



IJSRIS
journal
ISSN: 2820-7157

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RECEIVED
17 August 2026



ACCEPTED
09 September 2026



PUBLISHED
1 October 2026





October 2026



Volume 5



Number 5

777 to 785

Gender and alternative concepts in electrokinetics: from initial differences to the homogenisation of performance following instruction among students in the scientific humanities in Mbandaka (Democratic Republic of Congo)

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ABSTRACT

This study examines the influence of gender on alternative conceptions in electrokinetics and on how this change following instruction, amongst 192 pupils (111 girls, 81 boys) in the third year of the scientific stream in Mbandaka, Democratic Republic of the Congo. A pre-test/post-test design was implemented during the 2025–2026 academic year, supplemented by an in-depth qualitative analysis of reasoning profiles by gender. In the pre-test, the Mann-Whitney U test revealed a statistically significant difference in favour of girls ($U = 3592$; $Z = -2.391$; $p = 0.017$). In the post-test, this difference disappeared ($U = 4152$; $Z = -0.910$; $p = 0.363$), with the average gains for boys (+6.44 points) slightly exceeding those for girls (+6.09 points). The qualitative analysis identifies distinct styles of knowledge anchoring: material and infrastructural anchoring amongst girls, and energetic and dynamic anchoring amongst boys, accompanied by a higher initial rate of abstention amongst the latter when faced with abstraction. These results indicate that the gender differences observed stem from socio-cognitive styles rather than intrinsic abilities, and that teaching, even when delivered under constrained material conditions, serves to equalise performance. Implications for differentiated and equitable teaching practices in a sub-Saharan context are discussed.

Keywords: gender, alternative conceptions, electrokinetics, Mann-Whitney test, science education, conceptual change.

1. Introduction and research question

The issue of gender equity in the teaching of science, technology, engineering and mathematics (STEM) constitutes a major educational challenge on a global scale. In sub-Saharan Africa, the joint reports by ADEA and UNESCO (2018) highlight the persistence of worrying disparities between girls and boys in terms of access to and success in science-related courses. These disparities cannot be reduced to a single factor; they stem from a complex interplay between sociocultural constraints, internalised gender stereotypes, teaching practices and a chronic shortage of teaching resources in schools. In the Democratic Republic of the Congo (DRC), this issue is particularly acute. Provincial education systems suffer from structural deficits in infrastructure and laboratory equipment, which render the study of physical sciences highly abstract and exacerbate learners' difficulties in conceptualising these subjects (Kapakala, 2018; Massamba, 2012). In the city of Mbandaka, situated in Équateur Province, the teaching of electricity thus faces a twofold constraint: the lack of tangible experimental platforms and the predominance of disembodied lecture-based teaching.

In the specific field of physics education, the influence of gender on the development of pupils' conceptions has been the subject of some pioneering research. Cossette (1999), in her study of secondary school Year 8 pupils' conceptions of electromagnetism in Canada, highlighted significant variations in performance according to gender, the intensity and direction of which depended on the epistemological nature of the tasks set. More recently, Naoual et al. (2018), in a Moroccan context, documented gendered learning approaches to abstract concepts in physics, showing that girls and boys employ contrasting analogical frameworks and information-processing strategies.

All of this research points to a fundamental epistemological conclusion: the performance differences observed between the sexes are in no way attributable to intrinsic cognitive dispositions or a difference in intelligence, but rather reflect socially constructed ways of relating to abstract knowledge, differing attitudes towards epistemic uncertainty, preferred semantic anchors and varying sensitivities to modelling registers.

However, an analysis of the current educational literature reveals a complete lack of empirical data documenting the interaction between gender, alternative conceptions and the dynamics of their evolution following instruction within the socio-cultural and educational context of the Democratic Republic of the Congo. This blind spot constitutes a detrimental gap, both for understanding learning mechanisms in sub-Saharan settings and for the development of equitable education policies.

This research aims to address this gap by examining three central questions:

- Are there statistically significant differences between the initial alternative conceptions of electrokinetics held by girls and boys prior to any formal teaching?
- Does the formal teaching provided during the school year serve to reduce, accentuate or stabilise these initial gender differences?
- What qualitative patterns of reasoning, types of obstacles and gendered modes of semantic anchoring do an in-depth analysis of pupils' work reveal?

2. Theoretical and conceptual framework

To rigorously analyse the origins, structure and development of alternative conceptions according to gender, this study draws on three complementary conceptual frameworks.

2.1. The paradigm of alternative conceptions and epistemological obstacles

From an epistemological perspective, this research follows on from the work of Giordan and De Vecchi (1987), who define conceptions not as mere random errors or gaps in memory, but as ‘structured systems of functional ideas’ drawn upon by the learner to make sense of reality and resolve problematic situations. In electrokinetics, the seminal work of Closset (1983) demonstrated that the invisibility of microscopic conduction processes encourages the entrenchment of highly persistent spontaneous thought patterns, such as sequential reasoning (the idea that current is depleted as it travels through receivers) or the reservoir model. These representations resonate with the concept of the ‘epistemological obstacle’ theorised by Bachelard (1934/1986), according to which the scientific mind is always constituted in opposition to prior knowledge. Our hypothesis is that the expression and structuring of these obstacles are not gender-neutral, but are underpinned by distinct technical cultures and learning environments.

2.2. Educational equity and the learning profiles approach

To address the gender variable without falling into the trap of biological reductionism, the research draws on the conceptual framework of educational equity formalised by Driver et al. (1994). This approach makes a critical distinction between *equity of treatment* (providing the same tasks and materials uniformly to all pupils) and *equity of outcome* (ensuring an equivalent grasp of fundamental scientific concepts). Achieving equity of outcome requires recognising and understanding the socio-cognitive learning styles specific to girls and boys — in particular their respective attitudes towards the risk of making mistakes, towards tangible materials and towards conceptual abstraction — in order to adapt teaching interventions.

2.3. The dynamics of conceptual change

Finally, the assessment of changes in concept representations between the pre-test and post-test is based on the theory of conceptual change developed by Posner, Strike, Hewson and Gertzog (1982). According to this model, the transition from an erroneous alternative conception to valid scientific knowledge requires that the learner experiences cognitive dissatisfaction with their initial schemata, and that they are able to judge the new conception as intelligible, plausible and fruitful. If the initial performance gaps observed between girls and boys stem from different approaches to learning and levels of engagement rather than intrinsic cognitive abilities, a formal teaching programme should act as a catalyst for

rebalancing, by providing each group with the intellectual tools needed to overcome their specific obstacles.

3. Methodology

3.1. Research design

In order to meet the study’s objectives, a quasi-experimental research design of the pre-test/post-test type, involving a single group with a comparative breakdown by gender, was adopted. The protocol is structured sequentially as follows:

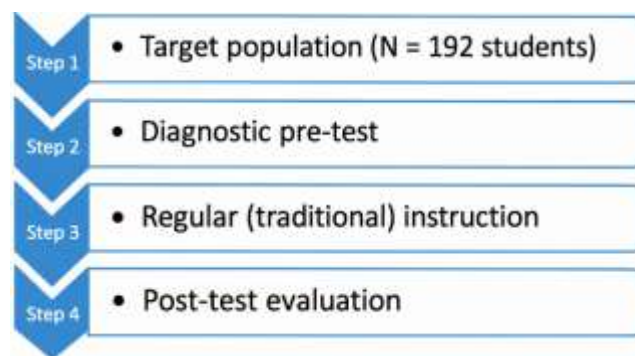


Figure 1. Flowchart of the methodological stages of the research.

3.2. Population and sampling

The study was conducted with an exhaustive sample of 192 pupils enrolled in the third year of the scientific stream during the 2025–2026 academic year in six schools in the city of Mbandaka. This sample comprised 111 girls (57.8 per cent) and 81 boys (42.2 per cent). The selection of schools covered all recognised education networks in the Democratic Republic of the Congo (Catholic, state, Protestant, Kimbanguist, Islamic and accredited private), thereby ensuring sociological representativeness of the urban environment of Mbandaka. Table 1 summarises the distribution of the sample.

Table 1: Breakdown of the study sample by school and by gender.

No.	School	Education system	Girls (n)	Boys (n)	Total enrolment (N)
01	Nsong'Alia nja Secondary School	State-funded Catholic school	22	8	30
02	EDAP/ISP-Mbandaka	Public (Training Centre)	16	25	41
03	Peace Institute	Protestant	14	13	27
04	Papa Diangenda Institute	Kimbanguist	12	20	32
05	The Glory of the Lord	Private, Approved	15	15	30
06	Nsang'Ean dotsi Secondary School	Catholic (Girls)	32	0	32
Total			111 (57.8 per cent)	81 (42.2 per cent)	192 (100 per cent)

3.3. Data collection tool and procedure

The assessment tool is a mixed-format questionnaire structured around 12 questions divided into six major topics in electrokinetics (electrical conduction in metals and solutions, circuit configuration, and the combination of resistors and generators), scored on a scale of 0 to 20 points. This test was administered at two key points in time:

- **Pre-test (O1):** Administered at the start of the 2025–2026 academic year, prior to any formal introduction to the chapters on electrokinetics.
- **Post-test (O2):** Administered following the lessons delivered by the permanent teachers, during the week of 4 to 9 May 2026.

Anonymity and the rigorous matching of individual answer scripts were ensured by the prior allocation of a personal code to each pupil.

3.4. Statistical processing and qualitative analysis

Quantitatively, the hypothesis of normality of the distributions was tested using the Kolmogorov-Smirnov and Shapiro-Wilk tests in SPSS. The results indicate that the hypothesis of normality is rejected for the girls' subgroup at both measurement points ($p < 0.05$) and for the boys' subgroup at the post-test ($p < 0.05$). Consequently, as the use of parametric tests was ruled out, the non-parametric **Mann-Whitney U** test was rigorously selected to compare the distributions of scores between the two independent groups (girls vs boys), at the conventional significance level $\alpha = 0.05$.

From a qualitative perspective, a thematic content analysis of the pupils' written responses was carried out. Errors and lines of reasoning were classified according to the typologies of epistemological obstacles (Bachelard, 1934/1986; Closset, 1983) in order to identify the reasoning patterns specific to each gender. Below are the graphs showing that the test results were not normally distributed:

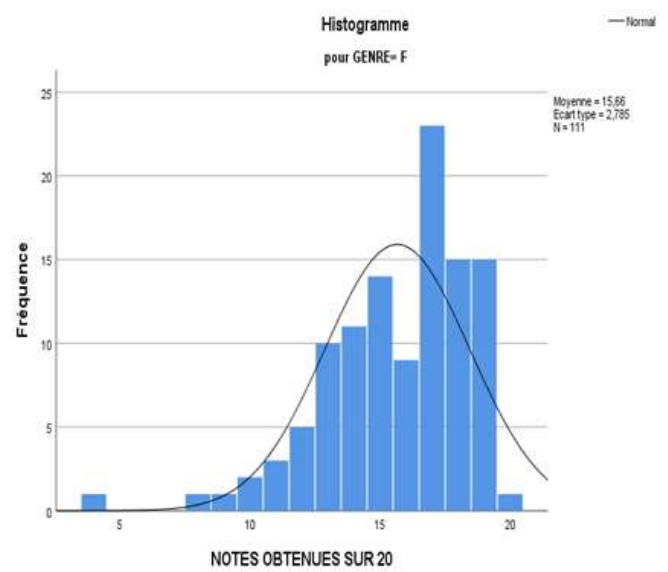
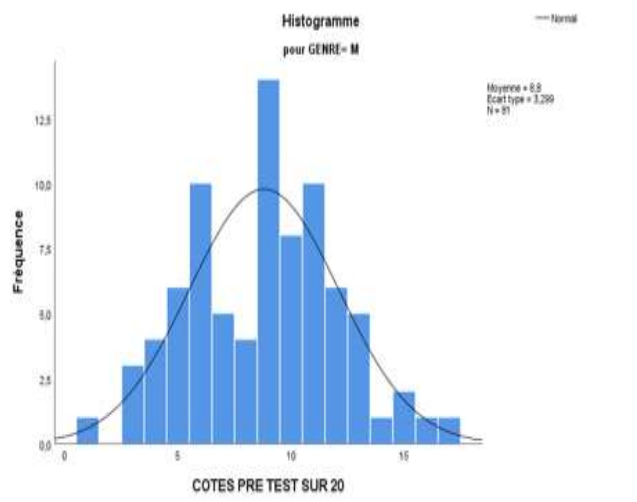


Figure 3. Graph showing the marks achieved by male pupils (left) and female pupils (right) in the post-test.

4. Results

4.1. Comparison of initial performance in the pre-test

At the start of the study, the overall mean score for girls in the pre-test was 9.57 out of 20 (standard deviation = 3.12), whilst that for boys was 9.02 out of 20 (standard deviation = 3.45). Application of the non-parametric Mann-Whitney U test (Table 2) shows that this difference in initial scores is statistically significant in favour of the girls ($U = 3592$; $Z = -2.391$; $p = 0.017$), with girls having a higher mean rank (110.64) than boys (85.35).

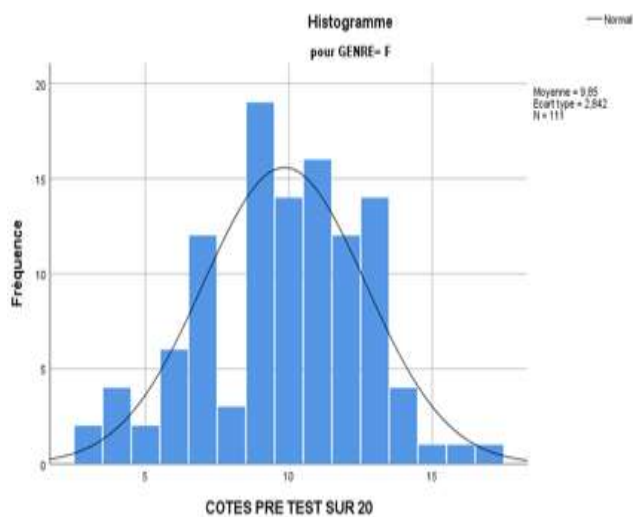


Figure 2. Graph showing the marks obtained by male pupils (left) and female pupils (right) in the pre-test.

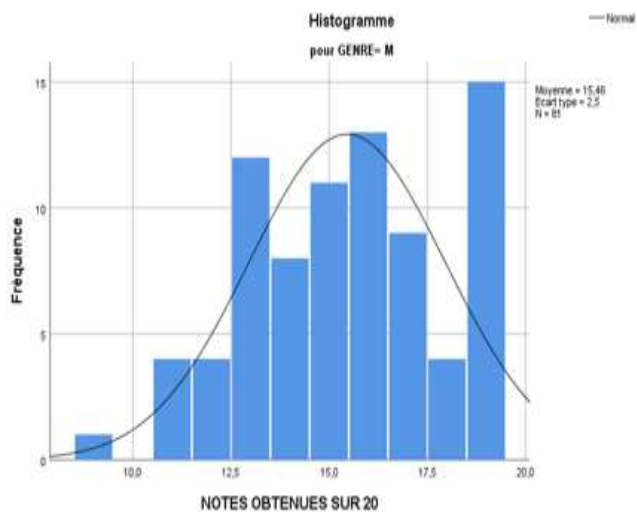


Table 2: Results of the Mann-Whitney U test comparing girls' and boys' performance on the pre-test and post-test.

Time of assessment	Group of pupils	Sample size (n)	Mean rank	Sum of ranks	U-statistic	Z-score	p-value	Statistical decision ($\alpha=0.05$)
Pre-test	Girls	111	110.64	12,281.0	3,592.0	-2.391	0.017	Significant difference (Girls > Boys)
	Boys	81	85.35	6,913.0				
Post-test	Girls	111	99.59	11,054.5	4,152.0	-0.910	0.363	No significant difference (Equivalent performance)
	Boys	81	92.26	7,473.5				

4.2. Qualitative profiles of reasoning and gender-related obstacles in the pre-test

Beyond the numerical gap in scores, the qualitative analysis of the answer sheets highlights contrasting cognitive approaches between the sexes.

A) Attitudes towards abstention and uncertainty

When confronted with the invisibility of electrical entities (particularly when identifying charge carriers in question Q1B), boys exhibited a significantly higher rate of non-response: 25 boys (30.9 per cent of the male cohort) provided no written response, compared with 15 girls (13.5 per cent of the female cohort). This silence reflects cognitive insecurity in the face of abstraction, characterised by a reluctance to articulate an uncertain hypothesis, whereas girls are more willing to engage with the writing task even at the risk of making a mistake.

B) Dichotomous semantic anchors

Analysis of the incorrect answers reveals the existence of two preferred types of anchoring:

- **A material and infrastructural anchor among girls:** girls preferentially draw on visible objects from their tangible environment. Thus, 22 girls explicitly identified the metal 'conductor' as the moving particle, anchoring their reasoning in the perceptible physical medium. No such instances were found among boys.

- **An energy-based and dynamic anchoring among boys:** conversely, 5 boys based their explanations on notions of driving force or 'energy' to characterise the moving particle, favouring a phenomenological approach based on effects.

C) Polarised difficulties relating to the sign of charges (Item Q2)

The distribution of errors in response to the question on the sign of charge carriers illustrates a gender-based polarisation of obstacles (Table 3):

- **The duality obstacle:** The simultaneous selection of positive and negative charges is overwhelmingly prevalent amongst girls (44.1 per cent, or 49 cases, compared with 9.9 per cent amongst boys). This pattern suggests an analogical mirroring of the apparent bipolar configuration of the generator terminals.
- **The 'positive' obstacle:** The attribution of exclusive movement to positive charge carriers is predominantly found among boys (44.4 per cent, or 36 boys, compared with 21.6 per cent of girls), reflecting a strict identification of the sign of the moving particle with the conventional direction of current.

Table 3: Distribution of responses to the question on the sign of charge carriers (Item Q2, pre-test) by gender.

No.	Response category	Girls (n=111)	% of girls	Boys (n=81)	% Boys
01	Negative (Expected scientific answer)	21	18.9%	12	14.8%
02	Positive (Conventional direction barrier)	24	21.6%	36	44.4%
03	Positive and negative (Obstacle of duality)	49	44.1%	8	9.9%
04	Neutral	7	6.3%	16	19.8%

05	No response / Abstention	10	9.1%	9	11.1%
Total		111	100 per cent	81	100 per cent

4.3. Comparison with the post-test and convergence of performance

At the end of the teaching sequence, a comparative analysis of the post-test marks reveals that the initial difference has completely disappeared: the Mann-Whitney U test indicates a non-significant result ($U = 4152$; $Z = -0.910$; $p = 0.363$). The average score for girls was 15.66 out of 20 (standard deviation = 2.41) and that for boys was 15.46 out of 20 (standard deviation = 2.88).

Table 4: Comparative trends in means and calculation of gross gains by gender.

Group of pupils	Pre-test average (out of 20)	Post-test average (out of 20)	Average gross gain (Δ)
Girls (n=111)	9.57	15.66	+6.09 points
Boys (n=81)	9.02	15.46	+6.44 points
Overall (N=192)	9.34	15.58	+6.24 points

As highlighted in Table 4, this convergence at the end of the programme results from a more pronounced upward trend in the male sub-sample (+6.44 points) compared with the female sub-sample (+6.09 points), indicating a process of catching up rather than a decline in girls' performance.

From a qualitative perspective, however, the structure of the post-test marks reveals nuances in the patterns of excellence: the girls form a homogeneous and compact group centred around marks of 17 and 18 out of 20 (23 girls with 17 out of 20 and 15 girls with 18 out of 20), whilst the boys' results show a more polarised distribution, characterised by a notable surge at the top mark of 19/20 (15 boys, or 18.5 per cent of the cohort). Furthermore, the rate of non-response among boys was completely eliminated in this second assessment.

5. Discussion

5.1. Nature of the initial differences: sociocognitive styles rather than aptitudes

The key finding of this study — the existence of a significant initial gap in favour of girls ($p = 0.017$) which disappears by the end of the course ($p = 0.363$) — contradicts the common misconception of an innate cognitive factor favouring one sex over the other in physics. The qualitative analysis confirms that girls' initial superiority stems from their ease with academic discourse and their willingness to engage with questions, even in situations of uncertainty. Conversely, the boys' initial reluctance to engage with abstract concepts, reflected in their high rate of abstention, indicates a fear of making mistakes within an unstable conceptual framework. These observations are consistent with the analyses by Naoual et al. (2018) on attitudes towards abstraction and build on the work of Cossette (1999).

5.2. Duality of anchors and epistemological obstacles

The identification of a material anchor among girls and a dynamic anchor among boys sheds light on the origins of their misconceptions. Girls rely on the tangible structures and visible components of the assembly, whilst boys focus on power and motor effects, in line with an action-oriented technical culture. In line with the framework proposed by Giordan and De Vecchi (1987), these approaches require the teacher to employ a variety of pedagogical entry points to address epistemological barriers.

5.3. Teaching as a mechanism for regulation and equity

The levelling of performance observed in the post-test provides a key lesson for educational equity in a sub-Saharan context. It demonstrates that formal education, despite the material constraints facing schools in Mbandaka, plays an effective role in reducing initial disparities. Boys, who were initially disadvantaged by their reluctance to engage with abstract concepts, drew on their technical interests and caught up with the girls' level of achievement once the conceptual barriers had been removed. This finding qualifies the concerns raised in the ADEA and UNESCO reports (2018): under consistent teaching conditions, gender gaps in physics stem from learning styles that can be overcome through pedagogical intervention.

6. Limitations of the study

Several methodological limitations constrain the scope of these conclusions:

Exogenous socio-cultural variables (families' socio-economic status, technological equipment in the home, parents' educational attainment) were not rigorously controlled for and may have contributed to the initial disparities.

The variability in teachers' individual teaching practices across the six schools in the city constitutes an unmeasured source of variation.

As the assessment was based on a questionnaire focusing on basic electrodynamics, the conclusion regarding the levelling of learning outcomes cannot be generalised without reservation to the entire physics curriculum.

Conclusion

This research has provided an initial rigorous comparative exploration of the influence of gender on alternative conceptions of electrokinetics in the Democratic Republic of the Congo. It highlights an initial performance profile favouring girls, rooted in differentiated socio-cognitive styles and modes of anchoring (material for girls, dynamic for boys) rather than in a difference in aptitude. It also establishes that the teaching provided serves to homogenise learning outcomes, with the initial gap narrowing by the post-test due to the progress made by the boys' group.

This research therefore constitutes the first empirical study conducted in the Democratic Republic of the Congo on the dynamics of alternative conceptions in electrokinetics, with a focus on the gender variable. The combination of quantitative and qualitative analyses carried out provides direct and substantiated answers to the three research questions that guided this study:

In the pre-test, prior to any formal teaching intervention, there is indeed a statistically significant difference in performance between the sexes, favouring girls ($U = 3592$; $Z = 2.391$; $p = 0.017$). Girls achieved a higher mean rank (110.64) than boys (85.35), an average score of 9.57 out of 20 compared with 9.02 out of 20, and a significantly lower rate of non-response (13.5 per cent compared with 30.9 per cent).

After the electrokinetics teaching sessions, the initial gender gap in performance disappeared entirely in the post-test ($U = 4,152$; $Z = -0.910$; $p = 0.363$). Mainstream education thus plays a genuine **role in levelling out and homogenising results**, with boys making significant progress, achieving a higher average gross gain (+6.44 points) than girls (+6.09 points), to reach almost identical averages of 15.46/20 for boys and 15.66/20 for girls.

Qualitative analysis reveals that the differences observed do not stem from asymmetrical cognitive abilities, but **from distinct socio-cognitive anchoring styles and epistemic stances**:

- **Among girls:** Thinking is primarily anchored in *tangible material and infrastructural* structures (the physical conductor viewed as a moving particle) and in a bipolar model (*the obstacle of duality* modelled on the generator's + and – terminals). Girls demonstrate greater mastery of academic discourse and are more willing to accept the risk of making errors in writing.
- **Among boys:** Thinking favours an *energetic and dynamic* framework (energy or force viewed as a particle) and is oriented towards conventional meaning (*the 'positive' as an obstacle*). Boys display initial cognitive insecurity characterised by a high rate of abstention when faced with abstraction, which they subsequently overcome to achieve a breakthrough in the post-test, scoring very high marks (18.5 per cent achieved 19 out of 20).

These findings open up three avenues for action and research to improve the teaching of physical sciences in the DRC:

Pedagogical: Implement a differentiated teaching approach combining dynamic analogical approaches (to overcome boys' reluctance towards abstraction) and formal decontextualisation activities (to help girls move beyond the framework of the immediate physical object).

Institutional: Integrate the framework for analysing gender-based barriers into initial teacher training at Higher Pedagogical Institutes (ISPs).

Technological: Assess the contribution of low-cost digital simulations and virtual laboratories (such as *Crocodile Physics*) to breaking down residual conceptual barriers that traditional teaching fails to eliminate.

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