Print ISSN 2710-0952 Electronic ISSN2790-1254

توظيف الذكاء الاصطناعي المؤسس معرفيًا في تعليم العلوم: دراسة جدوى تكنو-تربوية لتطبيق NotebookLM في سياق تدريس الفيزياء ضمن المنهج العراقي

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المستخلص

تتمثل الأهداف الرئيسة لهذه الدراسة البحثية في تقييم الموثوقية التقنية والمواءمة التربوية لأداة التوليد المدعم بالاسترجاع (RAG)، المعروفة باسم NotebookLM، في معالجة منهج الفيزياء للمرحلة المتوسطة في العراق. اعتمدت الدراسة على منهجية تحليل المحتوى النوعي واسترشدت بنموذج SOAR، مستخدمةً الكتب المدرسية الرسمية كمتن مغلق لتقييم قدرة الأداة على إنتاج محتوى تعليمي مبتكر ومؤصل. تُظهر النتائج أن أداة NotebookLM يمكنها تحقيق دقة سياقية عالية في تفكيك مفاهيم الفيزياء المتقدمة وتحويلها إلى دعائم إجرائية تعمل بمثابة "مختبر افتراضي قائم على النصوص". تمتلك هذه الأداة قدرات قابلة للأتمتة في بعض مهام هندسة المحتوى، بيد أن النتائج تسلط الضوء على ضرورة وجود "العنصر البشري في منظومة التحقق" للحفاظ على النزاهة العلمية. وتضع هذه النتائج اللبنات الأساسية لتوظيف الذكاء الاصطناعي المؤصل في البيئات التعليمية محدودة الموارد.

الكلمات المفتاحية: الذكاء الاصطناعي المؤصل، NotebookLM، طرائق تدريس الفيزياء، نموذج SOAR، الدعم الرقمي، المنهج العراقي.

Leveraging Grounded AI in Science Education: A Techno-Pedagogical Feasibility Study of NotebookLM in the Context of Physics Instruction within the Iraqi Curriculum

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Abstract:
The primary aims of this research study is the technical reliability and pedagogical alignment of a Retrieval-Augmented Generation (RAG) tool, NotebookLM, in the processing of Iraqi middle school physics curriculum. The study utilized qualitative content analysis and was informed by the SOAR Model, using official textbooks as a closed-corpus to evaluate the tool's ability to produce novel and grounded educational content. The results show that NotebookLM can achieve high contextual accuracy in breaking down advanced physics concepts as procedural scaffolds to operate as a 'Virtual Text-Based Laboratory'. This tool has automatable potential for some of the content engineering labor, but the findings highlight the need for 'human-in-the-loop' validation to maintain scientific integrity. These findings lay the groundwork to employ grounded AI in resource-limited educational domains.

Keywords: Grounded AI, NotebookLM, Physics Pedagogy, SOAR Model Digital Scaffolding, Iraqi Curriculum.

1. Introduction

The increasing pace of Artificial Intelligence (AI) is ushering in an unprecedented era of digital transformation in the global educational landscape. The wave of technology has gone beyond the support tool it used to be and has become one of the the core pillars which is helping design new educational frameworks and methodologies. Educational research discusses the use of such tools not only as a way to digitize the scientific curriculum but as a way of building cognitive structure for often abstract concepts which have the potential to usher in radical change in lessons and learning results for students (Torralba, 2025)

With its abstractness requiring development of relatively sophisticated analytic capabilities to connect real world phenomena to mathematical modeling, physics has continued to be among the most cognitively demanding subjects in the middle of secondary education. These challenges are amplified in the Iraqi context by an intersection of structural and operational determinants. These are (1) Lack of laboratory, (2) there is still a digital gap and (3) it is very necessary to boost the skills of teaching staff in order to keep up with knowledge requirements for the 21st century (Darwish, 2024).

In the face of such challenges, NotebookLM is an emerging model of a "Grounded AI" learning platform from Google. What does this mean tangibly from a scientific perspective? In short; it has much greater processing power to consume what would multiple knowledge corpora, and spit back correct educational content. Using this sophisticated technical tool, educators can now create adaptive learning environments that ultimately help bridge the STEM student achievement gap by streamlining these complex physical concepts (Reyna, 2025).

This study aims to offer a structured overview of AI tool roles in the educational ecosystem, especially focusing on how effective NotebookLM can be to enhance physics learning at a middle-school level in Iraq. Through an examination of the accumulated empirical evidence and results of comparative studies, this body of research seeks to produce a blueprint and set of practical proposals for educational practitioners and policymakers alike to make use of these technologies and reach quality instruction and epistemic equity.

2. Theoretical Framework and Literature Review

This work is grounded in a framework that synthesizes the latest developments in Generative Artificial Intelligence (GenAI) research with classical and contemporary education theories, offering an integrated perspective into the use of emerging technology in physics education.

2.1 Generative AI and Grounded Learning

Generative AI is a revolutionary change in Natural Language Processing (NLP), but this hallucinating pattern (generating factually incorrect information) has been one of the most prominent obstacles to its solely academic usage. Within this framework, the first principle is "Grounded Learning," which serves as the basis for tools like NotebookLM (Tufino, 2025).

"Grounding," in the AI context, is reminding the model of where any particular output is anchored into factual knowledge (for example, in official middle school physics textbooks) rather than one huge open-ended general purpose database of everything. A sound scientific justification for this is to ensure "Contextual Accuracy." Situating responses, summaries, and generated queries into the heart of the core curriculum minimizes the possibility of scientific error, further increasing the dependability of digital content to teachers and students (Reyna, 2025).

2.2 Modern Learning Theories: Adaptive Learning and Scaffolding

The integration of NotebookLM into physics education is closely related to two main approaches:

- Adaptive Learning: AI tools help to customize the educational course content based on the differences in students. NotebookLM generates explanations with varying degrees of complexity based on the analysis of physics curricula, which helps create a flexible learning environment that adapts to the comprehension pace of each student. It serves to move from "Standardized Instruction" to "Personalized Instruction" and helps to address multiple complex physical concepts at the individual level (Reyna, 2025).

- Scaffolding: Vygotsky's ZPD refers to how learners learn better when they are assisted (Vygotsky & Cole, 1978), and this is how NotebookLM acts as a digital scaffold. It does not just give final answers but is incremental, breaking down abstract concepts (that is, static electricity, laws of motion) into smaller cognitive units, simpler to understand, make use of, re-use. This is supported with gradual fading as the student’s conceptual understanding develops (Torralba, 2025).

2.3 Literature Review: Global Outcomes of ChatGPT and Google Tools in Education.

There have been several recent studies in global educational literature exploring the efficacy of AI tools in the classroom:

1. ChatGPT Studies: The recent incorporation of Large Language Models (LLMs) into science education has accelerated a paradigm change in the learning environment (e.g., (Lo, 2023); (Bitzenbauer, 2023)). One of the major ways these tools have greatly enhanced student motivation for self-directed learning is their ability to offer immediate, individualized feedback (Zhai, 2023) in real-time addressing conceptual obstructions.

2. Research on Google AI Toolbox: Following the creation of the NotebookLM platform and Intelligent Tutoring System(ITS), studies (Reyna, 2025) (Tufino, 2025) are now starting to highlight features in these tools that 'exceed' attributed accuracy compared to open-source models. (Reyna, 2025) states that the Retrieval-Augmented Generation (RAG) architecture guarantees all outputs are heavily anchored to and

associated with some hierarchical authority (p. 7). In addition, international news is that systems that operate on a “Closed Corpus” do an excellent job of improving problem-solving skills and the scientific method with middle and high school students through responses that are trustworthy, traceable, and evidence-based, (Tufino, 2025), p. 533).

3. Research Gap: Not only these global findings but there is a very big research gap with studies that addressed local context of developing nation, especially Iraq. Related to this, (Nasser & Mohammadi, 2026) argue that 'despite continued efforts, a significant gap still exists as this study indicates that no previous studies designed and validated a comprehensive professional competency model in the cultural and methodological context of Iraq' (p. 168). This highlights the importance of the current study in assessing whether these technologies are appropriate for the national curriculum, and whether they can be delivered locally when infrastructure is problematic.

3. Methodology

This study is of a descriptive-analytical nature in which we analyzed some of the technical feasibility and operational capacities of NotebookLM in an educational context The methodology is articulated to offer a comprehensive proof-of-concept assessment, linking formal curricular content from Iraq with the outputs generated by AI while ensuring that pedagogical alignment for the tool is tested.

3.1 Research Design: A Technical Feasibility Study

This research is designed as an exploratory qualitative study, distinct from experimental studies that assess direct classroom impact. It is concerned with applying a validated grounding while exploring retrieval-augmented generation (RAG) in service of scalable translation of official physics textbooks into pedagogical scaffolds. Instructional design allows for a systematic examination of the tool's function as a "digital instructional assistant" through more functional uses at scale, empirically.

3.2 Study Corpus

The corpus of the research includes the official physics books which are approved by the Iraqi Ministry of Education which are taught to middle school students. Three primary textbooks were selected:

- Physics for the First Intermediate Grade.
- Physics for the Second Intermediate Grade.
- Physics for the Third Intermediate Grade.

Print ISSN 2710-0952 Electronic ISSN2790-1254

These textbooks were then digitized (PDF) and uploaded to the NotebookLM platform as the only Grounded Source for responses. It bellat that all outputs remain firmly within the scientific and linguistic fields of the national curriculum.

3.3 Analytical Framework: The SOAR Model

As an evaluative lens, this study utilizes a qualitative framework known as the SOAR framework (Stavros et al., 2003). Despite being traditionally used to frame strategic planning, the SOAR model is modified here to outline the emerging technological capabilities of Grounded AI in developmental educational environments, closely aligned with trends applying this model to identify e-learning modules and AI risks ((Prabu Kumar et al., 2023); (Manaf et al.)) :

- **Strengths:** Assessing the tool for contextual summarization and accurate information extraction from the textbooks.
- **Opportunities:** Further research into the use of the tool to alleviate shortages of physical laboratory resources through process simulations.
- **Aspirations:** "Cognitive Democracy" identifying the promise of "Cognitive Democracy" and the dissemination of high quality explanations to under-served by geography, resources and privilege
- **Results:** Evaluating the technical standard of the products delivered, as to whether they fit with ministerial examination formats, and their capacity to lighten the planning load on teachers.

3.4 Experimental and Validation Procedures

The study was carried out through a multifaceted procedural workflow to ensure scientific robustness:

1. **Setup Phase:** Build a separate RAG instance by uploading the textbooks into NotebookLM.
2. **Querying Phase (Prompt Engineering):** Use structured, pedagogically-engineered prompts to examine specific learning objectives (See Table 1).
3. **Line-by-Line Validation Phase:** The most crucial phase that consists of a line-by-line comparison between the output generated by AI and the original content in the textbook. It was carried out as a wrapping human-in-the-loop step to ensure scientific integrity, discover possible "Knowledge Drift", and prevent factual hallucinations.

Table 1: Strategic Design and Objectives of the Core Prompts

Prompt ID	Targeted Pedagogical Objective	Expected Output Category

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Prompt A	Achieving Cognitive Democracy via Differentiated Instruction.	Multi-level explanations (Simplified/Standard/Enriched).
Prompt B	Assessment Engineering & Ministerial Pattern Simulation.	Exam-ready questions and step-by-step solutions.
Prompt C	Solving Resource Scarcity via Home Laboratory Scenarios.	DIY experimental protocols using local materials.

4. Results

The use of NotebookLM on the selected research corpus (Iraqi middle school physics textbooks) produced considerable analytical results. The results synthesized according to the SOAR framework are as follows:

4.1 Outcome Analysis via the SOAR Model

- **Strengths:** The tool had a high capability for "contextual understanding" of the Iraqi curriculum, generating summaries that were closely aligned pedagogically and scientifically with the original content. A human validation also confirmed that it stayed so narrowly in the textbooks they provided. In addition, the procedural speed of the tool was illustrated by the processing of entire chapters in record time (see Fig. 1), leading to an overall increase in teacher time management efficiency.

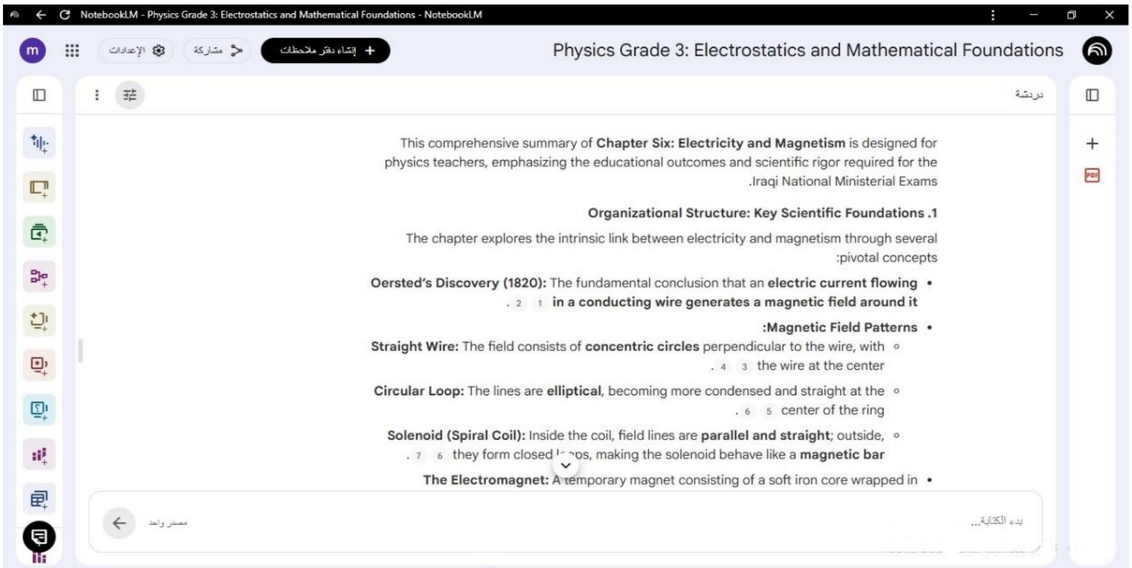

Figure (1) Configuration of NotebookLM, with the displayed structured outputs about chapter six Electricity and magnetism according to (Iraq syllabus).

- **Opportunities:** The results indicated the prospect of the instrument functioning as a "Virtual Text-Based Laboratory". This approach had successfully distilled abstract physical experiments into a simplified sequence of steps, either mentally simulated by the student or performed in the form of basic household items. This provides a technological way out for the restraint in laboratory instruments (See Box-1).

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NO.21A2   Jul.2026   Iraqi Journal of Humanitarian, Social and Scientific Research
Print ISSN 2710-0952   Electronic ISSN2790-1254

Box 1: Home-Laboratory Scenario (The Electroscope)

- ***Alternative Materials:*** *Glass jar, copper wire, and aluminum foil.*
- ***Execution Scenario:***
    - ***The Container:*** *Use a clear glass jar; glass acts as an insulator and allows students to observe the leaves clearly.*
    - ***The Conductor:*** *Use a thick copper wire to act as the internal rod and disc. Copper is an excellent conductor because its valence electrons are weakly connected to the nucleus.*
    - ***The Leaves:*** *Use two thin, identical strips of aluminum foil. Their light weight allows them to diverge easily under even small repulsive forces.*
    - ***The Stopper:*** *Use a foam plug or cork to hold the wire in place at the jar's mouth, ensuring the wire does not touch the glass directly, which maintains insulation.*
- ***Conceptual Challenge:*** *"What happens if the copper wire is replaced with a cotton thread?" (Reinforcing the concept of Conductors vs. Insulators).*

- **Aspirations:** Identify a few realistic aspirations of how you envision achieving "Epistemic Democracy". The tool is capable of delivering structured graphic diagrams along with quality explanations. The tool offered detailed levels of explanation of the principles of Cognitive Democracy, such as the specific application of (Levers) as shown in figure 2.

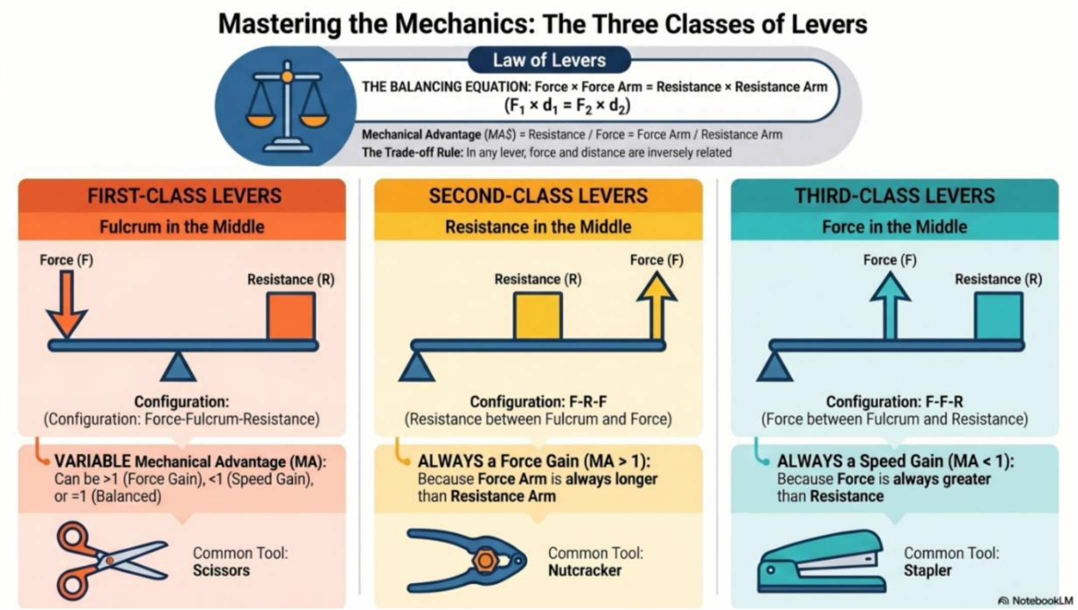

Figure (2): A detailed graphic diagram illustrating the three classes of levers and their mechanical advantages, autonomously generated by NotebookLM.

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Results: The outputs produced by NotebookLM highlight that a generative tool can remain supportive of the development of conceptual understanding, by turning high-level theoretical knowledge into procedural representations, as exemplified using the DIY Electroscope scenario. It offers students instant, customized feedback helping them independently form learning pathways while narrowing the divide between theory and practice.

4.2 Evaluation of Assessment Quality and Educational Flashcards

Using 'Assessment Engineering,' the tool generates evaluation queries that analyze the structural patterns and cognitive levels of Iraqi ministerial exams remarkably well. This ability is showcased in Table 2, which is a sample output of the tool. He goes on to show that NotebookLM fuses Sophisticated Physics problems with scaffolding mnemonic supports (Flashcards and ministerial style multiple-choice answer choices) to promote active recall and fidelity in the solution of the physics problem.

Table 2: Integrated Assessment and Review Model (The Electric Transformer)

Assessment Component	Model Output Snippet	Pedagogical Value
Ministerial MCQ	"Transformer connected to a 12V DC battery..."	Tests fundamental induction principles (The "Trap").
Numerical Problem	Efficiency calculation via the Six-Step System.	Ensures procedural accuracy for national exams.
Flashcards	Front: Transformer Efficiency Back: $\eta = \frac{p_2}{p_1} \times 100\ \%$	Facilitates active recall and structured review.

5. Discussion

Results point to NotebookLM not being a simple text generator, but an "intelligent pedagogical mediator". The following thematic lenses will help analyze the findings, with support from practical models derived from the study.

5.1 Effectiveness of Knowledge Grounding on Content Preservation

The high agreement rate (of how well the outputs of the tool align with the Iraqi curriculum) is largely due to the nature of the Grounded AI itself. So NotebookLM use official textbooks to anchor its knowledge base which is different from open-ended language models. As (Reyna, 2025) references, at the heart of the platform's advantage is the architecture which "grounds outputs strictly in user uploaded source documents" a structure that "greatly reduces hallucination" and allows for the "reliability and transparency of AI responses" (p.3). This guarantees Contextual Accuracy such an environment is scientifically safe and decreases the cognitive load of teachers in manual verification. The structured interface of the tool Figure 1 confirms that the tool respects the state-approved

Print ISSN 2710-0952 Electronic ISSN2790-1254

hierarchy of the Iraqi curriculum, such that the generated content respects the pedagogical boundaries of the state-approved materials.

5.2 Bridging Logistic Gaps via "Text-Based Laboratories"

Fundamentally, the tool's functionality for converting abstract physics experiments into "procedural scenarios" is a long-term remedy to the perennial shortage of laboratory instruments. An example of this is the DIY scenario for the Electroscope (Box 1), which enables Inquiry-Based Learning in spite of a "missing physical lab", and although other, "mental simulation and substitute at home" have to occur due to limitation of recourse. This result demonstrates that "Educational Equity" is best served when the quality of scientific inquiry in the classroom is not dictated by the logistical barriers that had made curricular access inequitable and that such barriers are now addressed through a simple schedule of barriers.

5.3 Teacher Empowerment: From Instructor to "Content Engineer"

Prompt Engineering is a game-changing new skill revealed through the study which is all about teaching competencies. This professional empowerment enables educators to develop customized resources faster than ever before. Its mastery is shown in the multi-layered explanation for (Levers) found in Figure 2, which embodies Digital Instructional Scaffolding. This change helps free teachers from the planning drones, putting their energy into helping students learn better in an individualized manner.

5.4 Towards Comprehensive "Cognitive Democracy"

In order to actualize the principle of Cognitive Democracy, the tool offered levels of explanation and assessment (grand and local), as seen in Table 2 for the Integrated Model for (The Electric Transformer. Interactive learning tools like NotebookLM can help close the urban/rural divide in unity by showing students high-quality explanations and enrichment questions (HOTS) that simulate ministerial patterns, all available for any student anywhere on the planet. The "Cognitive Democracy" delivered in this study is ensuring that, for example, a student in a remote village is as intellectually entered as their peers studying in prestigious schools in the city.

5.5 Limitations and Ethical Considerations

5.1.1 Study Limitations

This paper recognizes some limitations to NotebookLM, despite its impressive pedagogical potential. To commence, the tool will work best for text-based and structured data; it continues to struggle to read complicated physics diagrams or hand-drawn scientific designs in the curriculum. Second, the success of this AI-based path to productivity is dependent on stable digital infrastructure such as internet connection, which continues to be a logistical hurdle to accessing insight in some remote or underserved areas of Iraq. Third, this research also is a kind of exploratory study, and the results are based on qualitative content analysis and were found to be significant from a pedagogical and research perspective, thus, for future, large-scale empirical testing among students is required to generalize the effect on learning outcomes.

5.1.2 Ethical Considerations

Artificial Intelligence must be equipped with a strong ethical framework when it comes to education. This study highlight that NotebookLM is intended to be an "Educational

Partner", not a replacement for the human instructor (Holmes & Miao, 2023). (Stavros et al., 2003) warn students that if they use the tool (which provides direct answers) instead of thinking through the underlying problem-solving process they run the risk of 'Cognitive Dependency'. In light of this therefore, a moral imperative exists for educators to oversee interactions with AI so that it is function as a scaffolding mechanism (Vygotsky & Cole, 1978) that facilitates critical thinking and academic integrity as opposed to passivity or plagiarism.

6. Recommendations & Conclusion

6.1 Recommendations

Drawing on the effectiveness of NotebookLM in the Iraqi educational context, the study recommended the following:

1. **At Instructional Level:** Steer the teacher identity as a Digital Facilitator and have NotebookLM as a creative partner to craft tailored learning aids (smart summaries, assessments, flashcards) with the teacher as a critical reviewer of scientific and contextual truth.
2. **At the Institutional Level:** Urge educational authorities to create what we call "Grounded Digital Corpora" consisting of official curricula and supporting resources in AI-compatible formats. This will create an intelligent learning atmosphere that makes up for the shortage of another standard laboratory equipment.
3. **At the Professional Development Level:** Integrate "Prompt Engineering" techniques into teacher prep so teachers can leverage the pedagogical affordances of generative tools, such as clarifying physics concepts and assessments
4. **At the Educational Policy Level:** If we are to bridge the urban-rural divide, then we must give the missing bricks (the infrastructure) that surround AI so that it can play a role in closing the gap between classrooms in major urban centres and their counterparts in the rural communities.
5. **Future Work:** This study is exploratory in nature and it would make future research to not just validate the technique but also test it under on the ground conditions in a class room. More specifically, longitudinal studies are called for to quantitatively evaluate the degree to which NotebookLM-generated scaffolds impact upon student achievement scores and teacher cognitive load in the context of different Iraqi governorates.

6.2 Conclusion

NotebookLM is a promising technological pillar ready to lead the qualitative leap towards physics education in Iraq. As demonstrated via the SOAR framework (e.g., Table 2) and by the practical examples within this study (e.g., Box 1), it was shown that beyond simple automation, there exists a tool. It provides "Adaptive Learning", is a good way to offer "Digital Instructional Scaffolding" and Explains Concepts, Perfume Higher-Order Thinking Skills (HOTS) in students.

To conclude, leveraging AI in the Iraqi educational context is not a technological luxury anymore, but rather a strategic necessity to fill in cognitive and logistical gaps. In any event, however, the teacher is the final word for ethical and scientific guidance. The real power of using NotebookLM is, therefore, in the balance between what machines can do most effectively and pedagogical wisdom preparing a generation to work with 21st-century science and technology.

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