulary using processes, including antonym words, relevant words, convergent words, and divergent words [27].

The "Speech Companion" app helps to improve oral motor and language skills, using speech therapy exercises. It includes short videos which shows tongue and mouth actuation exercises [28]. "Speech Therapy for Apraxia" is a suitable application for children with apraxia and speech disorders. It lets the users select the phonemes or enter levels that challenge them with speech stimuli [29]. The application of "Auditory Analysis" teaches the children the relationship of the letters and the sounds, and helps them to speak and write using these connections. This app tries to treat audio processing disorder [30].

A number of speech therapy applications try to improve speaking skills. The "School of Multi-Step Directions" game is useful for children aged 5 to 12 years. User interface of this game looks like a school to improve the auditory complexity of multi-level commands in an educational environment [31]. "Syntax Workout" is prepared for primary school children who have difficulty in English grammar. There are some syntax exercises educating verbs, subjective noun, objective noun, property noun, independent property noun and demonstrative noun [32]. The aim of "Sentence Workout" game is to make children practice both oral and written sentence making. The app does it by "Repeat" and "Make a sentence" processes [33]. "Verbs News" is designed to teach the verbs tenses. The different tenses of the verbs are taught to the users by showing some movies which visually explain the tenses [34].

"The Multiple-meanings Library" is designed for children who have problem with multiple-meaning words. This game is suitable for students with cognitive and expressive language disorders, students suffer from learning disorders, and those who have problem with finding words [35]. In the game "Wh-Questions Island" the child answers the questions to practice aural perception and oral explanation. Although in the aural perception treatment, children should listen to the questions and choose the correct answer from the three options, in the oral explanation treatment, the children should answer the questions orally [36]. "Magical Concepts" teaches the children the opposing concepts such as up/down, angry/sad/happy/surprised, and small/large [37].

In "Prepositions Journey" game, the child can learn prepositions with the help of three animals in different scenes of a camp, an island and a city [38]. "Describe with Art" is suitable for the preschool or elementary children who have problems with oral descriptions or in performing commands with descriptive words. This game is designed to teach the children how to describe objects around [39]. The "Talk around IT Nature" app helps to improve the communication skills of those who cannot remember the words easily. There are some semantic features for each word's picture in the application which may help to remember the target word [40].

2. Materials and Methods

In this section, we are going to describe the developing method of the learning game. At first, a group of children with DS were selected and the interaction process of software was designed according to their needs. In order to detect the developing process, a primitive user interface of the application was designed. The primitive user interface was tested on the chosen children to realize if they can interact with mobile devices and mobile applications. After interaction pattern design, the interactive game was developed in Android. The Eclipse environment was used to develop the application. Also, the AndEngine Android library was used in order to gain accelerated graphics output.

Target users

Three youngsters with DS with aged between 7 and 10 years were selected. They suffered from limited vocabu-

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Table 1. Characteristics of the study participants

Features	Disorder	Age	User
Sociable and willing to interact with mobile device	Mild down syndrome	10	User 2; boy
Sociable and quiet child	Moderate down syndrome	7	User 4; girl
Sociable	Serious down syndrome	9	User 5; girl

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lary and pronunciation problems. They needed more vocal exercises to improve their speech skills (Table 1).

Applied speech therapy method

In long-term speech therapy, the first step is word meaning education, the second step is pronunciation and word generation skills, and the third step is conversational speaking [41]. Speech therapy includes seven steps; isolation, syllables, words, sentences, stories, conversation, and generalization [42]. As a matter of fact, the speech therapy method which is used in Iran intellectual disability schools is a combination of these steps; so the therapists start teaching Persian letters to the child from easily pronounced ones to hard ones. They show the words containing the target letter and ask the child to repeat each word several times.

The application is designed based on the schools' speech therapy method. First a letter of Persian is taught to the child; then the pictures of the words containing the letter are displayed to him. It is possible for the child to listen to the audio file of the word's pronunciation by tapping on the screen. In the next step, the application wants the child to repeat the words; the child's score of speaking will be shown to him with a suitable graphical user interface.

Hardware, software and algorithms of the application

The needed hardware in this research is an Android mobile which would be able to record the sounds. Android is a mobile operating system which is developed by Google based on Linux kernel. Android is mainly created for touch screen devices such as smart phones and tablets. Android user interface is based on direct interactions with touch gestures which have similar functionality in real word [43]. Android is useful for the companies which need a cost efficient and customizable operating system [44]. Its open source nature has attracted lots of programmers.

Eclipse is an open source platform based on Java which is created to develop Java-based applications. The base code of Eclipse is generated by IBM VisualAge [45]. The AndEngine library is a set of programs produced by Nicolas Gramlich in order to design 2D video games, executable in Android. AndEngine library is open source and contains a lot of useful programming capabilities. It is also usable at both Android Studio and Eclipse [46].

The designed speech therapy application needs speech recognition in order to check the child's speaking skill. Thus the user's sound signal features were initially extracted using MFCC1 algorithm. MFCC is the feature extraction algorithm of sound processing [47]. Next, the incoming signal of user and the correct signals in the database were compared using DTW2 algorithm. DTW or Dynamic time warping is a signal similarity detection algorithm [48]. The application offers mentioned process, without internet requirement.

Game designing

The application at the end of this research is a mobile learning game suitable for speech therapy of primary school children with DS. This application at first introduces each of the Persian alphabet, then after the child's repetition, the words containing the target letters will be shown to him. Generally, the application has three parts; teaching, speech practicing, and game. The cognitive and speech skills are considered in all parts.

In sequential teaching part (Part 1), the Persian language letters are taught to the child according to the special order of speech therapy used in intellectual disability children schools. In this part, the application uses figures and sounds, especially the audio files of words pronunciation to teach the vocabulary to the child. In order to make teaching process attractive, the application used an interesting character to express the words. This character moves its mouth to express the words by its childish voice.

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1. Mel-Frequency Cepstral Coefficients (MFCCs)
2. Dynamic Time Warping (DTW)

In speech practicing (part 2) the application wants the child to repeat the words in order to make him practice more. Then the application processes the incoming sound signal and compares it with the correct sound in the database. At last the application gives scores according to the similarity of incoming signal and signals in the database. The scores should be intelligible for child; therefore the application uses some eatable things rather than using numbers or graphs. In this way, as the pronunciation of the child becomes better, the application shows more eatable things as score.

At the third part of the application (Part 3), or game part, the teaching objectives will be introduced as a game. The main scenario is that the character of the game in each step eats the food which has a special letter of the alphabet; so at each step the child should find the eatable things which contain that special letter. For example for the question "which word begins with letter p?" the child should be able to find the target words. If he finds the correct words, he will be awarded and if he doesn't, the game will mention him. Finally, by giving the correct answer, the child will be able to pass the steps. After collecting all the eatables according to the game's question, the child can give them to the game character.

Evaluation method

The speech therapy application was tested on 5 children as shown in Table 1. The disorder severity was different among the selected children. Two of them had serious disorder, one had moderate disorder and the other two had mild disorder. In order to teach the application, the child was requested to interact with the app before evaluation. Therefore, at the pre-evaluation step, the app was installed on some mobile devices and given to the children. When the children had learned how to interact, the evaluation step began.

The evaluation has accomplished at the intellectual disability children's school; the app was installed on some mobile devices and were given to the children to play with. The test was done during 5 sessions and each session lasted 10 to 15 minutes. Only one child was evaluated on each session and his reactions was recorded by the researcher. A speech therapist was supervising the sessions. The child's behavior as he was interacting with the app and his responses were monitored at each session. Each user played with all three parts of the application consecutively. The main goal was exploring the effect of the application on learning and speech therapy; although the user interaction was reviewed simultaneously.

The application was assessed from two aspects; ease of use and efficiency. In order to study each of them, two distinct Likert-type questionnaires were designed. The ease of use questioner contains 5 questions which have 5 answers. But the efficiency questionnaire contains 4 questions each with 5 answers. The choices are "very good", "good", "average", "bad", and "very bad", which represent the scores 5 to 1, correspondingly. The scores were given to the children according to their performance during the game. As told before, the target children were divided into three groups, serious disorder, moderate disorder, and mild disorder; so the results will be different for each group (Figure 1 and Figure 2).

In order to study the efficiency, the main factors affecting to improve the speech therapy were extracted. The speech therapy will be effective only if the child listens to the words and repeats them several times. Finally he should be able to answer the therapist's questions. By considering these factors the application was given to the children to interact with.

The third part of the study investigates whether using the mobile application is better than the traditional speech therapy methods or not. It is found by comparing the child's records on traditional speech therapy and his scores on mobile app using paired samples t test. So the researcher extracted the main factors of speech therapy and allocates some scores on these factors in the children. These factors are how much children are interested in listening to words, remember the words. According to what was said, there are two hypotheses.

The 2 hypothesis are: There is no difference between traditional and mobile app method (Hypothesis 1); and There is a difference between traditional and mobile app method (Hypothesis 2).

3. Results

This part refers to the results of the tests. The first test, which evaluates user-friendliness of the app shows that all children can communicate well with the app. Children's interaction and behavior were different because of their different DS severity. As a matter of fact the children with mild disorder, were much faster than the children with severe syndrome in using and navigating the app. But all of them could communicate and play with the app games (Figure 1).

The app's efficiency based on children's learning was reasonable. The children were willing to listen, repeat, answer, and remember the words. They were listening
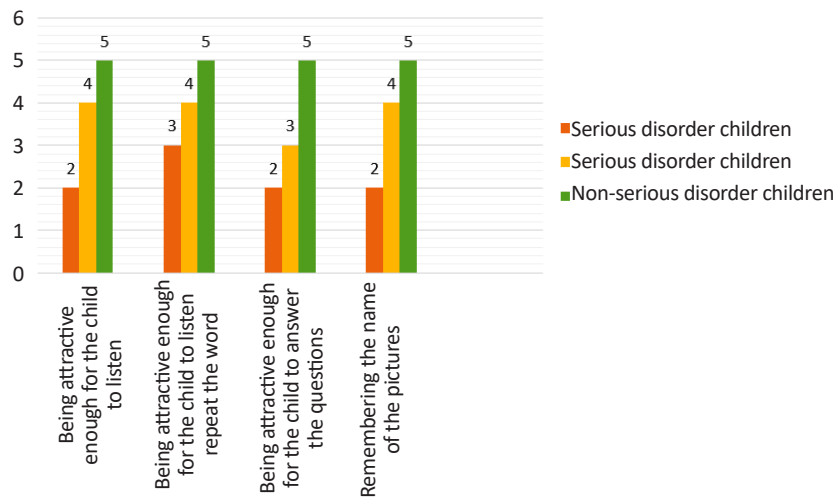
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Figure 1. Results of evaluating the ease of use and interactional features.

to the words' pronunciations, they were interested in repeating the words and answer the questions which were asked by the app. Although the results may be different in a serious DS disabled child compared to a mild DS disabled but the results generally showed improvement in all learning aspects (Figure 2).

The last part of evaluation compares the children's performance in traditional speech therapy with their performance in the mobile speech therapy application. The results of paired samples t test which was performed on grades of children's speaking ability before and after using the mobile application shows the decision measure as 0.020 which is less than 0.05, so the hypothesis 1 will be rejected. As a result, speech therapy by using mobile application prefers to the traditional method (Table 2).

4. Discussion

This research was conducted to examine a modern way of speech therapy for children with DS via smartphone apps. So that the designed app has to be effective and easy to use. Also it should be more efficient in comparison with the traditional method. Using graphical capabilities in software design, can make it much more engaging besides teaching how to pronounce the words. The more attractive a game is, the children will be more willing to deal with it. As they play more, they repeat the words more which is the key to speak fluently.

The results show that the application graphical user interface is interesting enough for all spectrum of DS disorder to interact with. It may be because of the absorbing pictures and attractive color scheme. In order to keep the child concentrated during the game, the application uses
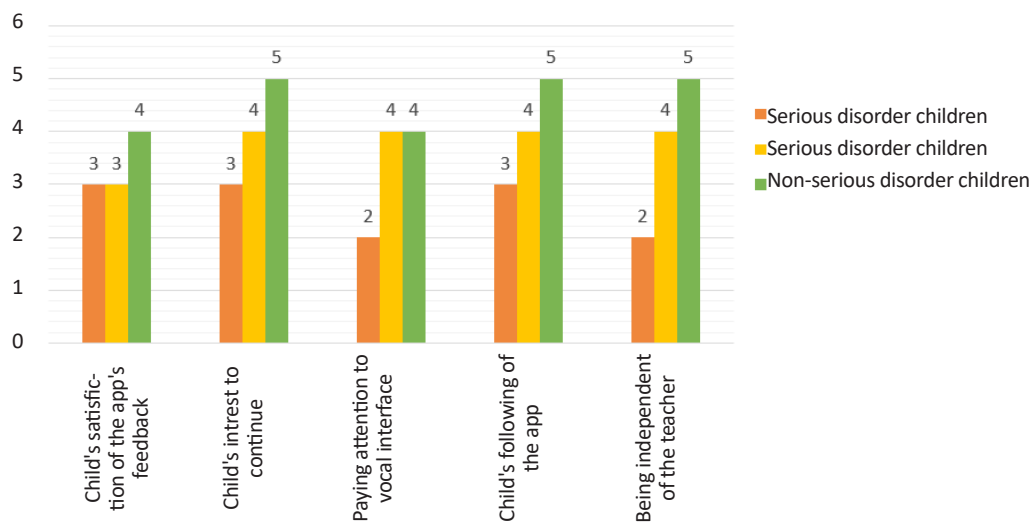

Figure 2. The application's effectiveness on children learning

Table 2. The results of paired samples t test conducted on children's grades before and after using game

Paired Samples		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% CI of the Difference				
					Lower	Upper			
Pair 1	Before - after	-2.33333	0.57735	0.33333	-3.76755	-0.89912	-7.000	2	0.020

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high resolution images without confusing details. Also the application is designed based on the user interface design principles. Because the target users are intellectual disabled children, no complicated task is assigned to the users. The user interface was satisfactory as the child could easily interact with the app. As it is obvious in Figure 1, children with mild disorder were very willing to play with the application; so that at the end of evaluation, they wanted to play with the application again. Children with moderate and serious disorder were also interested but sometimes they could not recognize the pictures. The audio interface was interesting for the children with mild and moderate disorder; not only they wanted to listen the word's names, but also interested in listening to the game audio explanations on each step. Apparently, because the combination of audio and visual aspect of a cartoon character is more appealing. The audio interface was not very attractive for children with serious disorder. All the children were willing to continue the game process. It may show the positive effect of the game's story. All of the target children, needed an educator to interact with the application for the first few sessions; but when they learned how to play, they could use it independently. Children with mild and moderate disorder learned to interact after getting help one or two times; but children with serious disorder needed more support from the educator.

The results of the efficiency evaluation shown in Figure 2, indicate that the app can be a suitable method for children to repeat and learn the words. The teaching method is graceful and the application focuses on playing the audio files of the words for the children and receiving their pronunciations. According to the tests results, children with mild and moderate disorder were more interested in listening to the word's pronunciation than children with serious disorder. Because of the attractiveness of the cartoon characters, they wanted to listen to the words several times. It shows the effect of using the game and multimedia as a means of education compared to the boring nature of traditional education. In traditional education, the therapist hardly trains the child and patiently wants him to repeat the words. In the word repeating part of the

application, because of the realizable method of showing the results, the children were willing to repeat the words to gain more scores. Children with mild disorder were more interested in repeating the words compared to two other groups. In the question responding part of the application, children with serious disorder had poor performance while children with mild disorder were responding immediately. Children with mild disorder were more inspired and could learn the words quicker than the others. Children with serious and moderate disorder were able to remember the words a bit slowly; however, when they could not remember a word at the first play they could memorize it until the second or third play.

The last part of evaluation compares the children's performance in traditional speech therapy with the mobile speech therapy application. Results showed that the children are more concentrated and motivated in mobile speech therapy application. They listen to the words and repeat them eagerly. Word repeating in traditional method is boring and the children hardly concentrate on the task. As a matter of fact the application makes the teaching method attractive by adding animated figures and sounds. Results also showed that unlike the traditional method in which children are reluctant to pronounce the words, in the mobile game the children enjoy repeating the words. The paired samples t test was performed on the grades given to the children's speaking ability before and after using the mobile application. According to Table 2, the decision measure is 0.020 which is less than 0.05, so the hypothesis 1 was rejected. Therefore speech therapy using mobile application prefers to the traditional method.

The teaching and treatment period more will become more interesting and effective by using a mobile application in the speech therapy. With a mobile app, the teachers can encourage children to practice more compared to the traditional way. Although using an app in speech therapy reveals an attractive way with a lot of potential capabilities, it may cause smartphone addiction in young children.

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This research offered a speech therapy mobile application for children with Down Syndrome which uses speech processing to assess the word pronunciation of the user. Practical speech therapy method combined with multimedia and technical capabilities of smartphone apps was implemented in this application. It is a story-based learning game which engages children to continue the treatment process. The application was tested on children with Down Syndrome, in groups of serious, medium and mild disorder. The app was evaluated from aspects of ease of use and efficiency. The results show that children can interact with the app independently after a short period. The graphical user interface attracts them to continue the game. They are more concentrated to listen and repeat the words which leads to learn better. According to paired samples t test results on using mobile app method and the traditional, it was revealed that using mobile application as a means of education will improve learning efficiency.

We recommend some ideas for the future works. In order to make the app more attractive, user voice simulation can be added to it. So the user can hear his voice and be able to refine it easier. The game can be developed as a multiplayer game. Adding the scientific resources such as dictionaries will make the app more worthwhile. Providing a feature in the app so that the therapist can access the results of the patient's rehearsals is helpful to evaluate the improvement process. The app can be designed in such a way that offers collaboration and knowledge interchange.

Ethical Considerations

Compliance with ethical guideline

All stages of the experiment were explained to students and school officials. We also assured them that all their personal information would remain confidential.

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Conflict of interests

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