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Using Digital Resources in the Measure of the Impact of Working Memory on Students' Acquisition of Mathematical Knowledge

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Abstract— Working Memory (WM) is the mental thinking space in which learners manipulate or act on aspects of their knowledge in mathematical learning situations. It is the activity that allows learners to create links between the data collected during such a situation, and the knowledge gained from long-term memory, to synthesize new knowledge in mathematics, and when they direct their learning and thinking activity to calculate or solve mathematical problems. This work investigates the impact of WM on the academic achievement of mathematics knowledge using electronic learning resources. It also attempts to determine the process of WM to foster and improve the cognitive structures of the learner to facilitate the transformation of information and to succeed in a learning mathematics session. The results obtained lead to a good correlation between these two variables. The digital resources used promote the expected results, and facilitate the collection and processing of the data needed for such research. This makes it possible to better understand the functioning of WM during a learning situation in mathematics, and thus to be able to lead to solutions when learning problems appear.

***Keywords*—**Working memory capacity, Digital resources, Learning, Academic achievement Mathematics

I. INTRODUCTION

Mathematics education involves students learning to perform tasks such as the sum of numbers, factoring and the development of mathematical expressions, and so on. The successful learning of these types of ideas implies that learners connect ideas in a particular way, indicated in the teaching to which they have been exposed.

However, some students have difficulty doing this. In other words, they have difficulty using the educational information that allows them to acquire the skills and understand associated with these tasks. They need to remember what they know, retain and connect ideas during learning and encode their new understanding into Long-Term Memory (LTM).

These requests make use of the different types of human memory: to capture and identify any new information perceived for a few hundred milliseconds only at the level of the Sensory Memory (SM), to keep this information for about a minute within the Short-Term Memory (STM), pending the determination and restitution of the necessary knowledge stored in LTM. All of this information will be stored and manipulated for short periods and when performing an activity, within the WM.

In a learning situation, the teacher, in his practice, must be alert to the student's motivation and ability to receive information. The student, for his part, must invest himself to the maximum in order to guarantee a real appropriation of knowledge.

The "theory of situations" distinguishes between three types of situations in terms of the relationships that the learner establishes with the object of knowledge and the educational system: situation of action, situation of formulation and situation of validation. This theory provides a fourth phase called the phase of institutionalization [1].

Several studies and research [1], [2], [3], [4], [5], [6], that focus on WM and its relation to school learning, especially mathematics learning, state that WM has a vital contribution to learning in the classroom, and that seems to play a vital role in all intellectual activities.

Any action that takes place over time requires the previous steps to be remembered to accomplish the next steps.

This guarantees the links between the steps in order to carry out the requested actions.

"The WM as a whole, by its complexity and diversity, operates in many cognitive domains such as intelligence, oral language, reading, writing, mathematics, the acquisition of a second language, etc. " [7].

Declaring WM as the mental thinking space in which learners manipulate or act on aspects of their knowledge in mathematical learning situations, or while performing mathematical tasks and problems, it is argued that it is the activity that students engage in when interpreting educational information with the help of the knowledge they recover from long-term memory when they retain and relate partial ideas of mathematics, to synthesize new knowledge in mathematics and when they direct their learning and thinking activity to calculate or solve mathematical problems.

So, what is the impact of WM on mathematics achievement? and what is the WM process, to be implemented, to promote and improve the cognitive structures of the learner to facilitate the transformation of information and to succeed in a learning situation of mathematics?

This work aims to study and analyze the relationship between Working Memory Capacity (WMC) and academic performance, based on the following hypothesis: 1/If the WMC is greater than the number of requests for a mathematical problem, in a well-constructed learning situation, will the problem be successful?; 2/ Conversely, if the WMC is less than the number of requests for a mathematical problem, in a well-constructed learning situation, will the problem be missed?

At this stage, we have used digital learning resources that lead, on the one hand, to measure the WMC and academic performance, and on the other hand, to study and develop the relationship between these two variables.

This article is structured as follows: the first part describes the different theoretical concepts related to this work, namely: the most common WM models in the scientific literature, the concept of WMC and the cognitive variables that intervene during a learning situation, as well as the concept of digital resources and their use in the learning process. The second part is devoted to the practical experimentation carried out, notably the WMC measurement tests, and those of measurement of the school performance. This section presents the adopted methodology, presents the results obtained and presents an analysis and an interpretation of these results. The last part gives the main conclusions and possible extensions.

II. Related Work

A. Models of WM

WM is a model of transient memory proposed in 1974 [8], as an alternative to the concept of short-term memory of the modal model proposed in 1968 (Figure 1). Like the latter, it is a model derived from the current "Information Processing System (IPS)" for which the information, which is abstract, symbolic, is treated in a localized way (in modules) and sequentially (in consecutive modules) [9].

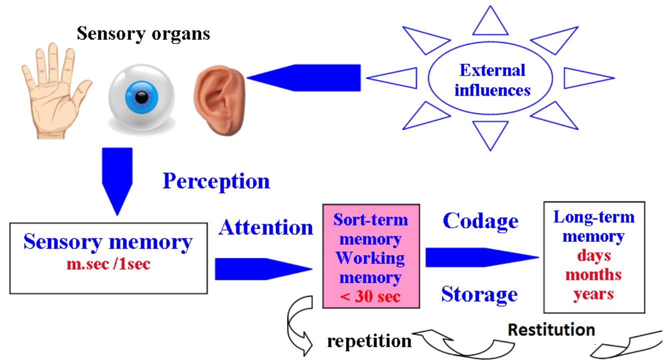

Figure 1. Atkinson-Shiffrin working memory model

WM allows you to temporarily retain and manipulate new information that is involved in processes such as comprehension, learning and reasoning. According to the model proposed [10], widely shared by neurobiologists, WM contains three subsets: the executive center, representing an attention control system capable of supervising the information from two enslaved systems and, the phonological loop and the visuo-spatial sketchpad. The phonological loop processes information from language and hearing, while the visual-spatial register holds images.

Despite the development of research into the exact model of WM, this model [11] remains the best model. In trying to improve and develop it further, the searchers [12] tries to deepen the research about its components and functions.

In 1992, the existence of a system responsible for controlling the WM and its component, was assumed [13] which named "central executive". He [14] pointed out that there are several subsystems that help the central executive perform his function.

In 2005, a new component of the WM was added [15] to its initial model called "the episodic buffer". This component responds to a number of experimental facts not predicted by the tripartite model (Figure 2).

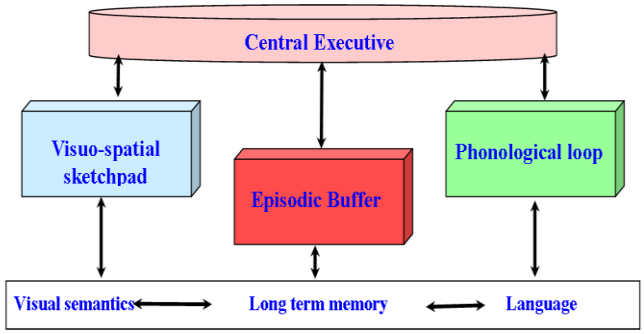

Figure 2. WM model [1]

B. *Working memory capacity (WMC)*

The WMC is a predictor of academic success. Then, problems of schooling can be linked to a deficit in this area, which teachers, parents and learners are not informed about. Between 10 and 15% of students have an undetected deficit.

It was in 1956 that the ability of an adult's WM was determined [16] to 7 items +/- 2. This means that one would have the ability to jointly manage 7 isolated +/- 2 elements before that these do not fade, replaced by others.

For children who are developing normally, the WMC increases steadily until the age of 14, when it reaches adult levels [17]. However, for some children, WM follows an atypical development path that results in a lower capacity than their age [18]

The memory span is the number of isolated items that can be stored in memory for up to one minute. It is measured by many tests. Strategies to "increase" one's memory span are the use of grouping the data into parts, to minimize the number of items to retain at the WM level.

C. *Cognitive variables*

Although intelligence is no longer considered as the main factor at play in academic success, many studies focus on the links between cognitive characteristics and academic performance [19]. In fact, cognitive skills, knowledge and academic skills (especially in reading, mathematics, and speaking) are very important for academic success [20]. Mnesic abilities also influence school performance. WM, which allows the maintenance and manipulation of relevant information during the performance of cognitive tasks, plays a crucial role here [21]. High correlations are reported between the WM span and performance in reading, comprehension, arithmetic and reasoning [22].

D. *Learning and transformation of information*

Learning is a dynamic process of building knowledge [23]. Here are the steps that make up this process:

- the establishment of links between new information and those already organized (representations);
- the incessant organization of knowledge;
- the mobilization of cognitive and metacognitive strategies as well as disciplinary knowledge.
- Learning any notion, concept or knowledge always refers to declarative, procedural or conditional knowledge.

Some recent studies [24] show that teachers and remedial teachers are often inclined to believe in misconceptions about how the brain works, called neuromyths. Currently, no scientific study proves that teaching with a student's preferred learning style helps him learn better. What's more, it can lead students to a biased perception of how they learn. To adopt a more effective pedagogy, pedagogues must make sure to use diversified means to help students learn [25].

It is important to be aware of the student's learning process to know better the strategies he uses and to teach him the ones he misses to better meet the requirements of the school subjects. Thus, instead of using the theory of learning styles to label students and limit teaching to their style, it is worthwhile to take an interest in learning about the different strategies that students can develop.

Today, with the evolution of educational technologies, learning process is no longer confined within a fixed classroom at scheduled time [26]. It has become open and flexible in terms of space and time [27].

E. *Using digital resources in the learning process*

1. *Définition of a digital resource*

A digital resource is a "Document (data or software) encoded in order to be processed by a computer and considered as a bibliographic unit. The electronic resources comprise on the one hand information resources stored locally, on the other hand those which require the use of a peripheral connected directly to the computer (for example, a hard disk, a CD-ROM reader) , and finally online services (for example, forums or discussion lists, websites). An electronic resource can have either text, still or moving image, or sound. It can be as multimedia.

One of the digital resources that interest us is the digital educational resource. It is a resource specifically designed for teachers and students for learning purposes. It must therefore meet the requirements of national education curricula and standards. The rights of use and reuse attached to it allow use in the school setting, in class and / or outside the classroom.

Digital resources combine content and services. They have technical characteristics that make their acquisition more complex than paper resources. Their choice also depends on the technical environment of the school or institution.

2. Use of digital resource in learning

The use of digital resources in learning has three advantages over traditional media:

- Theoretically unlimited access to all sources of information and communication
- Digitization (texts, sounds, images) that avoids aging and facilitates the transfer of one medium to another
- Interactivity that allows users to categorize information, confront it with other information and be guided in their research. [28]

A study [29] clearly shows that the use of digital resources in the classroom contributes to an improvement in the academic performance of primary school pupils . It has resulted in three main outcomes of integrating technological tools into the learning process:

- Students who are accustomed to using digital resources in the classroom are significantly better at learning in the long term, regardless of the type of support.
- Students who are accustomed to using digital resources in the classroom understand faster and better what they read.
- Knowledge and academic achievement have increased significantly for students accustomed to digital use.

Digital resources allow students to develop their argumentative capacity and their objectivity on three levels: "cognitive, psychomotor and emotional". They make it possible to learn with others, to "inter-learn" and thus to multiply the approaches: individual, mutualist or collaborative. The pedagogical approach used by the teacher when using these tools in teaching-learning situations, then came to the fore, “not the technology itself, but the application of technology, which has the potential to affect learning” [29].

III. METHODOLOGY

A. Choice of the sample

As a mathematics teacher, we chose a group of 3rd year high school students, made up of 96 students, as a study sample for this research. They have distinct averages in mathematics, between low and good.

This group is subject to different types of testing namely; IQ intelligence test, memory span test numerical and in letters, as well as school performance tests which are based on a specific choice of learning situations, as explained below.

B. Choice of evaluation tool

In trying to answer the hypotheses of the research, we use the tests of measure of the WMC as well as the tests of school performance in mathematics.

1. The WMC tests

These are tests that allow the measurement of digital memory and in letters. We have adopted a digital application available on the Internet that allows the user to take the test directly and get the test result as soon as it is finished.

The contents of the displayed interfaces allow the measurement of the numerical memory span and in letters. This test involves projecting numerical series, or series in letters for a few seconds, to hide them and after a while, the user is asked to remember and write them on the appropriate areas (Figure 3).

Figure 3. Interface of the digital resource on the internet adopted during the test

However, because we were unable to provide a computer for each student and to connect to the Internet in the space of the institution where we took the test, we only changed these tests so that they could be completed in class. . The fields that the student is supposed to fill in the application have turned into a table, on answer sheets, with boxes filled in according to the serial numbers that appear on our PC screen, and displayed to students using a video projector (Figure 4).

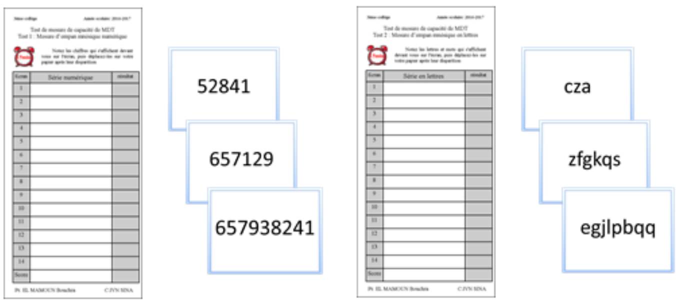

Figure 4. Documents of the digital resource adopted for measuring the WM capacity

It should be noted that the programming time allocated to each test as well as the time elapsed between the appearance of each digital string, or string in letters, were not random. We increase the space-time between two strings to give the learner's WM enough time to process the information it receives. An attempt to find a relation between the numerical numbers of the numerical series, and the words of the series in letters, is desired. It thus takes a strategy to keep the information longer in all its details.

2. School performance tests

These are learning situations constructed taking into consideration the number of requests for each mathematical problem, as well as the expected level of data transformation.

We worked on two courses: "The vectors in the plane" and "the equation of the line in the plane". The didactic choice of pedagogical situations differs according to the number of data to be collected via the Sensory Memory (SM), and to the knowledge to restore from the Long Term Memory (LTM), as well as the level of transformation and analysis achieved to succeed the mathematical problem posed.

The tables below present the classification of pedagogical situations constructed (Table 1, Table 2).

Table 1. Classification of pedagogical situations according to factors involved in learning (courses vectors in the plan)

	Restitution Number of requests		Application	Transformation
	SM	LTM	WM	
S1	2	2	yes	
S2	2	3	yes	yes
S3	2	3	yes	
S4	2	4	yes	yes
S5	3	4	yes	yes

Table 2. Classification of pedagogical situations according to factors involved in learning (courses the equation of the line in the plane)

	Restitution Number of requests		Application	Transformation
	SM	LTM	WM	
S1	1	2	yes	
S2	2	3	yes	yes
S3	2	3	yes	
S4	2	4	yes	yes
S5	2	5	yes	yes

All the results of these tests are presented and analyzed in the next section.

IV. Results and Discussion

We grouped the learners, who took the scheduled tests, into groups that differ according to the learners' WMC. This gives way to having five groups (Figure 5).

Group 2	Data substit-uted	WM capacity
élève15	5	4
élève16	6	4
élève17	4	4
élève18	4	4
élève19	5	4
élève20	4	4
élève21	3	4
élève22	4	4
élève23	5	4
élève24	5	4
élève25	3	4
élève26	3	4
élève27	4	4
élève28	3	4
élève29	2	4
élève30	3	4
élève31	2	4
élève32	3	4
élève33	4	4
élève34	4	4
élève35	3	4
élève36	3	4
élève37	3	4
élève38	2	4
élève39	2	4
élève40	3	4
élève41	6	4
élève42	3	4
élève43	4	4
élève44	3	4
élève45	3	4
élève46	4	4

Group 3	Data substit-uted	WM capacity
élève47	5	5
élève48	4	5
élève49	5	5
élève50	5	5
élève51	6	5
élève52	4	5
élève53	4	5
élève54	6	5
élève55	5	5
élève56	3	5
élève57	3	5
élève58	4	5
élève59	4	5
élève60	3	5
élève61	5	5
élève62	3	5
élève63	4	5
élève64	5	5
élève65	7	5
élève66	4	5
élève67	4	5
élève68	6	5
élève69	5	5
élève70	4	5
élève71	3	5
élève72	4	5
élève73	4	5
élève74	4	5
élève75	3	5
élève76	3	5
élève77	4	5
élève78	4	5
élève79	6	5

Group 1	Data substit-uted	WM capacity
élève1	4	3
élève2	3	3
élève3	3	3
élève4	2	3
élève5	2	3
élève6	2	3
élève7	4	3
élève8	3	3
élève9	3	3
élève10	5	3
élève11	3	3
élève12	3	3
élève13	3	3
élève14	3	3

Group 4	Data substit-uted	WM capacity
élève80	5	6
élève81	5	6
élève82	7	6
élève83	6	6
élève84	7	6
élève85	7	6
élève86	7	6
élève87	6	6
élève88	4	6
élève89	7	6
élève90	6	6
élève91	6	6
élève92	4	6
élève93	6	6

Group 5	Data substit-uted	WM capacity
élève94	5	7
élève95	7	7
élève96	7	7

Figure 5. Learners groups according to their WMC

We transformed the results found in the following graphic (Figure6).

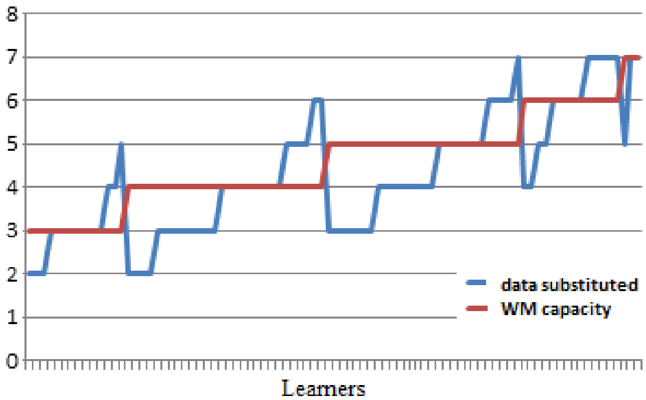

Figure 6. Data sibstituted evolution according to the WMC

The results found show that the number of data that each pupil can return during a learning situation is correlated with his WMC. Indeed:

- For students who have a low WM (between 3 and 4 items to remember), they can only return at most 4 data. Yet, any of them can return at most 5 data during the learning situation.
- For students who have an average WM (between 5 and 6 items to remember), they can only return at most 6 data. Yet, any of them can return up to 7 data during the learning situation.
- For students who have a strong WM (7 items to remember), they can return the maximum of the data presented during each chosen learning situation (7 data), while manipulating the skills necessary to reach the level of transformation and the calculation required by the problems posed.

The set of results obtained according to the well-chosen learning situations leads to classifying the research sample into three groups:

- Learners who quickly forget the returned data of the problem proposed in each learning situation.
- Learners who have difficulty making connections (WM) between what they have already learned (LTM) and what they have to return (SM)
- Learners who can retrieve all the data of the proposed problem, import useful LTM knowledge, and link the data set to a good level of transformation and analysis.

Moreover, we note that all learners manage to succeed in learning situations whose tasks are simple. But, by increasing the level of complexity of the proposed tasks, the number of students who are able to perform these tasks decreases, and this according to their ability to WM.

We can conclude that the ability of the WM is a predictor of success in mathematical learning situations. The recognition of the role of the different components of the WM in relation to the different learning activities of mathematics certainly helps to limit the educational failure of learners.

On the other hand, a learner who makes considerable efforts to learn Mathematics but fails to succeed in his learning situations, and subsequently achieves poor academic results in mathematics, must question the capacity of his WM.

V. CONCLUSION AND FUTURE SCOPE

The results of this research study are quite encouraging and lead to a good correlation between the ability of WM and the learner' performance in terms of mathematical skills. The digital resources used promote the expected results, and facilitate the collection and processing of the data needed for such research. This allows a better understanding of the functioning of the WM during a learning situation in mathematics, and subsequently can lead to solutions when the appearance of learning problems.

To make this clearer, new research will have to continue studying the improvement of mathematical learning in students while developing their WMC. It would be particularly relevant to know under which circumstances, with what objects and to what extent the development and maximum exploitation of the capacity of the WM is effective in learning mathematics.

Future research involves using educational technologies that can help to improve and develop the WMC to overcome the obstacles that hinder the learning of mathematics. For this, we are working on the design of An Intelligent Tutorial System (ITS) that will enhance the WMC in online learning situations.

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