Effects of an analogical reasoning touch screen computer test in individuals with disabilities

Caroline Denaes, PhD
Faculty of Psychology and Education Sciences, University of Geneva
Geneva, Switzerland

ABSTRACT

Analogical reasoning involves the comparison of pictures as well as the memorisation of relations. Young children (4-7 years old) and students with moderate intellectual disability have a short memory span, which hamper them to succeed in traditional analogical tests. In the present study, we investigated if, by providing external memory hints, the visual aid could enable these participants to succeed in analogies comprising more relations than their memory span was able to manage.

Our analogical test, composed of 2×2 matrices, was administered in two versions: The classic version, similar to traditional tests, required the participant to memorise all the relations involved in order to discover the solution, whereas the construction version required him/her to construct the answer part by part by using external memories, which potentially increased success by offloading the memory.

Our results show that students with moderate intellectual disability reached results similar to typically developing control children when provided with external memory hints (referred to as external memories). Moreover, in the most complex levels of the test, they did not spend more time than control children for solving the analogies.

Keywords: Analogical reasoning, touch screen computer, intellectual disability

THEORETICAL BACKGROUND

Defining Analogical Reasoning

Analogical reasoning is considered to be an important mechanism in learning and problem-solving [1, 2], as well as in cognitive development and intelligence [3, 4]. Generally, the traditional analogy format, usually called the classic analogy, is most of the time displayed as *A : B :: C : D*, either in linear form or in a 2 × 2 matrix form. In order to solve analogies, a process of systematic comparison is necessary, including looking for similarity and/or difference between attributes of a task and relations between these attributes [5]. For instance, the analogy Tree : Forest :: Room : (a. Door, b. Window, c. House, d. Kitchen) requires the coordination of several component processes, all described by Sternberg [6], such as encoding the A, B, and C terms (Tree, Forest, Room), inducing the relation between the A and B terms (here, a part-whole relation), applying the relation from the C term to the possible answers (here, Room is a part of a House), and responding [7].

Analogical Reasoning in young children and in students with intellectual disability

Many studies [8, 9, 10] demonstrated that young children get lower performances in analogical tasks when compared with older children. Several reasons were exposed to justify this statement, such as a cognitive deficit, the complexity of the material used, or the development of the prefrontal regions of the brain.

For individuals with moderate intellectual disability (MID; IQ: 35-40 to 50-55, mental age: 4-7 years), which represent part of our population study, analogies are difficult to solve. Generally, these individuals show an attention deficit. They do not usually compare the pieces of information, and are less likely to reach the sufficient level of abstraction, which are necessary processes for solving analogies [11]. In addition, several authors claimed and proved that individuals with MID do not use memory strategies as well as typically developing individuals, which could enable them to maintain the information longer in memory [12]. Furthermore, their working memory capacity can only treat 2-3 elements at the same time whereas typically developing adults can treat 5 ± 2 elements [13, 14]. Their limited memory capacity leads them to lose part of the information and, consequently, give up the task because of a memory overload [15, 16].

Computerized testing

Traditional tests are mostly presented on a paper-and-pencil format. Several authors have shown that tests presented on a computer are more effective for individuals with MID than paper-and-pencil tests [17, 18]. Specifically, the laptop computers were presented to be the most promising devices for this population [19, 20, 21]. Moreover, these individuals often have motor skill deficits, which hamper them from manipulating the computer mouse. Touch screen computers seem to be the best option for this population because their movements do not need to be as precise as with the computer mouse. Furthermore, the touch screen is also known to improve the motivation and the attention span of the participants [22, 23].

The present study

By taking into account all the beneficial effects of computers for individuals with MID, we designed an analogical reasoning test using a touch screen, the Construction of Analogical Matrices Test-Revised (CAM-R), which constitutes an elaboration of a previous study concerning the CAM [24]. This test is composed of two versions, one including external memories, which unload the working memory (the construction version), and the other overloading the working memory (the classic version). We chose to proceed with a touch screen computer because the screen was bigger than a smartphone and the capacitive tablets did not exist at that time. The touch screen computer was then considered to be the best tool for our population of research.

The main objective of this research consisted of evaluating the difference between both versions of the CAM-R and to observe the effects of external memories on the reasoning of our participants. We predicted that all the participants would get better scores in the construction version due to the presence of external memories. We also hypothesized that these external memories would enable our participants to overcome the limitations of their memory span.

The main contribution of this paper is to compare the performances of young children with the performances of students with MID, both populations sharing the same mental age.

METHOD AND MATERIAL

Participants

Before the beginning of data collection, ethical approval was obtained from the ethics committee of the University of Geneva. Our sample was comprised of two groups. A first group, called “MID group”, consisted of 13 adolescents with MID (chronological age: 12-16 years old; mental age: 4-7 years old), recruited in a special educational institution in the area of Geneva (Switzerland). We asked this institution to give us the names of volunteer students, which had MID according to their personal files. The ages of the students varied from 15 to 18 years, the mean age being 16.8.

A second group consisted of 13 typically developing children of the same mental age, recruited from one school in Geneva. All children were pupils with an average level and French as their mother tongue. This group was called “TD group” for “typically developing group”. We asked the school teachers to give us names of children which had a mean level at school and which were interested to participate in our research. The ages of the children varied from 4 to 7 years, the mean age being 5.8. Table 1 presents the participants’ distribution in each group according to their mental age (MA) and their chronological age (CA).

Table 1 Participants’ distribution in each group, means for MA and CA and standard deviations

Groups	*N*	*CA (m + sd)*	*MA (m + sd)*
TD	13	5;5 (6.07)	5;7 (.89)
MID	13	16;8 (10.9)	5;9 (1.93)

The Raven’s Colored Progressive Matrices Test (CPM) [25] was administered to the participants, as well as short-term and working memory tasks especially designed for this population (from Lanfranchi *et al*., 2004) [26]. The results of these three tests revealed no significant differences between both groups, which meant that they shared approximately the same mental age and the same memory capacities.

Material

Our analogical reasoning test, called the Construction of Analogical Matrices Test-Revised (CAM-R) was designed with the Authorware software (Macromedia Authorware 7 © Adobe Systems). A previous study [24] on the same topic as ours showed that students with MID did not demonstrate a problem in analogical reasoning, but rather suffered from a working memory limitation, which hampered them to solve the analogies with success. In order to prove this hypothesis of working memory overload, we designed two versions: a classic version, similar to classical analogies, and a construction version, supposed to unload the memory.

In both versions of the CAM-R, participants were confronted with 2×2 matrices, in a figurative concrete modality, presented on a touch screen, where they perceived the *A, B* and *C* terms. The elements potentially constituting the answer were available permanently at the bottom of the screen. Once touched, the pictures (in the classic version) or the separated elements (in the construction version) slided into the *D* zone of the matrix. In the classic version, answer *D* had to be chosen among several pictures, only one being correct. In order to find out the correct picture, the participants had to memorize all the relations at the same time, which could potentially lead them to a memory overload. In contrast, in the construction version, answer *D* had to be constructed with the elements available permanently at the bottom of the screen. The advantage of the construction version was that it allowed the participants to consider one relation after another, without remembering those previously taken into account. The elements of answer represented external memory hints and could potentially unload the participants’ memory.

Figure 1 presents the “Ladybird” Item in the classic version and construction version respectively (classic version on the top and construction version on the bottom).

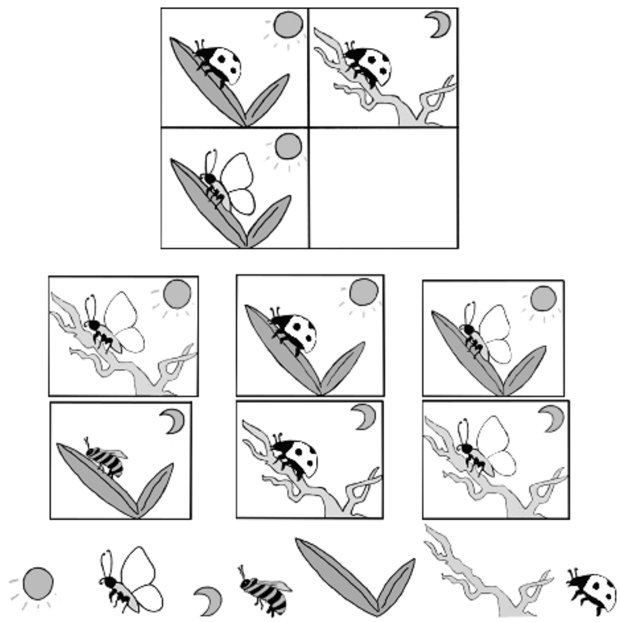

Figure 1 Ladybird Item

Each version was composed of sixteen items. We checked the test reliability of each version. The 16 items of the construction version showed high internal consistency, with a KR-20 of .91. As for the 16 items of the classic version, they also showed high internal consistency, with a KR-20 of .94.

Each version was composed of 4 levels of complexity, characterized by the number of relations. In both versions, the number of elements grew according to the levels of complexity, from 2 relations in the first level to 5 relations in the fourth level. The CAM-R is composed of 56 relations. The number of relations between the *A*, *B*, and *C* terms varied from 2 relations (in the 1st level) to 5 relations (in the 4th level). In order to avoid possible frustrations among our participants, no more than 5 relations were used, which was a little more than their memory span (approximately 2-3 elements) [13] can incorporate at a time.

In both versions we added incorrect elements, in order to know if the participants were attracted by them. In Figure 1, the incorrect element is the bee. Analyses about incorrect elements showed that MID students chose these elements more often than TD children but the number of occurrences was very low [26, 27].

Procedure

The CAM-2 followed an individual administration. Each participant was seen by an experimenter in an independent room, free from disturbance. Each participant was randomly assigned to receive one version and then 6 weeks later the other version. For the first version, we began with MID participants, then with the TD children. When the first round was over, we began again with MID participants for the other version, and finally with the TD children. The 6 weeks interval between the administrations of both versions was the same for all the participants. This interval, including holidays (Christmas or Easter holidays), was judged large enough to prevent the participants from remembering the items they saw during the first round.

Test items were preceded by 8 training items, allowing the familiarization with both the task and the touch screen. In addition, the participants had the opportunity to solve each item a second time if they failed at the first attempt. In this case, they received standardized help, like "You saw that the color changed between A & B, but look closer to the change between A & C" and they could try the item a second time.

We decided to give 1 point for each correct relation, which brings the maximum number of points to 56 representing the total number of relations. We chose to proceed in this way, in order to give value to our participants' reasoning.

The Authorware software (Macromedia Authorware 7 © Adobe Systems) recorded the number of correct and wrong relations, as well as the time spent (expressed in seconds) to solve each item for all participants.

RESULTS

We first hypothesized that all the participants would obtain better scores in the construction version compared to the classic version, due to the external memories. As the construction version of the CAM-R allowed the students to treat one relation after another without constantly needing to remember the relations already taken into account by a previous choice, hence their working memory should not be overloaded like in the classic version, in which they had to memorize all the relations involved in the matrix. Results for each group according to both versions are presented in Table 2.

Table 2 Means scores and standard deviation for each group in both versions (min = 0; max = 56)

	TD (n = 13) *m (sd)*	*MID (n = 13)* *m (sd)*	*TOTAL (n = 26)* *m (sd)*
Construction version	47.17_a (5.64)	46.23_a (4.89)	46.77 (5.27)
Classic version	47.17_a (7.15)	40.38_b (6.08)	44.32 (7.44)

Note: Means sharing a subscript in common were not significantly different from each other in both row- and column-wise comparisons (Tukey test).

A mixed 2 (test version: construction and classic structured within-subject factor) × 2 (grouped between-subject factor) factorial analysis of variance with repeated measures was performed. The data revealed a significant interaction effect group x versions ($F(1,24) = 6.385$, $p < .05$, $\eta2 = .18$). Firstly, this meant that there were score differences according to the test version and secondly, that the range of these differences varied according to group members.

For the TD group, the ANOVA revealed no significant differences between the versions ($F<1$), whereas the differences were significant between both versions for the MID group ($F(1,24) = 7.677$, $p < .01$, $\eta2 = .209$), which obtained better performances in the construction version ($M = 46.23$) than in the classic version ($M = 40.38$). Our hypothesis was therefore confirmed only for the MID participants, indicating that external memories were only beneficial for this group but not for the other.

In addition, post hoc comparisons using Tukey B revealed no significant differences in the construction version between both groups (MID = 46.23 compared to TD = 47.17). Regarding the classic version, there were significant differences between the groups. The TD group received better performances than the MID group.

In order to dispose of a finer analysis, we observed the behavior of each group according to each level only in the classic version (no significant differences were found in the construction version). Results for each group according to each level are presented in Table 3.

Table 3 Means and standard deviations for the number of points at each level for both groups in the classic version

	1st level (max. 8 pts) *M (sd)*	*2nd level (max. 12 pts)* *M (sd)*	*3rd level (max. 16 pts)* *M (sd)*	*4th level (max. 20 pts)* *M (sd)*
TD (N = 13)	7.56* (.78)	10.28 (1.96)	13.78 (2.46)	15.56 (3.94)
MID (N = 13)	6.46 (.97)	9.92 (1.49)	11.69 (2.59)	12.15 (3.29)
F(1,25)	12.088	.298	5.178	6.427
p	< .01	NS	< .05	< .05

*Time in seconds

A mixed 4 (levels structured within-subject factor) × 2 (groups structured between-subject factor) multivariate analysis of variance for the classic version. The data revealed a significant effect of the groups ($F(1,25) = 3.976$, $p < .05$, $\eta2 = .380$) and of the levels ($F(1,25) = 701.382$, $p < .01$, $\eta2 = .991$). The TD group got more points than the MID group at each level, except at the 2nd level. Moreover, this augmentation of points increased along the levels: at the 1st level, TD groups got 1 point more, then 2 points at the 3rd level, and finally 3 points at the 4th level. We could logically suppose that this gap between both groups would have increased if we had more levels of complexity.

DISCUSSION

Our main hypothesis, which stated that both groups would obtain better scores in the construction version than in the classic version was confirmed only for the MID participants indicating that the external memories were beneficial only for this group but not for TD children.

In the construction version, students with MID were able to obtain similar performances compared to TD children, due to the presence of external memories. We noticed the role played by the intellectual disability: despite the fact that both groups shared the same mental age and the same memory capacities, the TD children received better performances in the classic version. It seemed that the MID students could not reach the same level of performances, probably because of a working memory overload.

The differences indicated that the students had difficulties in information processes rather than in abilities. The MID students were able to reason by analogy but probably had more problems to treat several relations at the same time than TD children. In the classic version, the TD children received more points than MID students at each level. It seems that the intellectual disability played a crucial role in the performances, more than the mental age. Several authors demonstrated that differences in working memory capacity depended on several factors, such as the amount of information the participants could memorize [29, 30], knowledge and skills [31], or the amount of available resources [32]. In addition, deficits in working memory were also found in the MID population compared to TD individuals of the same mental age [33, 34, 35, 36]. Moreover, individuals with MID present a shorter memory span compared to TD children of the same mental age [13].

CONCLUSION

Our results have educational benefits for individuals with MID because they showed that these participants were able to solve analogical matrices that were made up of different levels of complexity. They also received results equal to children of the same mental age when the test version offered external memories. These external memories enabled our participants to go beyond their memory span limit. Indeed, they were able to solve items composed of 5 relations, whereas their memory span can usually treat 2 or 3 relations at a time [13], which was also true for the young children. In his article, Büchel [24] stated that the problem was to know if persons with MID had a limitation in analogical reasoning or rather a memory limitation. Our results indicated that, by having a support, the MID participants were completely able to reason by analogy and did not have a limitation in this area. On the contrary, their problem was more located in their memory, which could be enhanced with external help, as we demonstrated. Educational implications of these types of studies go against what professionals generally assume, in that, persons with MID are not able to reach higher levels of abstract reasoning. On the contrary, the devices show that they were able to perform better than what is usually expected of them [37].

In addition to these positive outcomes, we also observed that the level of attention span of our participants increased. As mentioned before, theoretically, individuals with MID tend to demonstrate a lack of attention. At the beginning of our study, we presented our test to support workers and teachers in the selected special institutions/schools. While they were very enthusiastic with regard to the touch screen computer test, they warned us about the duration of each version. They claimed that their daily tasks (academic tasks or leisure tasks) did not exceed 10 to 15 minutes. However, each of our versions lasted 30 minutes, which represented more than two times the maximal duration of their usual tasks. The positive outcome of our study is that all participants were able to reach the end of each version. This increase of attention could be due to the touch screen computer as it was demonstrated by some researchers [23].

Even if computers made their introduction into education in the early 1960s, touch screen computers were unknown by all our participants when we began our study. The use of a touch screen computer was seen as motivating because it was new, different and provided a feeling of agency or control over the task. Therefore, the touch screen can be effective for individuals with MID for enhancing their cognitive skills [40] and their motivation [38, 39]. It is known that persons with MID have low expectations for success because they are too often confronted with failure experiences [41]. In the CAM-R, each participant could work at his/her own rhythm. The touch screen computer increased the feeling of direct manipulation, which was very important for their self-confidence.

Even if the use of computers cannot completely overcome the difficulties and limited functions that are associated with a MID, our research showed that this device enhanced performances and reduced the memory load, as it was demonstrated by other studies [40, 22, 39]. Following the obtained results, we intend to develop a new version of the test composed of more levels and hence more relations, in order to observe and assess the maximum number of relations with which students with MID and typically developing children can cope.

REFERENCES

[1] D. Gentner, "Why we’re so smart", In D. Gentner & S. Goldin-Meadow (Eds.), Language in mind: Advances in the study of language and thought, Cambridge, MA: MIT Press, 2003.

[2] K.J. Holyoak, “Analogy”, In K.J. Holyoak & R.G. Morrison (Eds.), Cambridge Handbook of Thinking and Reasoning, Cambridge, UK: Cambridge University Press, 2005.

[3] U. Goswami, "Analogical reasoning in children", In D. Gentner K.J. Holyoak & B.N. Kokinov (Eds.), The analogical mind: Perspectives from cognitive science, MIT Press, Cambridge, 2001.

[4] U. Goswami, "Inductive and Deductive Reasoning", In U. Goswami (Ed.), Blackwell's Handbook of Childhood Cognitive Development, Blackwells, Oxford, 2002.

[5] K.J. Klauer & G.D. Phye, "Inductive reasoning. A training approach", Review of Educational Research, Vol. 78, 2008, pp. 85-123

[6] R.J. Sternberg, Intelligence, information processing, and analogical reasoning: The componential analysis of human abilities, Erlbaum, Hillsdale, 1977.

[7] S. Robins & E. Mayer, "Schema training in analogical reasoning" Journal of educational psychology, Vol. 85, 1993, pp. 529-538

[8] A.E. Green, J.A. Fugelsang, D.J. Kraemer, N.A. Shamosh & K.N. Dunbar, "Frontopolar cortex mediates abstract integration in analogy", Brain Research, Vol. 1096, 2006, pp. 135-137

[9] L.E. Richland, R.G. Morrison & K.J. Holyoak, "Children’s development of analogical reasoning: insights from scene analogy problems", Journal of Experimental Child Psychology, Vol. 94, 2006, pp. 249-273

[10] K.E. Singer-Freeman, "Analogical reasoning in 2-year-olds: The development of access and relational inference", Cognitive Development, Vol. 20, 2005, pp. 214-234

[11] R. Primi, "Complexity of geometric inductive reasoning tasks. Contributions to the understanding of fluid intelligence", Intelligence, Vol. 30, 2001, pp. 41-70

[12] J.M. Bebko & H. Luhaorg, "The development of strategy use and metacognitive processing in mental retardation: Some sources of difficulty", In J.A. Burack, R.M. Hodapp & E. Zigler (Eds.), Handbook of Mental Retardation and Development, Cambridge University Press, Cambridge, 1998.

[13] C. Hulme & S. Mackenzie, Working memory and severe learning difficulties, Hillsdale, NJ: Erlbaum, 1992.

[14] C. Jarrold, A.D. Baddeley & A.K. Hewes, "Genetically dissociated components of working memory: Evidence from Down's and Williams syndrome", Neuropsychologia, Vol. 37, 1999, pp. 637-651

[15] T.P. Alloway, S.E. Gathercole, H. Kirkwood & J. Elliott, "The Cognitive and Behavioral Characteristics of Children With Low Working Memory", Child Development, Vol. 80, No. 2, 2009, pp. 606-621

[16] N. Cowan & T. Alloway, "Development of Working Memory In Childhood", In M.L. Courage & N. Cowan (Eds.), The development of memory in infancy and childhood, Hove, East Sussex, UK: Psychology Press, 2009.

[17] A. Bosseler & D.W. Massaro, "Development and Evaluation of a Computer-Animated Tutor for Vocabulary and Language Learning in Children with Autism", Journal of Autism and Developmental Disorders, Vol. 33, No. 6, 2003, pp. 653-672

[18] O.E. Hetzroni & J. Tannous, "Effects of a Computer-Based Intervention Program on the Communicative Functions of Children with Autism", Journal of Autism and Developmental Disorders, Vol. 34, No. 2, 2004, pp. 95-113

[19] D.K. Davies, S.E. Stock & M.L. Wehmeyer, "Enhancing independent time-management skills of individuals with mental retardation using a palmtop personal computer", Mental Retardation, Vol. 40, No. 5, 2002, pp. 358-365

[20] D.K. Davies, S.E. Stock & M.L. Wehmeyer, "Computer-Mediated, Self-Directed Computer Training and Skill Assessment for Individuals With Mental Retardation", Journal of Developmental and Physical Disabilities, Vol. 16, 2004, pp. 95-105

[21] S.E. Stock, D.K. Davies, K.R. Davies & M.L. Wehmeyer, "Evaluation of an application for making palmtop computers accessible to individuals with intellectual disabilities", Journal of Intellectual & Developmental Disability, Vol. 31, No. 1, 2006, pp. 39-46

[22] J.D. Foshay & B.L. Ludlow, "Implementing computer-mediated supports and assistive technology", In M.L. Wehmeyer & M. Agran (Eds.), Mental retardation and intellectual disabilities: Teaching students using innovative and research-based strategies, Boston, MA: Pearson Custom Publishing, 2005.

[23] D. Lee, A. McGee & S. Ungar, "The Effectiveness of a Computer-Based Safety Programme for Children with Severe Learning Difficulties", Child Abuse Review, Vol. 10, 2001, pp. 198-209

[24] F.P. Büchel, "Analogical reasoning in students with moderate intellectual disability: Reasoning capacity limitations or memory overload?", Educational & Child Psychology, Vol. 23, No. 2, 2006, pp. 61-80

[25] J. Raven, J.C. Raven & J.H. Court, Manual for Raven's Progressive Matrices and Vocabulary Scales. Section 2: The Colored Progressive Matrices, Harcourt Assessment, San Antonio, 1998.

[26] S. Lanfranchi, C. Cornoldi & R. Vianello, "Verbal and Visuospatial Working Memory Deficits in Children With Down Syndrome", American Journal on Mental Retardation, Vol. 109, 2004, pp. 456-466

[27] C. Denaes (in press), "Analogical Matrices in Young Children and Students with Intellectual Disability: Reasoning by Analogy or Reasoning by Association?", Journal of Applied Research in Intellectual Disabilities, Vol. 25, 2012

[28] C. Denaes Bruttin, "Computerized assessment of an analogical reasoning test: Effects of external memory strategies and their positive outcomes in young children and adolescents with intellectual disability", Educational & Child Psychology, Vol. 28, No. 2, 2011, pp. 18-32

[29] P. Shah & A. Miyake, "The separability of working memory resources for spatial thinking and language processing: An individual differences approach", Journal of Experimental Psychology: General, Vol. 125, 1996, pp. 4-27

[30] J. Sweller, "Cognitive load theory, learning difficulty, and instructional design", Learning and Instruction, Vol. 4, 1994, pp. 295-312

[31] K.A. Ericsson & W. Kintsch, "Long-Term Working Memory", Psychological Review, Vol. 102, 1995, pp. 211-245

[32] M.A. Just & P.A. Carpenter, "A capacity theory of comprehension: Individual differences in working memory", Psychological Review, Vol. 98, 1992, pp. 122–149

[33] S. Baker, S. Hooper, M. Skinner, D. Hatton, J. Schaaf & P. Ornstein, "Working memory subsystems and task complexity in young boys with Fragile X syndrome", Journal of Intellectual Disability Research, Vol. 55, 2010, pp. 19-29

[34] B. Carretti, C. Belacchi & C. Cornoldi, "Difficulties in working memory updating in individuals with intellectual disability", Journal of Intellectual Disability Research, Vol. 54, 2010, pp. 337-345

[35] B. Carretti & S. Lanfranchi, "The effect of configuration on VSWM performance of Down syndrome individuals", Journal of Intellectual Disability Research, Vol. 54, 2010, pp. 1058-1066

[36] K. O'Hearn, S. Courtney, W. Street & B. Landau, "Working memory impairment in people with Williams syndrome: Effects of delay, task and stimuli", Brain & Cognition, Vol. 69, 2009, pp. 495-503

[37] W.C.M. Resing, "Assessing the learning potential for inductive reasoning (LIR) in young children", In C.S. Lidz & J.G. Elliott (Eds.), Dynamic Assessment: Prevailing models and applications, Elsevier Science, New York. 2000.

[38] J.C. Burguillo, "Using game theory and Competition-based Learning to stimulate student motivation and performance", Computers & Education, Vol. 55, 2010, pp. 566-575

[39] M. Papastergiou, "Digital Game-Based Learning in high school Computer Science education: Impact on educational effectiveness and student motivation", Computers & Education, Vol. 52, 2009, pp. 1-12

[40] D.J. Brown, "Some uses of educational and assistive technology for people with disabilities", Computers & Education, Vol. 56, 2011, p. 1

[41] J. Woodward & H. Rieth, "A Historical Review of Technology Research in Special Education", Review of Educational Research, Vol. 67, 1997, pp. 503-536