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Chemistry app for children with cerebral palsy based on the eye-tracker

Introduction

A topical issue of our time is the development of strategies for the inclusion of people with disabilities at all levels of education by adapting educational processes and environments (Mikhailova, 2023). Particular difficulties arise for students with cerebral palsy, who often suffer from intellectual, visual, hearing and speech impairments in addition to motor impairments, which makes them one of the most vulnerable groups in the educational process (Sadowska, 2020). Therefore, there is a need to provide people with cerebral palsy not only physical access to learning tools, but also learning technologies appropriate to their cognitive abilities. Currently, many applications for educational purposes are being developed, some of which try to take into account the characteristics of children with mobility impairments to provide them with access to digital environments for communication, play and learning (Yao, 2023). Therefore, there is a need to study and analyse aspects of the interaction of children with cerebral palsy with digital educational products in order to identify the most effective strategies and methods that can be used in digital educational content, which was the purpose of this study.

Methods

The study sample was 10 students (3 girls and 7 boys) diagnosed with cerebral palsy (G80 according to ICD-10), mean age M=18±0.5.
We investigated aspects of interaction of learners with cerebral palsy with digital educational technologies by selecting the most appropriate method of controlling virtual objects.
To understand the peculiarities of controlling and interacting with interactive objects on the monitor screen in a group of adolescents with cerebral palsy, we developed an author's testing methodology. The purpose of developing this methodology is to understand which actions (clicking, moving objects) will be easier to perform with a computer mouse and which will be easier to perform with a specialised button with a joystick.
Testing of mechanics of interaction with digital content on the monitor screen included 3 tasks: tapping test to investigate motor dynamics, testing of "movement" mechanics, and range testing. Moving objects within 20 seconds using a mouse demonstrated higher performance (M = 3.6±1.53) compared to moving with a joystick (M = 0.75±0.5). Student's criterion for independent samples showed that the number of objects moved was greater with mouse control, $t = -3.67$, $p = 0.014$.
Range testing was aimed at identifying the optimal distance between objects on the screen, which is the most accessible in terms of the user experience of subjects with cerebral palsy. The parameters of number of clicks and average speed were analysed. The mean number of mouse clicks was M = 13±6.08; the mean number of joystick and button clicks was M = 3.75±2.06. Student's criterion for independent samples showed that the number of clicks was significantly greater with mouse control at a low level of statistical significance, $t = -2.91$, $p = 0.033$. The mean cursor movement and click rate during mouse control was 382.97±250.1 pixels per second; the mean cursor movement and click rate during joystick and button control was 138.74±94.8 pixels per second.

The analysis of the results of testing the mechanics of interaction showed that there is a great variability in the computer control abilities of learners with mobility impairments. The data suggests a rather decreasing rate of clicking dynamics and better dynamics using the mouse. The joystick proved to be of little use for two participants who normally use the mouse fluently, whereas for the other subjects it was the only available mode of interaction due to severe hand spasticity. Despite this, their dynamic capabilities remain severely limited, which needs to be taken into account when designing digital educational content.
The intelligence of students with cerebral palsy was assessed using the Raven's Progressive Matrices technique (Małkiński, 2022).
The method allows to determine the ability of the examinees to logical operations (comparison and distinction, analysis, etc.) using non-verbal material, which limits the influence of socio-cultural characteristics of a particular examinee and provides an opportunity to determine the ability to purposefully search for the necessary solution. The non-verbal nature and the possibility of assessing the ability to perform logical operations with graphic images were the key factors for applying the methodology in this study.
The psychodiagnostic technique consists of black-and-white matrices (60 matrices measuring 7.5 × 11 cm), each of which is missing one of its constituent elements. The subject must choose the missing matrix element among 6-8 proposed options. The tasks are grouped into 5 series - A, B, C, D, E, each series consists of 12 matrices.
In the process of the study, only 9 out of 10 subjects moved on to performing Series D. Series D is composed according to the principle of rearrangement of figures in the matrix along horizontal and vertical directions. The success of the solution depends on the examinee's ability to identify quantitative and qualitative patterns in the construction of the matrix as a whole and its individual columns and rows. The results indicate that with probability $\gamma = 0.95$ the percentage of correct answers will be in the range of 30 - 67 % (M = 49.2±24.2). The range corresponds to the average level of intelligence in the corresponding age group.
Only four out of 10 subjects proceeded to Series E, which is the most difficult series of the methodology. The process of solving the tasks of this series consists in analysing the figures of the main image, identifying significant features that may vary, and then "assembling" the missing figure piece by piece. The average percentage of correct answers to Series E (M = 29.3) indicates that it is difficult for the examinees to cope with the tasks aimed at activation of analytical and synthetic activity. At the same time, there is a great variation in the percentage of correct answers of the examinees: two pupils with cerebral palsy scored 17% of correct answers each, one pupil - 8%, and one person - 75%.

Parameter	N	M±SD	95% confidence interval		Min	Max
			Lower	Upper		
Number of correct answers	10	30,2±10,7	22,52	37,9	18	48
Percentage of correct answers (%)	10	50,3±17,9	37,51	63,1	30	80
Series A (%)	10	77,4±25,1	59,46	95,3	17	100
Series B (%)	10	75,1±24,3	57,70	92,5	33	100

Series C (%)	10	43,3±15,1	32,50	54,1	17	67
Series D (%)	9	49,2±24,2	30,6	67,9	17	83
IQ	10	82,2±14,5	71,80	92,6	66	108

Table 1. Statistics of parameters of measuring the level of intelligence of children with cerebral palsy.

Series A is aimed at revealing the ability to differentiate separate elements of the structure, to reveal the interrelationships between them, to identify the missing part of the structure and to compare it with the presented sample. With the probability $\gamma = 0.95$, it can be stated that with a larger sample of students with cerebral palsy the percentage of correct answers in this series will be in the range of 59 - 95%, which corresponds to the average value of the number of correct answers M = 77.4±25.1.

Series B is reduced to finding analogy between pairs of figures, comprehending symmetry, and completing relations. The results of the analysis of Series B showed that with a larger sample of students with cerebral palsy with probability $\gamma = 0.95$, the percentage of correct answers would be in the range of 57 - 92 % (M = 75.1±24.3), which corresponds to average and unremarkable intelligence for this age group.

Series C contains complex changes of figures in accordance with the principle of their continuous development, "enrichment" vertically and horizontally. The results of performing Series C by the subjects with cerebral palsy turned out to be at a slightly lower level compared to the other series: with a larger sample size, with probability $\gamma = 0.95$, the percentage of correct answers will be in the range of 32 - 54 % (M = 43.3±15.1). This range corresponds to the average level of intelligence in the corresponding age group.

Thus, with a probability $\gamma = 0.95$ we can state that the level of intelligence of students with cerebral palsy is in the range of 71 - 92 points, which corresponds to the borderline and average level of intelligence according to Wechsler (M = 82.2±14.5).

The examinees showed good attentiveness, the ability of imagination and visual distinction (discrimination), the ability of linear differentiation and inference on the basis of linear relationships. At the average level was the ability to dynamic observation and tracing of continuous changes, dynamic attentiveness, as well as the ability to analyse quantitative and qualitative changes in the composition of figures according to the pattern of changes used. At a low level is the ability to observe the complex quantitative and qualitative difference of kinetic, dynamic series. It was concluded that adolescents with cerebral palsy who are not diagnosed with mental retardation still need adapted teaching methods.

Chemistry assignments were developed taking into account all technical and software features of the system.

As the aim of the study was to explore the gamification mechanics of interaction of students with cerebral palsy with digital educational content through "bodily engagement", we developed tasks that "mimic" a laboratory workshop.

Theories of embodied cognition view sensorimotor activity as the basis for learning, knowledge, and reasoning. To explore the role of physical movement in conceptual learning, the Chem-Lab learning environment (rnf-cp.cedne.ru) was developed.

The Chem-Lab learning environment includes a personal computer, a computer simulation (application), and a device for interaction with the application: a Tobii 5 i-tracker and a special button that simulates a click. In the interaction process, students control the mouse cursor using eye movement and use the "click" method to select test tubes and mix reagents. A pilot study was conducted on a group of learners without disabilities to test the learning process and improve the methodological component.

The procedure of interaction with the Chem-Lab learning environment is as follows:
1. Viewing educational voice-over videos on chemistry;
2. Going through the practical part immediately after watching the video. This practice is aimed at bodily involvement, thus the learner imitates the real fusion of reagents in a test tube. The practice allows to better consolidate the theory just learnt after watching the video with the possibility of interactive interaction with elements similar to those presented in the video.
3. Testing is designed to structure and consolidate general knowledge on all the material learnt.

A total of 10 topics were developed, videos were filmed for each topic, and practical and test parts were developed.

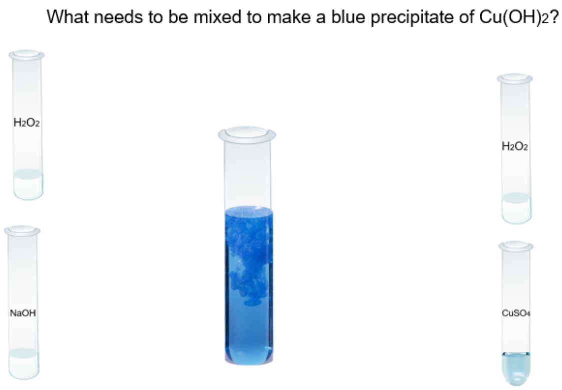

Figure 1: Example of tasks where students need to answer a question and choose the correct reagents.

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