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Impact of Digital Learning Tools on Student Performance in Science: A Comparative Study in Two High Schools in Yaounde

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ABSTRACT: The use of digital learning tools in the Cameroonian education system has become a major issue in education policy in recent years, a situation exacerbated by the COVID-19 pandemic, which revealed the fragility of African education systems in the face of pedagogical disruptions (OECD, 2022). The Education Orientation Law N° 98/004 of April 14, 1998, the conceptual framework for this policy commitment, states that “teaching in schools should take into account the evolution of science and technology”. It is in this context that we propose, in this study, to observe the results of a classroom practice in a biology course conducted with a digital tool in a 9th-grade secondary school class. Our sample for this mixed-methods study consists of 196 students from two high schools in the city of Yaoundé. In a performance assessment test, students in the experimental group at the first high school achieved an overall average of 13.8, compared to 11.20 for the control group. At the second high school, students in the experimental group achieved an overall average of 13.65, while the control group achieved 10.8. We conclude that the use of this digital learning tool contributed to improved student performance in the biology course at both secondary schools, and that its use warrants wider implementation, provided that adequate infrastructure and teacher training are available.

KEYWORDS: Digital learning tools, educational technology, academic performance, biology, secondary education, software tutorial

I. INTRODUCTION

The need to integrate information and communication technologies (ICTs) into education has become both evident and a major challenge in the knowledge acquisition process, worldwide in general and in Cameroon in particular. This shift has potentially positive effects, as ICTs can improve skills acquisition for both learners and teachers. However, in developing countries, the implementation of ICTs in teaching and learning remains contingent on easy access to computers and the internet, two resources that are still unevenly distributed.

The situation in African schools is marked by an endemic lack of teaching materials and resources (E-Learning Africa, 2012; Karsenti et al., 2011; UNICEF, 2013). Indeed, textbooks are lacking in high schools, and photocopies are difficult to obtain. This material insecurity deprives teachers of the necessary teaching materials, while students desperately lack learning resources (Pitteloud, 2004; Menkoué, 2013). The COVID-19 pandemic, which began in 2020, further exacerbated this situation: in West and Central Africa, nearly 54 million students, representing 48% of the school population, were unable to benefit from distance learning or access to resources due to a lack of adequate digital infrastructure, devices, and internet connectivity (OECD, 2022).

In this context, the question of the pedagogical effectiveness of digital tools arises with renewed urgency. Recent work in educational technology shows that ICTs, and in particular interactive tutorials and simulations, can compensate for the lack of real-world laboratories and promote active and meaningful learning (Hillmayr et al., 2020; Morales-López et al., 2022). In Cameroon, the national digital policy “Digital Cameroon 2020” and the Strategic Framework for Basic Education (2022) reaffirm the ambition of integrating ICTs into teaching; however, substantial gaps persist between policy guidelines and the reality of classroom practices (Bakonga, 2021; MINESEC, 2022).

This research is situated within this tension between institutional ambition and practical realities. We propose to observe and evaluate the effects of a tutorial on the performance of 9th-grade students in a Life and Earth Sciences (SVT) course focusing on the expression of genetic information.

II. STUDY CONTEXT AND PROBLEM STATEMENT

The integration of ICT in education in Africa, and particularly in Cameroon, is more focused on infrastructure than pedagogy (Karsenti et al., 2011; Bakonga, 2021). While significant progress has been made in terms of equipment, notably through the creation of Multimedia Resource Centers inaugurated in 2001 in several public high schools in Yaoundé, the question of the effective and pedagogically relevant use of these resources remains poorly documented. According to recent data, 70% of Cameroonian secondary schools have a computer lab (MINESEC, 2022), but the majority of teachers have not received any formal training in the pedagogical integration of ICT (ADEA, 2022).

Life and Earth Sciences (SVT) is a discipline particularly affected by this issue. Formerly called Biology, it requires illustrations of practical and demonstrative phenomena, which the appropriate laboratories, when they exist, do not cover in all schools. Methodologically, SVT relies on controlled laboratory experimentation, field observation, and modeling. However, in Cameroon, this experimentation encounters a number of economic and material constraints (Karsenti et al., 2011) that make practical work difficult, if not impossible, in most public schools.

Recent research in science education shows that simulations and virtual laboratories constitute a credible and complementary alternative to real-world experimentation (Canopé, 2021; El Abboud et al., 2021). According to a meta-analysis of studies on science education in resource-limited settings, appropriate digital interventions produce significant learning gains, particularly when they combine animation, interactivity, and immediate feedback (de Hoop et al., 2023). This finding aligns with the theory of educational virtual environments (EVEs), according to which immersion in digital simulations promotes the understanding of complex scientific phenomena, especially those that are invisible to the naked eye or difficult to reproduce in the classroom (Nafidi et al., 2018; El Abboud, 2021).

However, the effectiveness of these tools is neither automatic nor universal. Multilevel analyses of PISA data show that the effect of ICT on science performance varies considerably depending on students' level of digital autonomy, their attitude towards the tool, and the quality of the pedagogical scenario implemented (Skryabin et al., 2015; Aesaert et al., 2022). Furthermore, a recent systematic review highlights that more than 80% of research on ICT and academic performance focuses on mathematics and science, and that the observed effects are generally positive but moderate, and highly context-dependent (Morales-López et al., 2022). In sub-Saharan African countries, the digital divide between well-equipped private institutions and public schools, rural or peri-urban, tends to widen, reducing the potential impact of digital devices that do not rely on prior investment in infrastructure (ADEA, 2022; Piebop, 2023).

These observations lead to the formulation of the following research question:

What are the effects of a science classroom practice using a tutorial on the performance of secondary school students in the Cameroonian context, and what factors, motivational, contextual, pedagogical, mediate these effects?

This question incorporates a broader problematic dimension: in an environment marked by inequalities in access to resources, a lack of teacher training in digital technology, and curricula focused on theoretical transmission, can we expect a positive and generalizable effect of a digital tool on scientific learning? And if so, under what conditions?

III. THEORETICAL AND CONCEPTUAL FRAMEWORK

Our study is part of two complementary theoretical traditions: socio-cognitive constructivism and educational technology theory.

III.1. The tutorial as a tool for pedagogical mediation

A tutorial is an instructional design tool intended to facilitate the teaching and learning process. It is a type of software used in pedagogy and can be behaviorist or constructivist in orientation, incorporating interactive sequences with the learner. It may consist of exercises, tutorials (course content), simulators (for virtual practical work), glossaries, or games.

From a constructivist perspective, ICTs promote greater student ownership of learning and align with cognitivism and constructivism (Klotz, 2005). The impact of ICTs on teaching and learning can be considerable: with ICTs designed as tutorials, teaching conditions can be improved given the strong presence of interactivity (text, image, animation, video, sound).

In the specific field of science education, simulations and educational virtual environments (EVEs) allow students to observe dangerous, costly, or inaccessible phenomena that would be difficult or even impossible to reproduce in a school laboratory (Canopé, 2021). When used in conjunction with real-world experiments or as a substitute in resource-limited settings, they improve learning outcomes (El Abboud et al., 2021; de Hoop et al., 2023). This observation is particularly relevant for teaching genetics in life and earth sciences, a field where molecular and cellular phenomena are inherently invisible and require modeled representation.

III.2. Motivation and commitment as mediating variables

Contemporary research on ICT in education emphasizes the importance of motivational and attitudinal dimensions as mediating variables between the tool and performance. A recent meta-analysis by Morales-López et al. (2022), covering 87 studies published between 2000 and 2020, shows that the effect of ICT on performance is more pronounced in scientific disciplines when the tools are integrated into systems that promote active student engagement. Similarly, Aesaert et al. (2022), using PISA 2009-2018 data, report that a positive attitude toward ICT is the strongest predictor of performance in science.

These results echo the interviews conducted in our own study with teachers: the ergonomics of the tutorial and its animations maintained the students' attention, providing an additional source of motivation for learning.

III.3. The quasi-experimental framework

Methodologically, learning assessment plays a central role. It refers to all the means used during a learning process to measure learners' levels and performance, and helps to make the various necessary adjustments. The pre-test/post-test design with a control group is the most widely recognized method for evaluating the effectiveness of a teaching intervention, although its limitations must be taken into account, particularly the impossibility of controlling all contextual variables (Marsden & Torgerson, 2012).

According to Ministerial Decree No. 19/D/30/MINEDUC/IGP/ESG of April 24, 1994, which defines the biology curriculum, assessment must focus on the skills developed by students based on predefined objectives. Three types of assessment are provided for: diagnostic assessment (at the beginning of a unit), formative assessment (during the learning process), and summative assessment (at the end of the learning process).

IV. METHODOLOGY

Our work involves testing a tutorial in a real-world classroom setting at two high schools. The digital learning environment, the central element of our project, is a tutorial on the expression of genetic information for 9th grade (3ème) students, developed at the Department of Computer Science and Educational Technology at the Higher Teacher Training College of Yaoundé. Its aim is to improve students' understanding of the various genetic phenomena involved in this life and earth sciences (SVT) lesson, as outlined in the official curriculum.

This work is part of a mixed method; whereby quantitative and qualitative data are used in order to retain the preferred method for optimizing the academic performance of learners in Life and Earth Sciences.

IV.1. Population and sample

For this study, the target population consisted of 9th-grade students selected from two different high schools in the city of Yaoundé: one class at the Etoug-Ebé High School (LE) with 82 students, and another at the Mendong Bilingual High School (LM) with 114 students, as well as the SVT teachers from these two schools. One class represented the control group (without use of the software tutorial) and the other, the experimental group (which used the software tutorial). Regarding the teachers, we used the non-probabilistic method of suitability until theoretical saturation, obtained after interviewing 3 teachers (two in LM, one in LE).

IV.2. Tutorial Experimentation

The teaching approach initially involved delivering a lecture on genetic information using a tutorial projected on the board, while the biology (or SVT) teacher explained the lesson. Subsequently, the software was installed on the computers in the computer lab, where the students practiced independently, guided by the research team.

IV.3. Data Processing

The information obtained from the questionnaire was processed using Microsoft Excel. The qualitative data from the interviews was processed manually, by grouping the responses thematically. The interview data supplemented and contextualized the quantitative data from the questionnaire administered to the learners.

V. PRESENTATION OF RESULTS

In this section, we report the results from the data collected and processed, presented in the form of tables followed by an analysis.

V.1. Learner and teacher profiles

Table 1 shows the distribution of the sample: 114 respondents from Mendong High School and 82 from Etoug-Ebé High School, for a total of 196 students. We worked with three teachers (two from the LM and one from the LE).

Table 1: Distribution of students by gender and by high school

MENDONG HIGH SCHOOL (LM)		
Sex	**pupils**	**Percentage**
Male	44	38.28
Female	70	61.72
Total	114	100

ETOUG-EBE High School (LE)		
Sex	**pupils**	**Percentage**
Male	34	38.28
Female	48	61.72
Total	82	100

Table 2 shows that the majority of learners have an intermediate level of computer skills: at LM, 47.36% have an intermediate level; at LE, 52.43%. This data is important because it indicates that the students were not complete novices with digital tools, which limits a possible bias in learning about the tool itself.

Table 2: Learner's level of computer skills

Level	**LM**		**Level**	**LE**	
	students	**%**		**students**	**%**
Weak	36	31.57	**Weak**	25	30.48
AVERAGE	54	47,36	**Moyen**	43	52,43
Bon	21	18,42	**Bon**	13	15,85
Excellent	0	0	**Excellent**	1	1,21
Total	114	100	**Total**	82	100

V.2. Factors that motivate learni

Table 3: motivation to learn using the tutorial

The elements that motivate learning using a tutorial	**LM**		**LE**	
	EXPERIMENTAL Group		**EXPERIMENTAL Group**	
	students	percentage %	students	percentage %
Facilitates understanding of the course	52	86.66	38	90.47
Animation that prevents fatigue and sleep	50	83.33	36	85.71
A sound that captivates our attention	48	80	37	88.09

As shown in Table 3 above, at the end of the experimental session, students in the experimental group indicated that the software tutorial facilitated comprehension of the lesson (86.66% in the experimental group at LM, 90.47% in experimental group at LE), that the animations reduced fatigue and sleepiness (83.33% in LM group, 85.71% in LE group), and that the sound captured their attention (80% in LM group, 88.09% in LE group). These results are consistent with recent work on the effects of multimedia interactivity on student engagement in African contexts (Bakonga, 2021; ADEA, 2022).

V.3. Pre-test Results

V.3.1. Pre-test evaluation

Table 4: Pre-test evaluation results

		Pre-Test Evaluation							
Mark ranges	**LM**					**LE**			
	Likert scales	**Experimental Group**		**Control group**		**Experimental Group**		**Control group**	
		Students	**%**	**Students**	**%**	**Students**	**%**	**Students**	**%**
[0 – 6 [	**Poor**	03	5.00	4	07.40	2	04.76	3	07.50
[6 – 08[	**Weak**	08	13.33	8	14.81	05	11.90	6	15.00
[08 - 10[	**Insufficient**	07	11.66	2	03.70	06	14.28	5	12.50
[10 – 12 [	**Fair**	29	48.33	24	44.44	17	42.50	19	47.50
[12 – 14 [	**Pretty good**	07	15.00	12	22.22	06	14.28	4	10.00
[14 – 16 [	**Good**	03	5.00	03	5.55	03	07.42	02	05.00
[16 – 18 [	**Alright**	02	3.33	01	1.85	01	02.38	0	00.00
[18 - 20	**Excellent**	01	1.66	00	00.00	2	4.76	01	02.50
Total		60	100	54	100	42	100	40	100
Overall Average		10.63		10.51		10.90		10.52	

Source: Pre-test evaluation results

At the Table 4 above, the pre-test results revealed a similar distribution of scores between the experimental and control groups in both high schools. The overall averages were almost identical: at the LM, 10.63 for the GE (Group Experiential) versus 10.51 for the CG (Control Group); at the LE, 10.90 for the GE versus 10.52 for the CG. The failure rate on the pre-test was 30% in the experimental group at the LM versus 25.92% in the control group, and 30.95% in the experimental group at the LE versus 35.00% in the control group. These results confirm the initial homogeneity of the groups, an essential condition for the validity of the quasi-experimental design.

V.3.2. Pre-test comparison of results

Table 5: Comparison of successes and failures

Assessment result	Pre-Test Evaluation							
	LM				LE			
	Experimental Group		Control group		Experimental Group		Control group	
	Students	%	Students	%	Student	%	Students	%
Failures	18	30	14	25.92	13	30.95	14	35.00
Successes	42	70	40	74.07	29	69.04	26	65.00
Total	60	100	54	100	42	100.00	40	100.00

Table 5 shows that the failure rate during the pretest was 30% in the experimental group at LM versus 25.92% in the control group and 30.95% in the experimental group at LE versus 35.00% in the control group of the same high school.

V.4. Post-test Results

V.4.1. Performance Comparison

Following the implementation of the software tutorial, the post-test results demonstrate a clear and consistent improvement in the experimental groups at both high schools. Table 6 below shows the results of the Post-test evaluation. At the LM, the overall average for the GE group was 13.80 compared to 11.20 in the GT (a difference of 2.6 points). At the LE, the overall average for the GE group was 13.65 compared to 10.80 in the GT. Standard deviations remained low in all groups (between 2.56 and 3.16), indicating a homogeneous distribution of scores around the mean.

Table 6: Post-Test evaluation results

		POST-TEST EVALUATION							
Mark ranges		MENDONG HIGH SCHOOL				ETOUG HIGH SCHOOL-EBE			
	Likert scales	Experimental Group		Control Group		Experimental Group		Control Group	
		Staff	%	Staff	%	Staff	%	Staff	%
[0 – 6[	Poor	0	0	1	01.85	0	0	0	0.00
[6 – 8[	Weak	0	0.00	08	14.81	0	0.00	02	05.00
[8 – 10 [	Insufficient	03	05.00	06	11.11	02	04.76	04	10.00
[10 – 12]	Fair	13	21.66	16	29.62	08	19.04	15	37.50
[12 - 14[	Pretty good	18	30.00	13	24.07	14	33.33	06	15.00
[14 – 16[	Good	14	23.33	05	09.25	9	21.42	07	17.50
[16 – 18[	Alright	07	11.66	02	03.70	06	14.28	02	05.00
[18 – 20]	excellent	05	8.33	02	03.70	03	07.14	0	0.00
Total		60	100	54	100	42	100	40	100
Overall average		13.8		11.20		13.65		10.8	
Standard deviation		2.88444		3.16661		2.56		2,75	

In terms of success rates, the experimental group in the LM achieved a 95.00% success rate compared to 72.22% in the GT in the LE, the success rate was 95.23% in the GE compared to 85.00% in the GT. The failure rate thus decreased dramatically in the groups that benefited from the tutorial: 5.00% in the GE-LM group compared to 27.77% in the GT-LM group, and 4.76% in the GE-LE group compared to 15.00% in the GT-LE group.

V.4.2. Results of interviews with teachers

Interviews with the Biology teachers revealed that students are usually inattentive and sometimes very distracted in class. However, the computer's playful nature sparked the students' curiosity, and the tutorial's user-friendly design kept them focused on the content. The teachers emphasized that students prefer a visual lesson, involving seeing and touching, to a purely oral lecture. They unanimously agreed that the tutorial provided an additional source of motivation for learning the Biology curriculum.

VI. DISCUSSION OF RESULTS

The results of our study confirm the hypothesis that the use of a tutorial software tool improves students' performance in SVT or Biology in the Cameroonian context. These results are consistent with a body of recent work at the international and African levels.

In terms of measured performance, the observed differences in mean scores between the experimental and control groups (2.6 to 2.85 points) are comparable to the gains reported in studies conducted in sub-Saharan Africa. De Hoop et al. (2023), in a quasi-experimental study conducted in Zambia, document significant gains in science learning for students exposed to interactive digital devices. Hillmayr et al. (2020), in a meta-analysis of 92 studies, confirm the positive effect of digital technologies on learning in science and mathematics, with particularly large effect sizes for interactive simulations.

In terms of motivational factors, our results confirm that the interactivity of the software tutorial, animations, sounds, multimedia games, played a crucial role in maintaining student attention and engagement. This finding is consistent with the conclusions of El Abboud et al. (2021) on virtual educational environments in life and earth sciences at the secondary level: immersion in animated representations of biological phenomena invisible to the naked eye fosters a deeper conceptual understanding than reading or listening alone.

However, our results must be qualified in light of the structural limitations of the Cameroonian context. As Bakonga (2021) and Piebop (2023) point out, substantial disparities persist between well-equipped schools, generally urban and private, and rural or public schools lacking resources. Our study, conducted in two urban high schools in Yaoundé equipped with computer labs, cannot be generalized to the entire country without taking into account the digital divide between schools. Furthermore, the SVT teachers who participated in the study had not received prior training in the pedagogical use of the software tutorial; the potential for improvement would be even greater with appropriate training.

Finally, the lack of longitudinal measurement in our design makes it impossible to assess the sustainability of the gains. Recent research emphasizes the need to distinguish between immediate effects, generally stronger, and medium-term effects, which are often more modest in the absence of regular practice (Morales-López et al., 2022; Ran et al., 2021).

CONCLUSION

This quasi-experimental study evaluates the pedagogical effectiveness of digital learning tools in biology with 196 ninth-grade students from two high schools in Yaoundé. The results reveal substantial learning gains for the experimental groups, with performance differences ranging from 2.6 to 2.85 points compared to the control groups. This convergence observed in two distinct contexts attests to the robustness of the pedagogical intervention.

These empirical observations are consistent with the Education Orientation Law No. 98/004 of April 14, 1998, thus validating the relevance of Cameroonian policy orientations regarding the modernization of education, subsequently reinforced by the Strategic Framework for Basic Education (MINESEC, 2022). They also align with the recommendations of ADEA (2022), which advocates a contextualized and progressive approach to the integration of digital technology in sub-Saharan Africa.

The study recommends a gradual generalization of these digital tools, conditioned by: (1) the continuing training of teachers in the pedagogical integration of ICT; (2) the development of adequate and equitable technological infrastructures between urban and rural areas; (3) the production of contextualized digital educational resources, responding to the official Cameroonian programs; (4) a reduction of the inter-institutional digital divide, which otherwise risks accentuating existing educational inequalities.

Further research is needed to explore the underlying cognitive mechanisms, analyze the differentiated effects according to learner profiles (particularly according to gender and socio-economic background), assess the sustainability of learning, and measure the optimal conditions for digital teacher training in the Francophone African context.

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