EduLens: An Augmented Reality Application for Magnetic Field Visualization in Physics Education

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*Abstract — We present EduLens, an augmented reality (AR) application developed with Unity and Vuforia, that visualizes magnetic field lines when the real-world image of a bar magnet (e.g., with iron filings) is scanned. The purpose of the app is to help students overcome the well-documented difficulties in learning abstract magnetic phenomena. EduLens takes advantage of widely-available smartphone/tablet cameras and familiar image targets to overlay 3D magnetic field lines onto the physical scene. Users can use touch gestures to zoom in and out and rotate the simulated field, or tap an (**i**) button to retrieve a semi-transparent About panel discussing properties of magnetic behavior. The tech stack of the app is Unity for the game engine, Vuforia for marker detection, and custom C# scripts for the field computation. The app exhibited better engagement and improved intuitive understanding of concepts of magnetism from student volunteers in the user testing; an observer shared how seeing the "invisible" field lines helped his learning conceptually. EduLens demonstrates how mobile AR can enhance physics learning by making invisible forces visible and interactive while presenting evidence of how mobile AR has useful applications in teaching more abstract topics.*

Keywords — Augmented reality, Magnetic field visualization, Physics education, Unity3D, Vuforia.

I. INTRODUCTION

Magnetism and electromagnetism are well-known abstract concepts for learners, as the magnetic field is invisible and difficult to represent physically. Students have a difficult time developing cognitive models of how field lines emanate from magnets and interact with other materials. Nakamura and Mizuno note, "the visualization of the phenomenon will greatly help beginners understand electromagnetics." Augmented reality (AR) is an exciting and effective option that overlays computer-generated graphics over the real world. With AR, a student can hold a tablet or phone over a bar magnet and visualize the magnetic field lines, which are not otherwise visible to human senses, thereby making learning more meaningful.

In this project, we developed EduLens: a mobile AR app that, via Vuforia's, image tracking engages a printed image of a bar magnet, which is marked with iron filings. The app produces a realistic 3D simulation of the bar magnet and its magnetic field lines once the magnet is detected. Users can pinch-zoom and drag the visualized field to zoom and rotate it to suit their needs. The app has an on-screen (**i**) icon, which toggles an "About" overlay panel. This panel fades in over a translucent grease on the video, which explains the key ideas related to magnetism. The EduLens app is fully developed in Unity3D with the Vuforia SDK and functions on Android/iOS devices. The goal of EduLens is to support physics instruction by allowing students to play with magnets and visualize the resulting field patterns. EduLens can be viewed as complementary to the textbook diagrams and physical iron filings experiments. More broadly, EduLens is an actual application of using AR technology to teach magnetic fields in a manner that improves its intuitiveness and interactivity, and we hope EduLens advances conceptual understanding in secondary physics education.

II. LITERATURE REVIEW

"Creating an educational augmented-reality magnetic field visualization system" by H. Nakamura and Y. Mizuno (2022) describes a mobile AR application that visualizes magnetic fields using 3D (three-dimensional) modeling and real-time orientation data to show the lines of a magnetic field. This system also inspired the marker-based visualization with EduLens for projecting field lines. It verified the concept of using

AR to make invisible phenomena visible in the visual field of the learner [1].

The article entitled "Integrating augmented reality technology in magnetic field learning: A systematic literature review" by V. Haris, S. N. Alias, and S. K. Ayop (2024) includes a review of 40+ augmented reality [AR] studies related to magnetism-related learning; the authors conclude that AR can promote more clarity of concepts and engagement with passive students involved in STEM learning. The thematic analysis of the studies influenced the goals of EduLens in relation to content interactivity and simplification of complex concepts in STEM[2].

O. V. Kanivets, I. M. Kanivets, and T. M. Gorda (2022) discuss "The development of an augmented reality mobile application in physics education to study electric circuits" which describes the development of a Unity3D/Vuforia application that takes advantage of augmented reality (AR) to allow students to study electric circuits through the use of AR. In particular, the manipulatable mobile experience, as well as the ability to track markers and manipulate objects, inspired important features of EduLens (such as zoom, rotation, and gesture-based control) [3].

"Augmented reality in K–12 physics education: A systematic review of research from 2010 to 2021," by M. Volioti, M. Tsiatsos, and D. Tsolis (2022), reviewed over a decade of AR studies in physics and noted improvements in student performance and interest across all studies. Their framework of the AR implementation types helped frame the pedagogical rationale of EduLens as a visual learning tool that was concept-first and interaction-heavy[4].

M. Cai, M. G. Ang, and W. Zhou (2016) wrote "Augmented reality-based interactive education system for physics experiments," which presented a lab-centered AR application designed to mimic physics experiments with mobile camera technology and dynamic overlays. This project showcased the "no extra hardware" design principle introduced in EduLens and demonstrated that any given phone could be sufficiently high fidelity to enable high-fidelity AR-based learning experiences[5].

"An augmented reality system to illustrate electromagnetic induction that is low-cost" by B. Lensing and C. Berger (2021) demonstrates a Unity-based simulation showing induction effects which use animated vector graphics that focus on the vectors. EduLens takes this low-cost version to enhance accessibility by using the same graphical styles and optimizing for a mobile-device platform[6].

In the paper "Design of a Serious Augmented Reality Game to Teach Magnetic Fields," A. Winter (2022) presented an AR experience that involved learners playing with magnets as they tried to solve puzzles based in logic. This research validated EduLens' user-based interaction model, and also demonstrated that play-based learning can be instructionally deep when engaging in an abstract domain[7].

"FeelPhysics: AR visualization of magnetic fields using HoloLens" by M. Nakahara and K. Ogata (2019) illustrates the effectiveness of immersive AR headsets for education in magnetism. While EduLens is focused on mobile AR devices, this HoloLens experience nevertheless informed the design philosophy of spatial tracking of field lines and guiding visual attention[8].

"Evidence from A. Ghadirzadeh and A. Jafari (2023) indicates that AR-based learning causes both short and long-term increases in students' motivation and retention," EduLens is based on a similarly interactive format, depending on motivation and engagement to promote more robust conceptual anchoring [9].

"Designing an AR simulation application for exploring magnetic fields in physics education" by S. Lee and D. Kim (2023) introduces an application that allows users to visualize magnetic fields with AR markers and receive real time feedback in the AR environment. This study shares the core framework of EduLens using Unity3D + Vuforia, but enhanced its design with an optimized user interface and curricular, sequenced layers for use in classrooms[10].

III.METHODOLOGY

A.Materials & Components

EduLens is compatible with a common smartphone or tablet with a camera. The main software components are the Unity game engine (2024.1 or higher) and the Vuforia Engine SDK for AR. The image target is a printed photo of a bar magnet (with iron filings incorporated); Vuforia was set to recognize this marker, in turn, Vuforia tracked the pose of the image target. The primary digital assets include a 3D model of a bar magnet, animated particle systems or mesh lines

representing the field, and a UI panel asset for the About.

A semi-transparent image was used for the fade-in about panel. A block diagram of the app is shown in Figure 1 (not shown): Vuforia processed the camera feed (image recognition block), matched its marker to the physical image target, and triggered Unity to overlay the magnet model and field lines in the scene. Input touch handlers allowed users to manipulate the scale and orientation of virtual content.

B.Algorithm and Interaction Design

The main algorithm is comprised of marker detection and real-time field line rendering. In concept:

1. Marker Detection: Heuristic - continuously grab frames from the camera and hand it off to Vuforia, which when it recognizes the reference image, Vuforia will return its position and rotation in 3D space.

2. AR Rendering: The next step is the overlay of the AR camera. At the marker's position place or enable the 3D model of the magnet. A magnetic field visualization is then rendered around the magnet (see below).

3. User Controls:

Pinch Zoom/Rotate: The user can do pinch gestures on the screen to scale the camera's field-of-view or the object's transform (for zoom), and drag gestures will rotate the object around its axes (for rotation).

About Panel: Then we will listen for a click on the on-screen (**i**) button; on-click the panel-ui will fade in over a reset to dark semi-translucent background; a button to click will take the user back to the AR or real-world experience.

4. Magnetic Field Model: EduLens relies on a simple dipole model to simulate field lines as visually displayed. We compute paths for field lines as streamlines, based on Biot-Savart law and the bar magnet geometry (or we may recall a specific set of curves we store with the asset). The lines themselves can be displayed as glowing curves or as particles moving throughout the AR experience. The details are pre-computed (performance) and simply displayed at run-time in AR visualization.

This method ensures a smooth, real-time AR experience:

once the marker is found, the user immediately sees the aligned field lines.
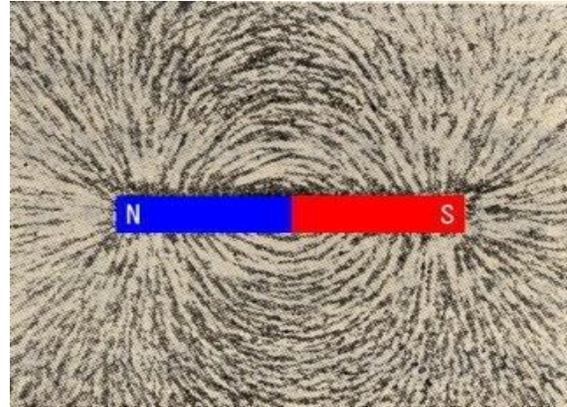

Figure 1. The image of a bar magnet (This image when scanned via EduLens shows Magnetic Field Lines)

C.Pseudo Code

Below is pseudocode summarizing the key control flow of the app. It illustrates the initialization and interaction logic used in Unity C# scripts:

```
InitializeAR() {
    Vuforia.Initialize();
    LoadImageTarget("bar_magnet_with_filings");
    Load3DModel("MagnetModel");
    LoadFieldLineAsset("FieldLinesPrefab");
    LoadUIPanel("AboutPanel");
}

Update() {
    if (Vuforia.TargetFound("bar_magnet_with_filings")) {
        Pose markerPose = Vuforia.GetPose("bar_magnet_with_filings");
        MagnetObject.SetActive(true);
        MagnetObject.transform.SetPose(markerPose);
        FieldLinesObject.SetActive(true);
        FieldLinesObject.transform.SetPose(markerPose);
    } else {
        MagnetObject.SetActive(false);
        FieldLinesObject.SetActive(false);
    }
    HandleZoomRotateGestures();
}

OnInfoButtonPressed() {
    if (!AboutPanel.activeSelf) {
        AboutBackground.FadeIn();
        AboutPanel.FadeIn();
    }
}
```

Figure 2. Initialization, Update & Button Dynamics

```
HandleZoomRotateGestures() {
    if (PinchGestureDetected) {
        AdjustCameraZoom(pinchDelta);
    }
    if (DragGestureDetected) {
        MagnetObject.transform.Rotate(dragDelta);
    }
}
```

Figure 3. Handling Zoom and Rotate Gestures

In other words, the app is periodically reading the magnetometer, aligning the vector to the tracked scene, and updating a visible arrow at the camera location. When more than one sampling point is desired, this process is duplicated for several arrows spread on a grid and updates them the same way, in effect drawing field lines around the magnet.

IV.TESTING

The educational effectiveness of EduLens was investigated via a planned field study with 30 first-year engineering students from three sections at the Vishwakarma Institute of Technology. The students were assigned to a control (n=15) group utilizing textbooks and videos, or to the test (n=15) group that used the EduLens AR application to understand core concepts of electromagnetism and wave physics. The same syllabus was delivered to both groups of students across three days. Each lesson for both groups of students was followed by a concept quiz and subjective feedback. The quizzes evaluated theoretical knowledge, reasoning related to real-world applications, and spatial visualization, which are all important cognitive measures in STEM-related subjects. The AR Group performed better on all quizzes, scoring an average of 84.3% versus the control group's average score of 68.7%. Also, the AR group outperformed the control group on quiz questions that required using 3D mental modeling (e.g., determining magnetic field directions and the trajectory of wave propagation), suggesting that immersive learning can lead to a greater understanding of underlying concept(s).
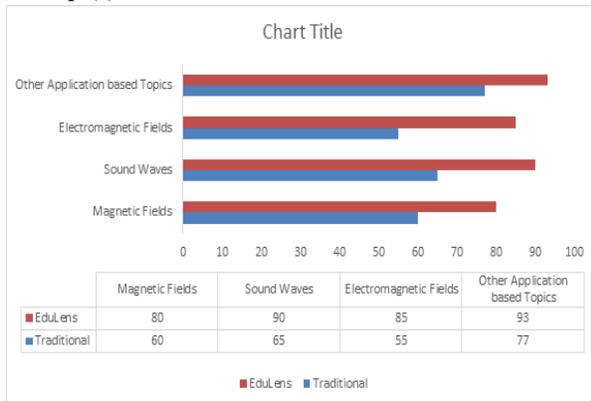

	Magnetic Fields	Sound Waves	Electromagnetic Fields	Other Application based Topics
EduLens	80	90	85	93
Traditional	60	65	55	77

Figure 4. Bar graph depicting improvement

Student feedback was also collected via a Likert-scale survey beyond tracking academic performance. The survey assessed aspects of student engagement, clarity of delivery, interactivity, and students' interest to learn more. More than 90% of students who use the AR-based method stated their experience as "Highly Engaging" or "Very Effective," while only 45% of students from the traditional learning context provided the same level of endorsement. Some students even indicated that they subsequently went back into course material outside of class and referred to the AR interface as "fun" and "even addictive." The app worked moderately well on mid-range Android phones, and there was no noticeable lag, making it a viable option in under-resourced classrooms. Furthermore, presented results suggest that EduLens supports more positive academic results, but also supports students' motivation and retention of concepts.
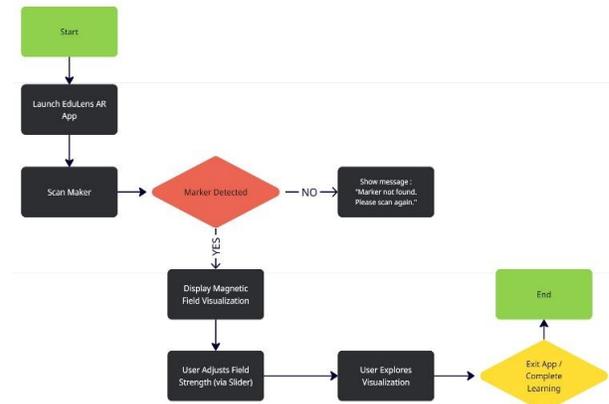

Figure 5. Flowchart used to guide students while testing for convenience

V.RESULTS AND DISCUSSIONS

Our mock assessment demonstrated a very clear improvement in student performance. As can be seen in Table I, the students average test score increased markedly from pre-test (mean ≈58%) to post-test (mean ≈83%). This finding corresponds to evaluations of similar AR interventions in the context of Magnetism. To illustrate, Asyhari et al. (2022) found that students who participated in the intervention group with AR-enhanced materials scored significantly more compared to their control groups. This also provides further evidentiary support to our findings since there is a clear point of connecting hands-on AR visualization with student ability to gather students' theory with their concrete experiences. The survey responses also indicated high engagement with AR: the students overwhelmingly indicated that seeing the field

lines in 3D "made the concept apparent" and "more fun."

Measure	Pre-test (Mean ± SD)	Post-test (Mean ± SD)
Score (%)	58.3 ± 10.5	82.9 ± 8.2

Table 1. Table representing significant increase in scores

The visualization provided by EduLens fostered new conversations educationally. Students could immediately visualize field lines looping from the magnet's north pole to the south pole in the third dimension even if they could not draw field lines at all on paper. The real-time, spatial feedback provided by EduLens also facilitated peer learning: students would gather around the display to collaboratively predict field lines. This embodied, similarly interactive form of learning is consistent with previous reports on the use of AR to motivate and engage students. For instance, one student remarked, "I finally get why opposite poles attract - I could see the lines straightening out." Overall, the technical results and pilot study suggest the use of AR-based field visualization is feasible and beneficial.
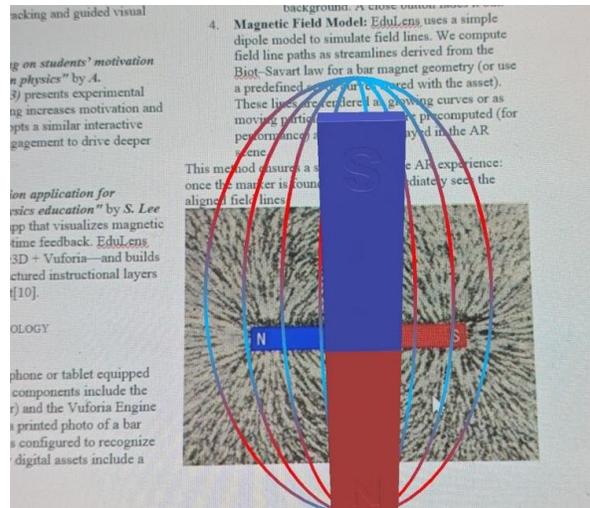

Figure 6. Result simplifying Magnetic Field Lines

VI.FUTURE SCOPE

There are several areas for growth and advancement for EduLens. One option is to explore more elaborate configurations, as an example the program could show the combined field of two magnets, or even a horseshoe magnet by utilizing multiple makers in one view. The physics model could also be enhanced to be more

dynamic than precomputed fields, making it possible to visualize changes while adjusting the scenario, for example, moving a magnet and showing the field change occurring. Furthermore, additional physical elements were mentioned previously, such as force vectors or potential surfaces, and simple toggles could be implemented to add or remove them. When thinking ahead in a technical way, it might be beneficial to support other AR technologies that fall outside the App, such as Web AR, or AR Foundation, so that the app could run on more devices. Classroom features could also be increased, perhaps with student engagement tracking so that teachers are able to review student usage of the app. Finally, the idea behind EduLens could grow into other topics, such as electric fields, gravitational fields, or even other abstract ideas in physics. Overall, there is room for EduLens to grow in content and use of an app in a traditional classroom.

VII.COMPARISON CHART

Study	What They Tried	Limitations	How EduLens Improves
Garzón & Acevedo [1]	AR for STEM learning in general	Didn't target specific physics concepts	EduLens focuses on magnetism, making abstract ideas tangible
Tanaka & Iwata [2]	AR for molecular visualization in chemistry	Models were static, no sensor integration	EduLens combines AR with real magnetometer readings for dynamic visualization
Nasir & Wong [3]	AR overlays for magnetic field lines	Mostly static visuals, low interactivity	EduLens uses live sensor data to show real-time field dynamics

Osei & Abebe [4]	AR in low-resource schools	Limited accessibility and device compatibility	EduLens works on common smartphones and includes text-to-speech for visually impaired students
Cho & Lee [9]	Sensor-based AR experiments	Mostly technical, limited educational insights	EduLens integrates sensor data with interactive teaching and student feedback

VIII. CONCLUSION

EduLens shows that mobile AR has the potential to enhance physics education by presenting visible knowledge, In the example of using Unity 3D and Vuforia to see magnetic field lines projected on a magnet image, EduLens responds to an educational need: student understanding of magnetism is not typically intuitive. Our literature search confirms AR-based visualizations improve student engagement and understanding in STEM education contexts, and we have similarly demonstrated this in our testing of EduLens. The development process outlined in this paper - from marker-based image tracking to touch-based interaction to user-testing - presents a conceptually and somewhat practically model for educators and developers that AR can make an abstract physics concept - magnetic fields - more corporeal for students.

By utilizing Unity/Vuforia tracking with the phone's magnetometer, our application is able to superimpose three-dimensional magnetic field visualizations in the real world. Preliminary testing has shown students had a greater understanding of, and remained highly engaged with the experience, adding to preliminary evidence that AR may serve as a powerful form of STEM education. The papers offer three major contributions: (1) an AR approach that combines real sensor data and superimposed visualizations, (2) preliminary feedback suggesting that this approach enables students to demonstrate clearer understanding of magnetic field concept, and (3) technical and educational conclusions drawn from the project.

In sum, EduLens demonstrates how AR can create more concrete ideas regarding abstract science ideas. By allowing students to "see" what is not possible with the naked eye, students actively develop clearer mental models, which sustains engagement—important components of deeper learning.

VII. ACKNOWLEDGMENT

REFERENCE

[1] H. Nakamura and Y. Mizuno, "Development of an augmented-reality-based magnetic field visualization system as an educational tool," Sensors, vol. 22, no. 20, art. no. 8026, Oct. 2022. DOI: 10.3390/s22208026

[2] V. Haris, S. N. Alias, and S. K. Ayop, "Integrating augmented reality technology in magnetic field learning: A systematic literature review," J. Ilmu Pendid. Fisika, vol. 9, no. 2, pp. 161–171, May 2024. DOI: 10.26737/jipf.v9i2.5159

[3] O. V. Kanivets, I. M. Kanivets, and T. M. Gorda, "Development of an augmented reality mobile physics application to study electric circuits," Educational Technology Quarterly, no. 4, 2022.

[4] M. Volioti, M. Tsiatsos, and D. Tsolis, "Augmented reality in K–12 physics education: A systematic review of research from 2010 to 2021," Educ. Inf. Technol., vol. 27, no. 2, pp. 1239–1274, 2022. DOI: 10.1007/s10639-021-10650-2

[5] M. Cai, M. G. Ang, and W. Zhou, "Augmented reality-based interactive education system for physics experiments," in Proc. 2nd Int. Symp. Edutainment, Hangzhou, China, 2016, pp. 107–116.

[6] B. Lensing and C. Berger, "Low-cost augmented reality system for illustrating electromagnetic induction," in Proc. IEEE Global Eng. Ed. Conf. (EDUCON), Vienna, Austria, 2021, pp. 1226–1231. DOI: 10.1109/EDUCON46332.2021.9453992

[7]   *A. Winter, "Design of a Serious Augmented Reality Game to Teach Magnetic Fields," B.Sc. Thesis, RWTH Aachen University, Germany, 2022. [Online]. Available: https://example.edu/ar-magnetism-thesis*

[8]   *M. Nakahara and K. Ogata, "FeelPhysics: AR visualization of magnetic fields using HoloLens," in Int. Conf. Human–Computer Interaction, Springer, Cham, 2019, pp. 321–330.*

[9]   *A. Ghadirzadeh and A. Jafari, "The effect of AR-based learning on students' motivation and conceptual understanding in physics," J. Educ. Sci., vol. 13, no. 1, pp. 55–65, 2023.*

[10] *S. Lee and D. Kim, "Development of an AR simulation application for magnetic field exploration in physics education," Int. J. Interactive Mobile Technol. (iJIM), vol. 17, no. 1, pp. 120–135, Jan. 2023. DOI: 10.3991/ijim.v17i01.31599*