Making the Invisible Visible: Using Augmented Reality to Teach Abstract Physics Concepts

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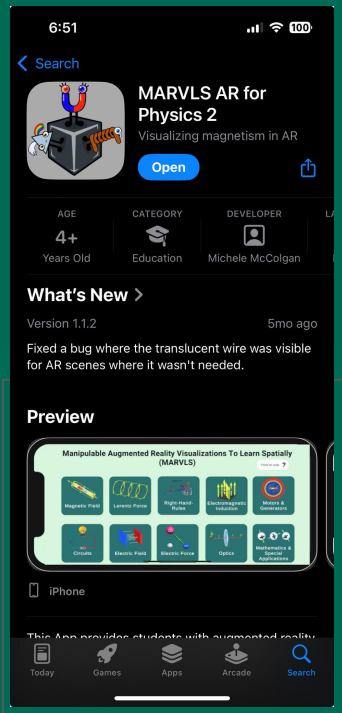
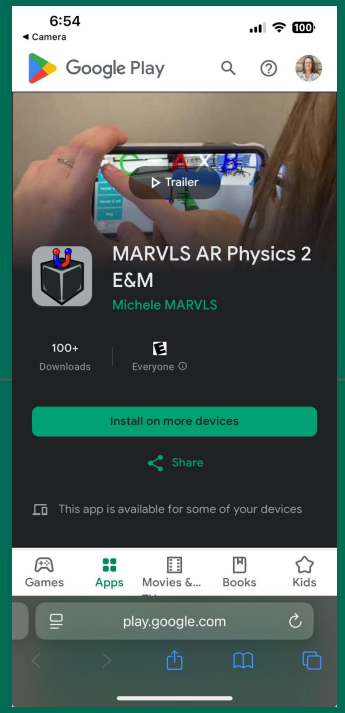
Schedule for Today

- Introduce the motivation for AR in Physics - MARVLS Apps
- Let's use the App and a cube to explore the magnetic field!
- PER Research applied to using AR to teach physics concepts
- Explore some of the AR scenes in the Apps
- Questions

Apple App Store

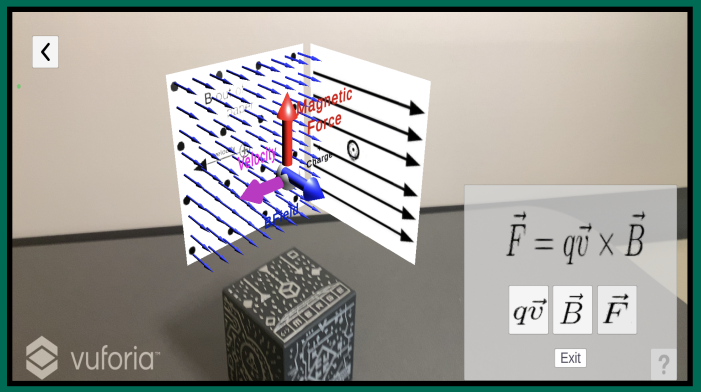
Google Play Store

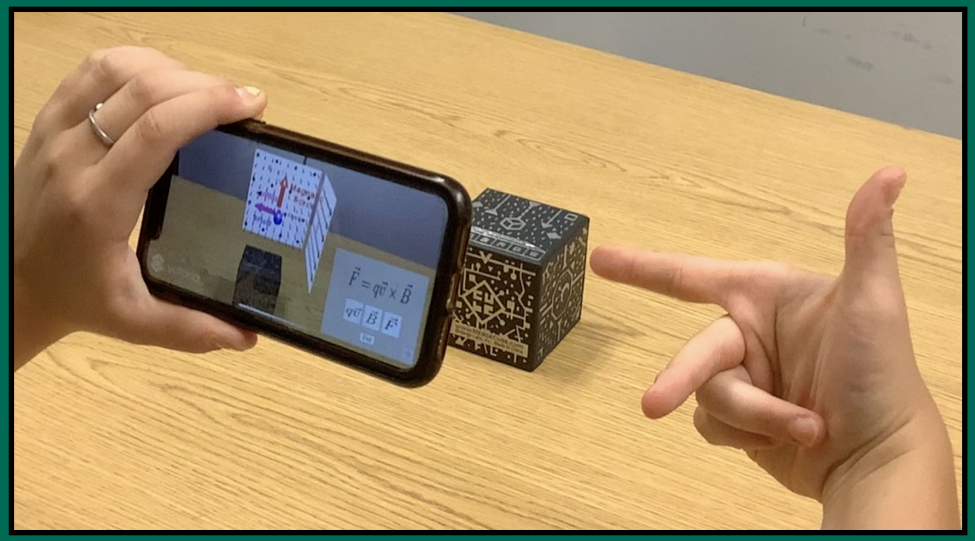




What is Augmented Reality

- AR uses the camera of a phone or tablet to digitally overlay an AR representation of a physical object visually onto a target cube.
- Interactive elements such as buttons and sliders also appear on the screen





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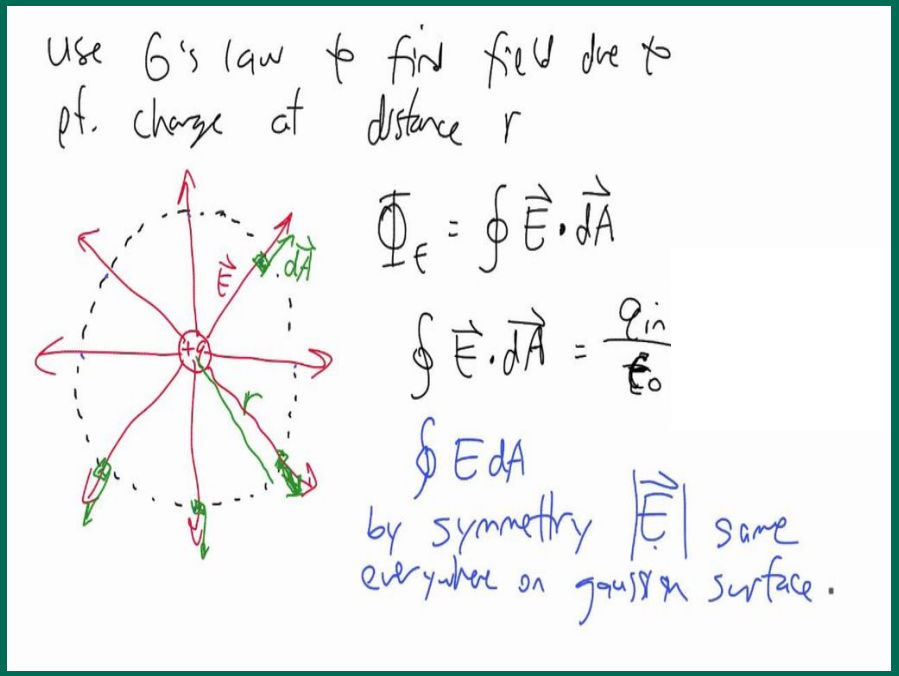
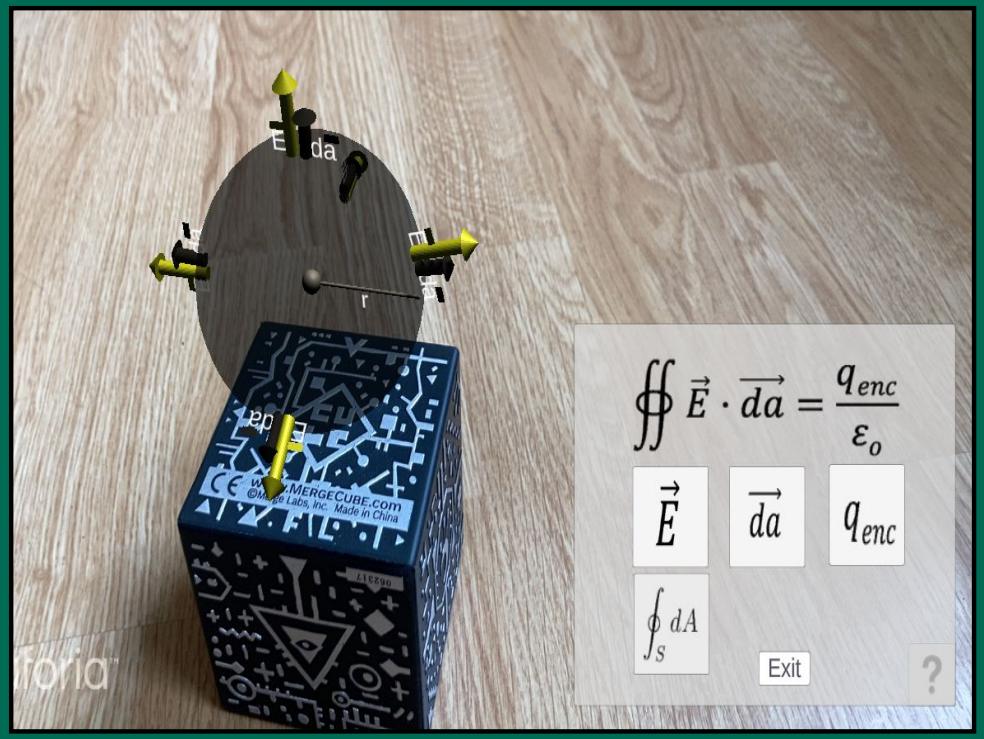
Challenges for Physics Instruction



- Difficulty visualizing 3D concepts
- Difficulty connecting equations to concepts
- Time sink
- high DFW rates, low attendance

MARVLSolutions

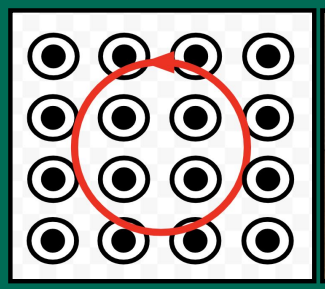


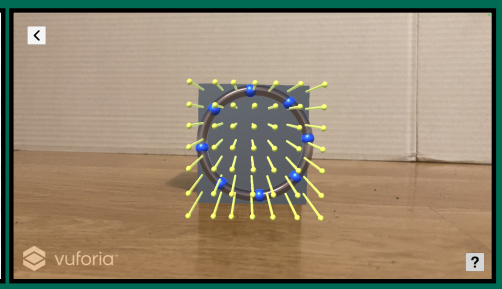
- increase engagement
- reduce teaching time
- reduce DFW rates
- portable
- connect 2D to 3D

What are MARVLS?

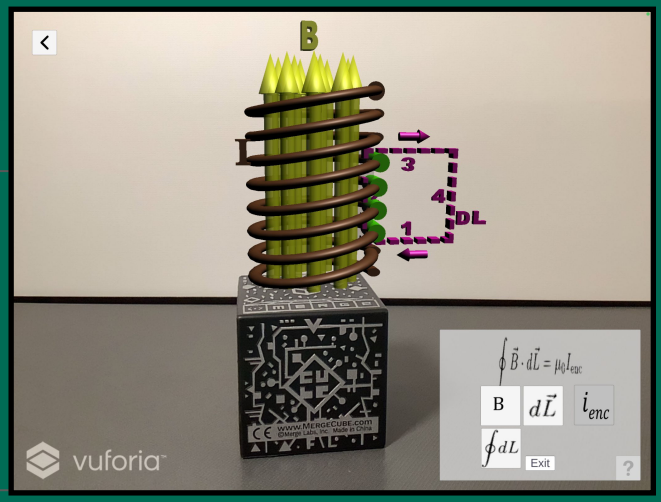
Manipulable Augmented Reality Visualizations to Learn Spatially

- AR models of 3D concepts that students can manipulate
  - Rotate Merge cube
  - Sliders and buttons





- Visualize **abstract and 3D concepts**
- Visualize **2D representations** of **3D models**
- Visualize **variables of an equation** to **digital elements** in the AR representation



Benefits of Using MARVLS

- All students have the correct visualization
  - No awkward demos (hula hoops around wires, bed of nails)
  - No inferences (magnetic field lines from iron filings)
  - Students have their own demo
- It's FAST! It's FREE! It's INTERACTIVE! It's COLLABORATIVE!
- Opportunity to explore concepts you don't have time for
  - Force on electrons in a moving rod
- Opportunity to explore advanced topics conceptually
  - Biot-Savart, E&M waves, induction

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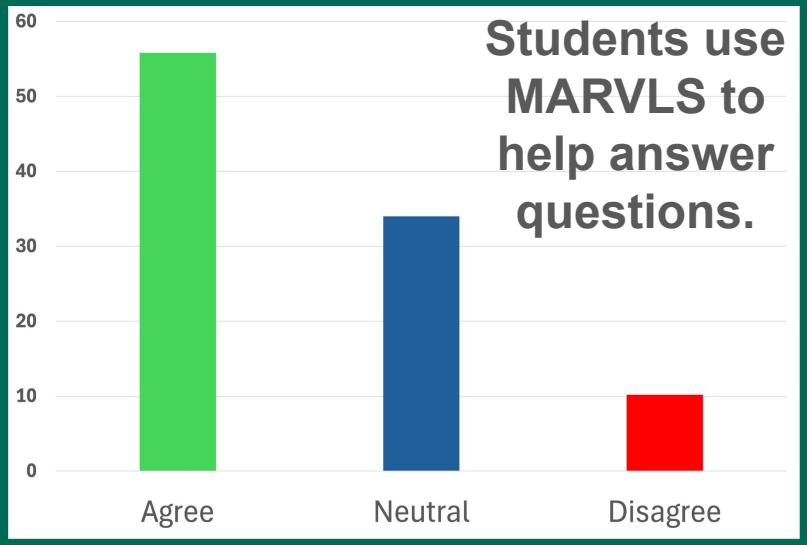
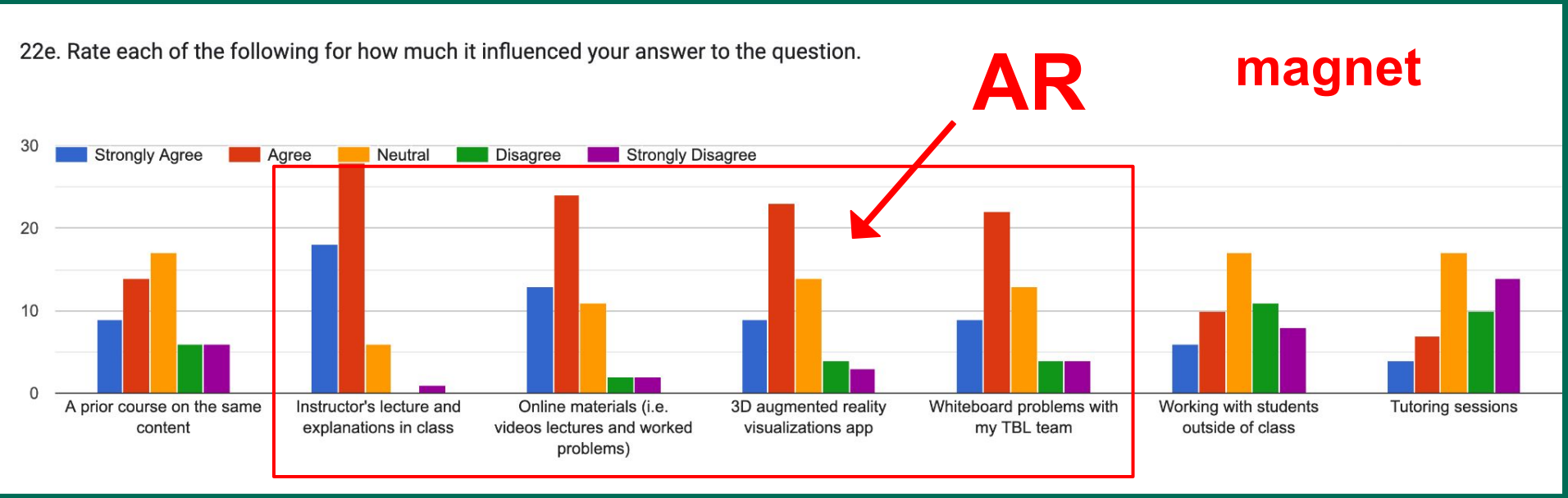
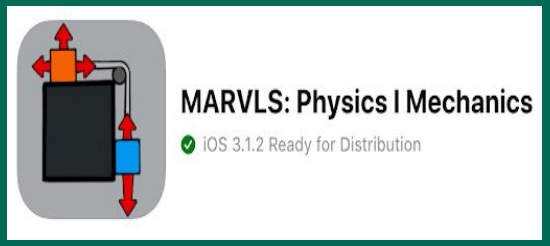
MARVLS are student-approved & classroom tested

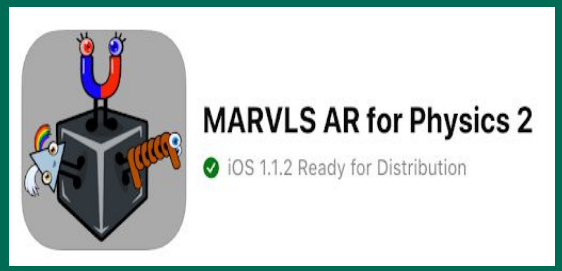


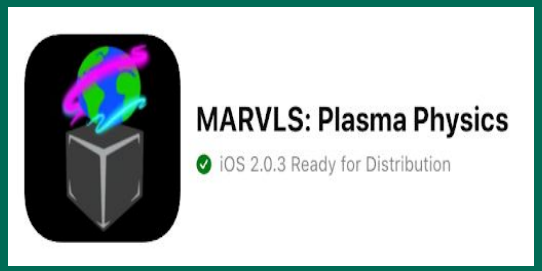
Comparing Active Learning and AR Models in Physics

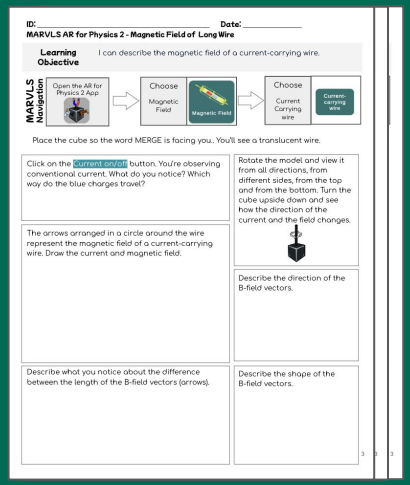


MARVLS Available in the App & Google Play Stores









over 9000 downloads!

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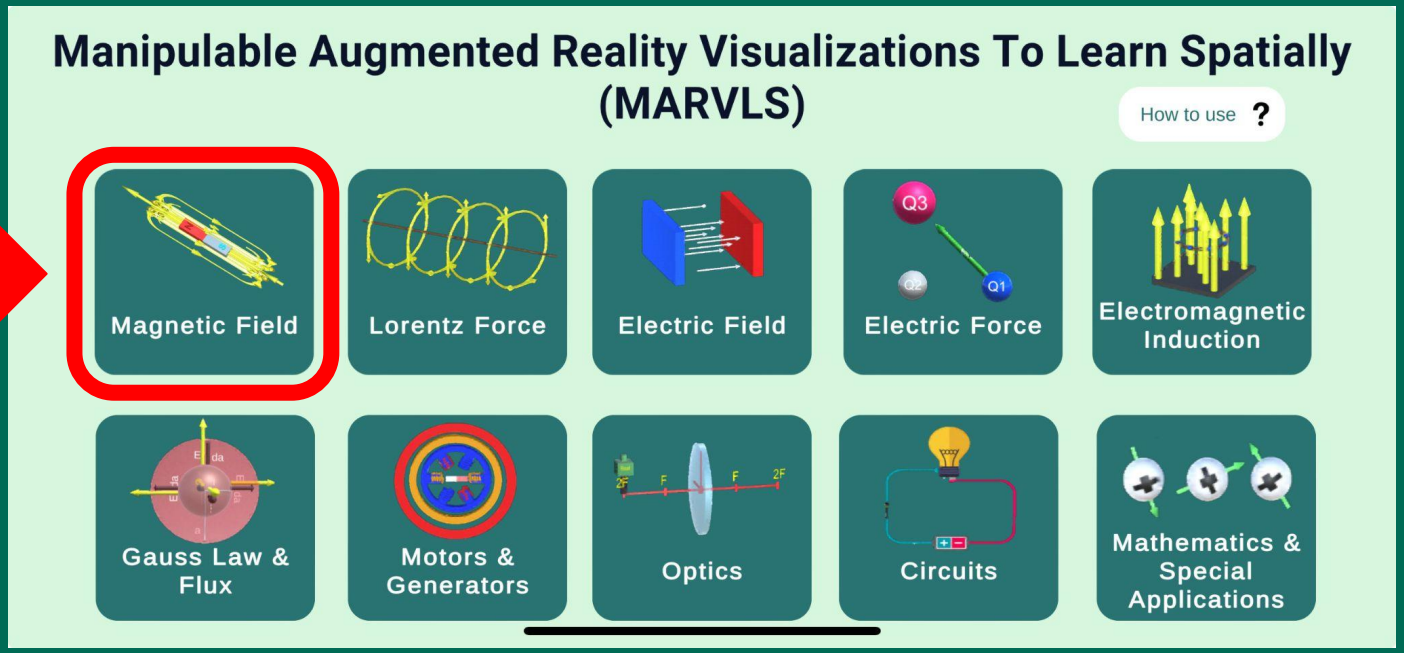
Download and try out the App with a Merge cube



Apple App Store

Google Play Store

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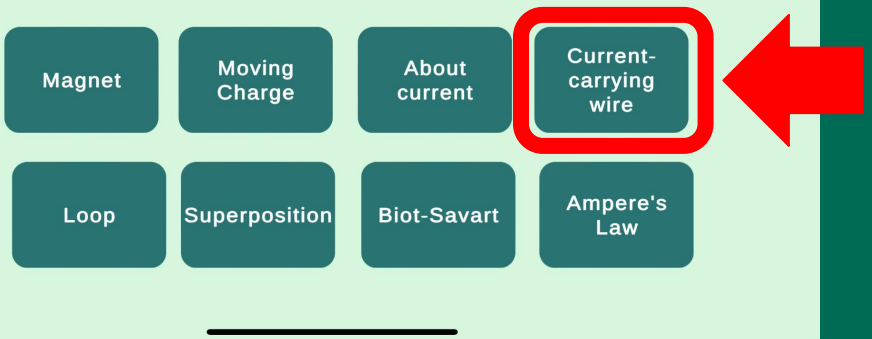
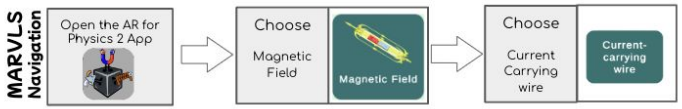
Magnetic field of a wire

Magnetic Field MARVLS



MARVLS AR for Physics 2 - Magnetic Field of Long Wire

Learning Objective I can describe the magnetic field of a current-carrying wire.



Place the cube so the word MERGE is facing you.. You'll see a translucent wire.

Click on the Current on/off button. You're observing conventional current. What do you notice? Which way do the blue charges travel?

Rotate the model and view it from all directions, from different sides, from the top and from the bottom. Turn the cube upside down and see how the direction of the current and the field changes.

The arrows arranged in a circle around the wire represent the magnetic field of a current-carrying wire. Draw the current and magnetic field.

Describe the direction of the B-field vectors.

Describe what you notice about the difference between the length of the B-field vectors (arrows).

Describe the shape of the B-field vectors.

3

Learning Objective I can connect the 2D representation with the 3D model. I can create 2D representations of 3D models.

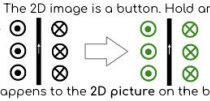
2D Representations and 3D Models

Click on the 2D button and make sure the current is on. Orient the cube so that the 2D image is facing you. Describe what you see on the 2D images (front and back).

Draw the 2D image that you see in the 3D model. Then rotate the cube and draw the image that is on the back.

Front | Back

Click on the ? in the bottom right corner of the screen. The 2D image is a button. Hold and press the button.



What happens to the **2D picture** on the button when you press and hold it?

Rotate the model as you press and hold the button. Describe what you notice about the **vectors** in the 3D model when you press and hold the button. How are the ⊙'s in the 2D image related to the B field vectors? The ⊗'s?

Press Axes and notice the coordinate system added to the scene. The positive direction for each direction is labeled with x, y, or z in the 3D model.

Press x. Draw the current, the green arrows when the button is pressed, and the the +x and -x vectors.

Which direction are the vectors represented by the ⊙s the ⊗s?

Press y. Draw the current, the green arrows when the button is pressed, and the the +y and -y vectors.

Which direction are the vectors represented by the ⊙s the ⊗s?

4

Some of the lessons

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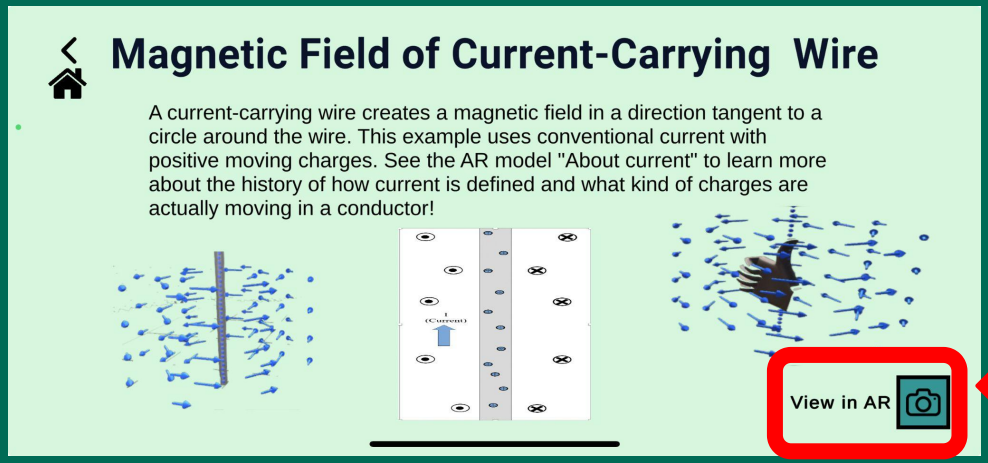
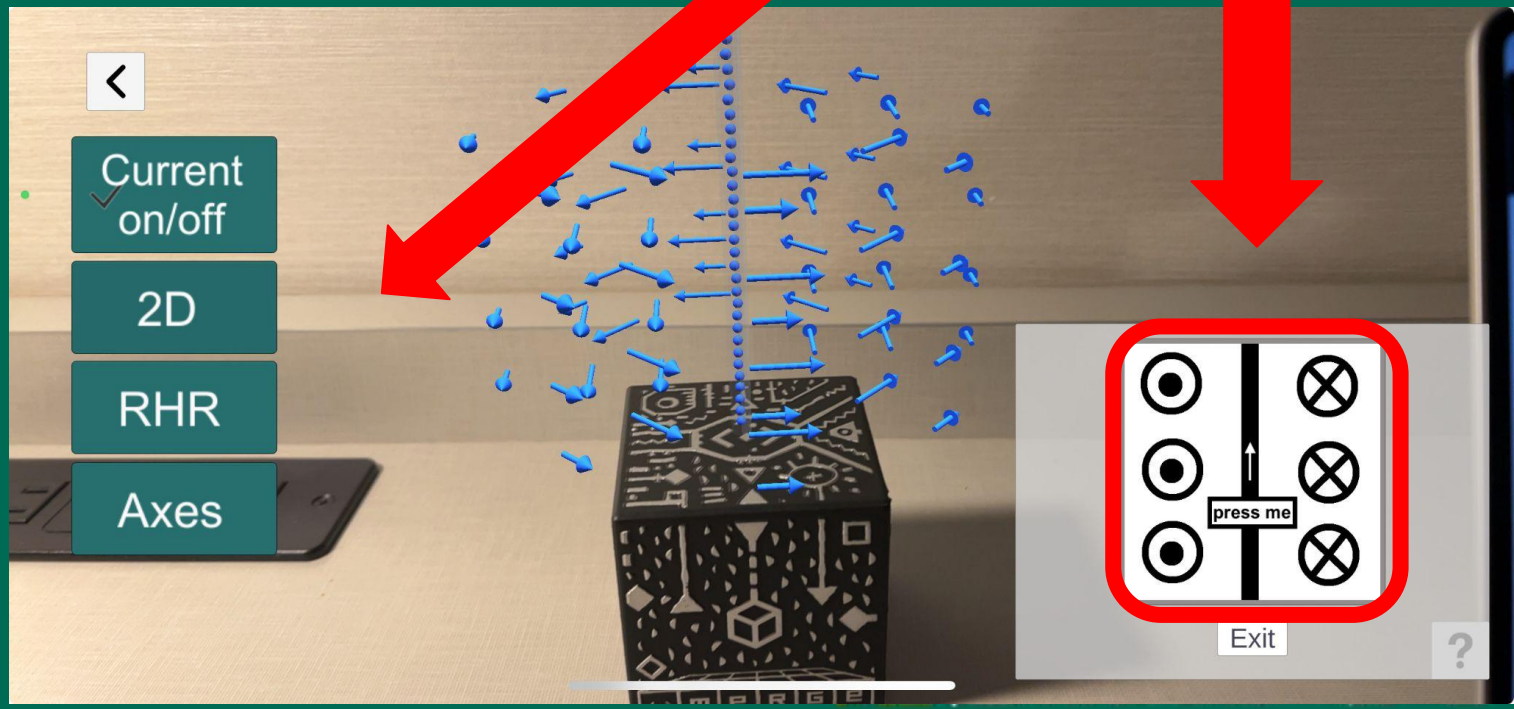
Magnetic field of a wire

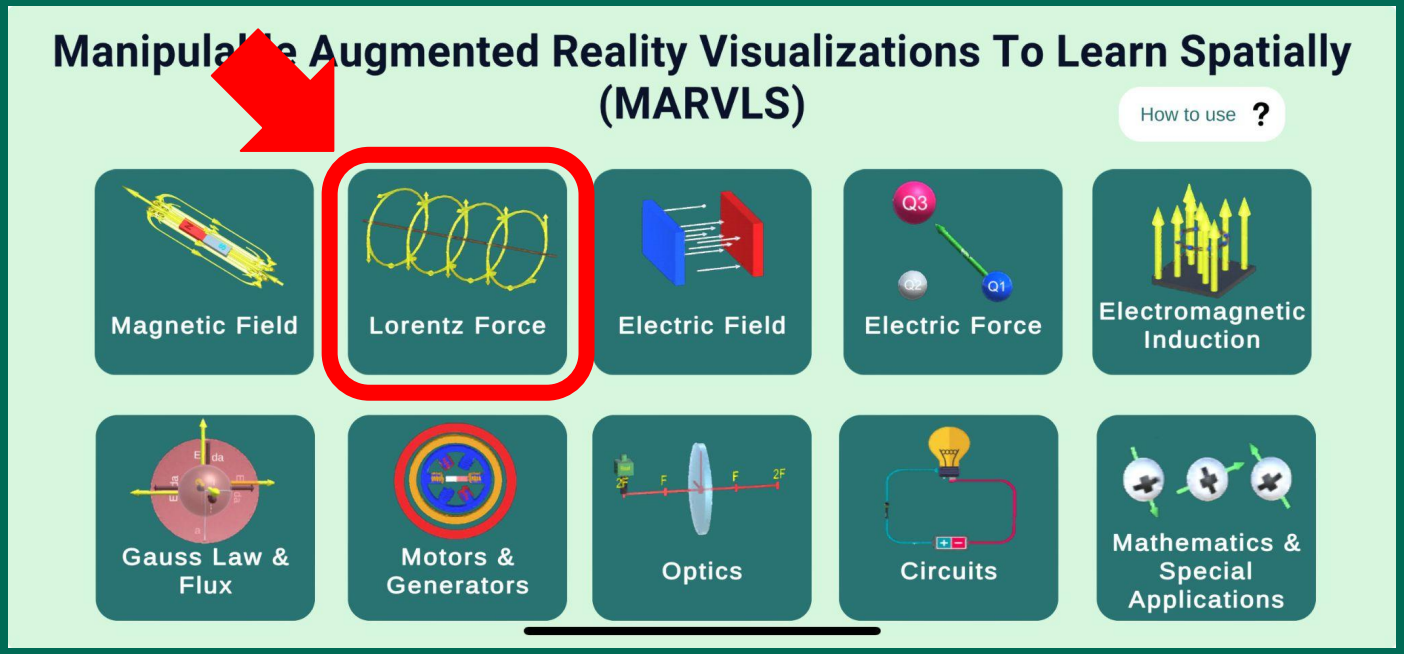


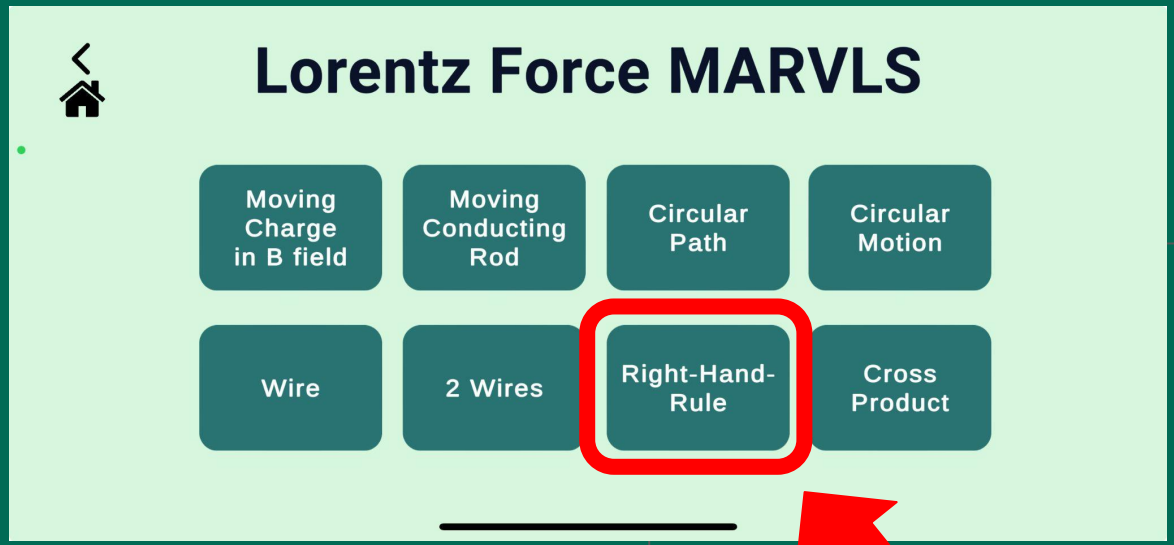
Try out the buttons

Rotate
he cube



Right Hand Rule





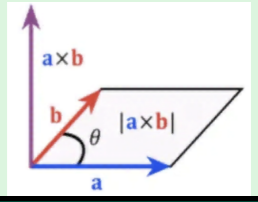
Right-Hand-Rule

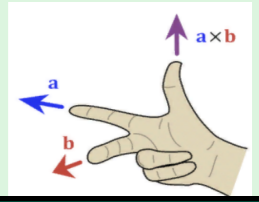
Right-Hand-Rule

The right hand rule tells us the direction of the cross product of 3 vectors.

The cross product of two vectors a and b is in a direction perpendicular to both a and b, as shown in the picture and given by the right hand rule.

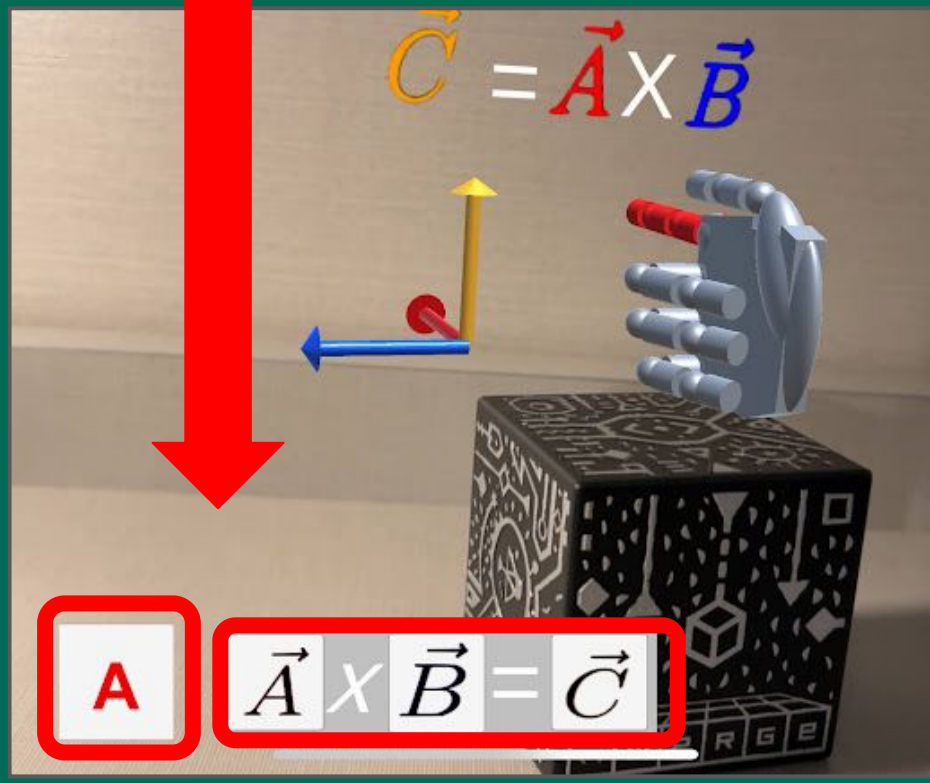
The magnitude of the cross product is the magnitude of a multiplied by the perpendicular component of b.





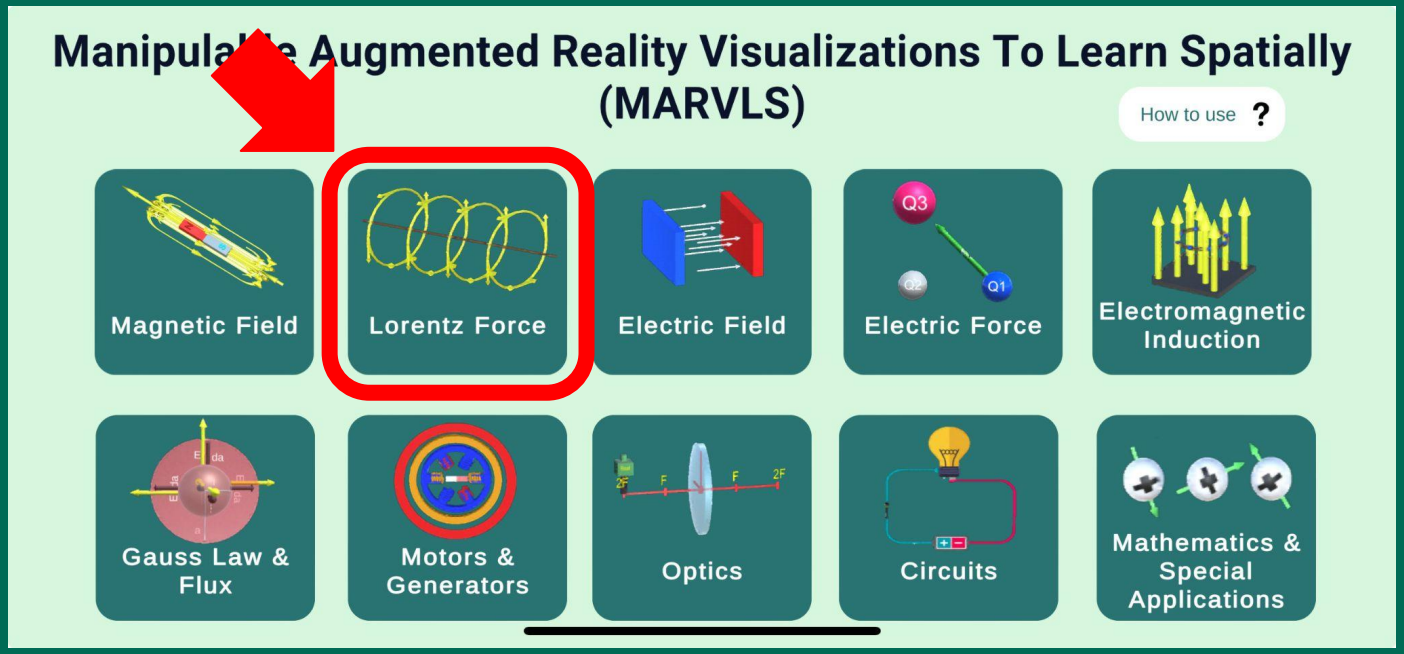
View in AR

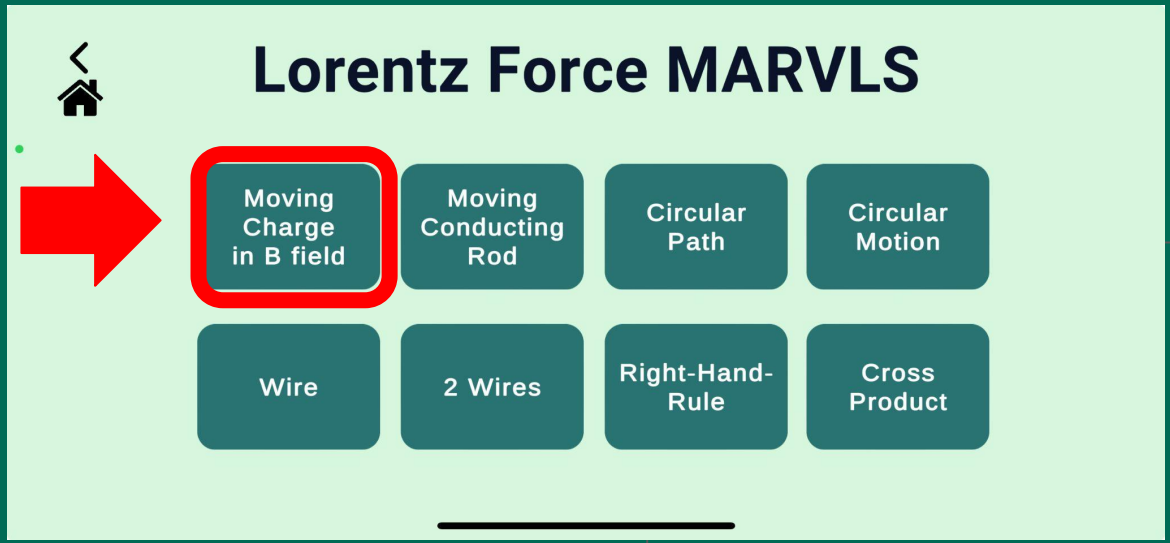
Try out the buttons



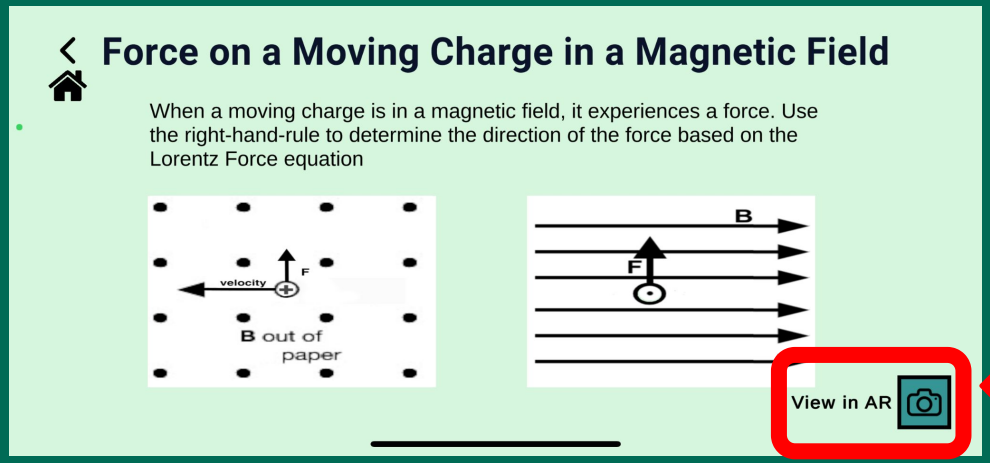
Rotate the cube

Magnetic Force AR Models



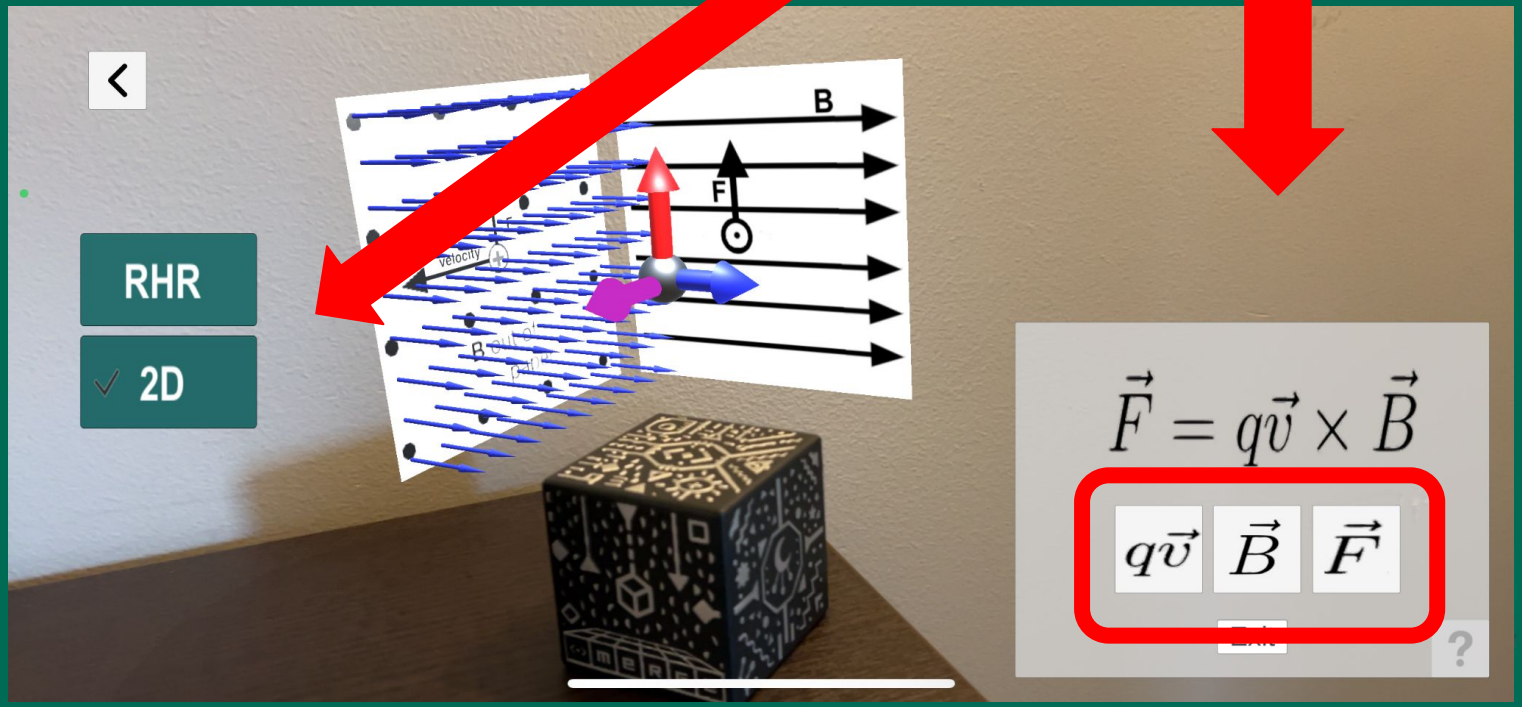


Magnetic Force

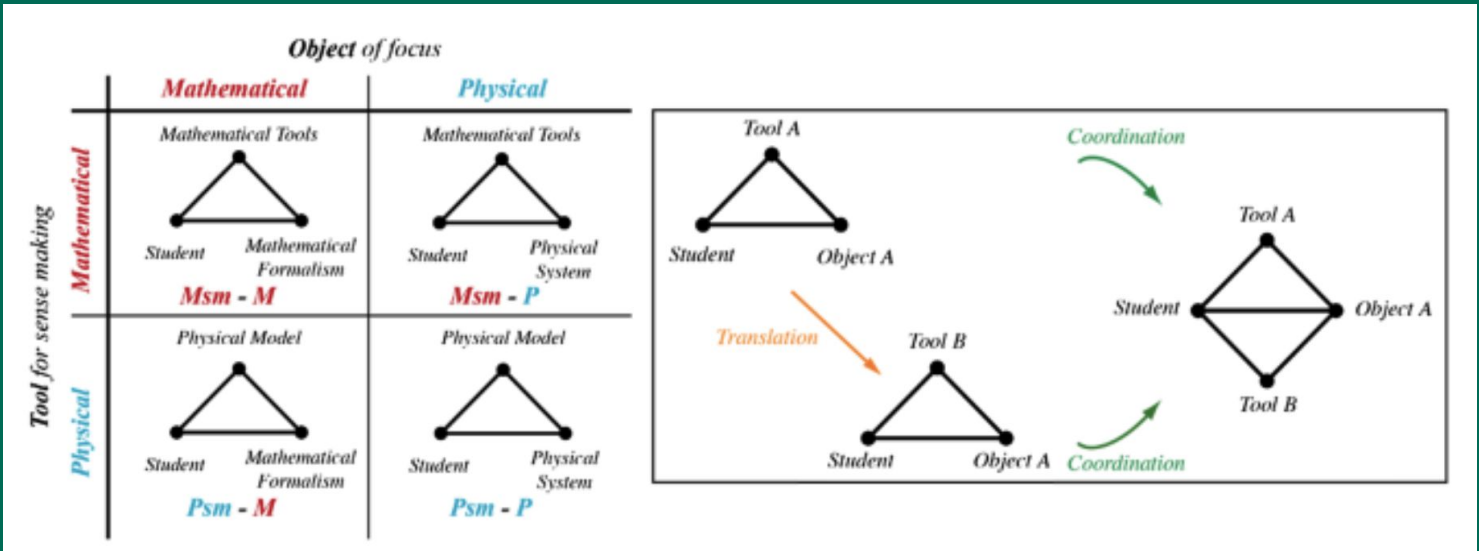


Try out the buttons

Rotate the cube



PER Research - MSM Framework and AR Physics



The four modes in the framework include Msm-M, Msm-P, Psm-M, and Psm-P. Specifically,

- Msm-M: a mathematical tool mediates the interaction with a mathematical object
- Msm-P: a mathematical tool mediates the interaction with a physical object
- Psm-M: a physical tool mediates the interaction with a mathematical object
- Psm-P: a physical tool mediates the interaction with a physical object

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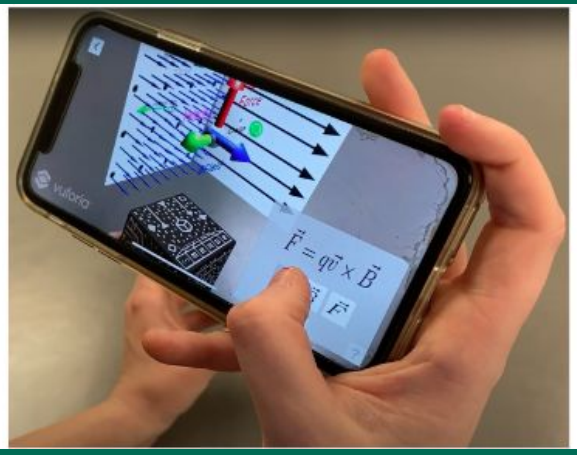
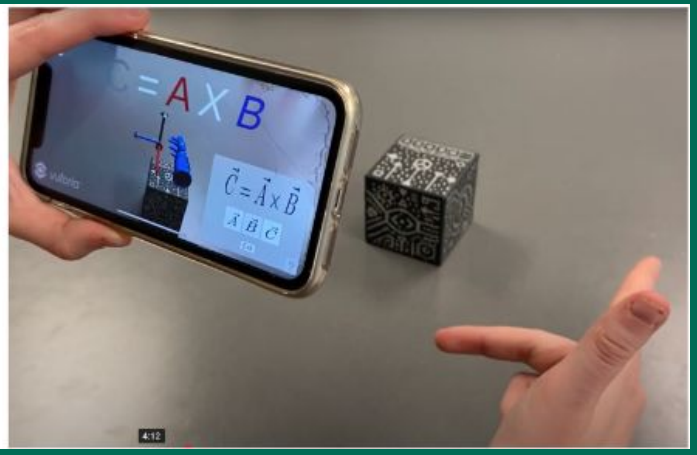
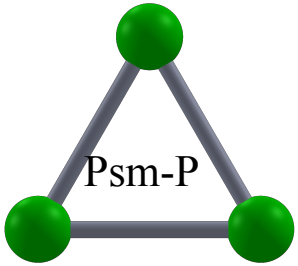
Gifford J. D., and Finkelstein, N. D., “Applying a Mathematical Sense-Making Framework to StudentWork and Its Potential for Curriculum Design”, Phys. Rev. Phys. Educ. Res. vol.17, 2021.

MSM Framework - Magnetic Force

Basic MSM Modes

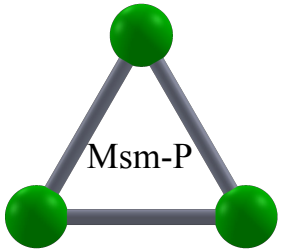
AR model



Student

Force on a moving charge in a magnetic field

$$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$$



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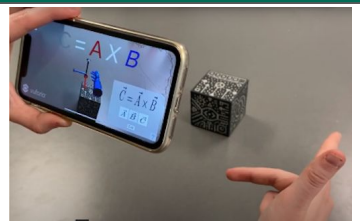
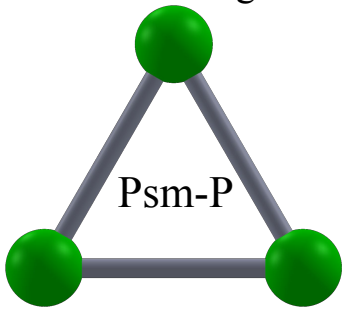


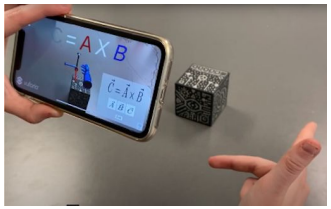
AR RHR fingers



Student

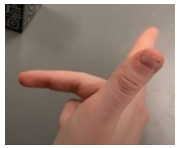
RHR Gesture

MSM Chaining



AR RHR fingers

chaining

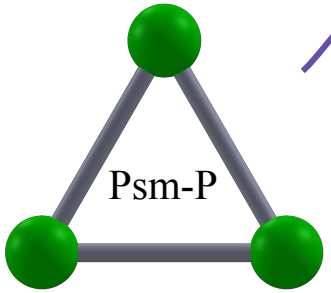


RHR Gesture

chaining

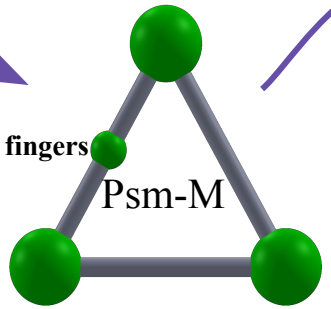
$\vec{C} = \vec{A} \times \vec{B}$

Cross Product



Student

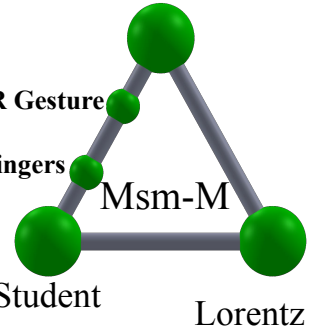
RHR Gesture



Student

Cross Product

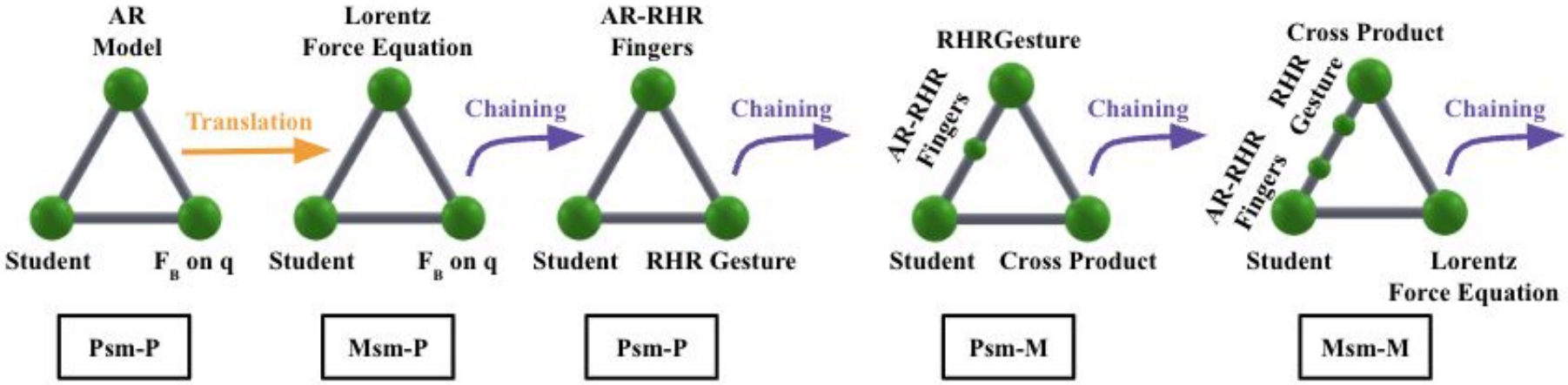
$\vec{C} = \vec{A} \times \vec{B}$



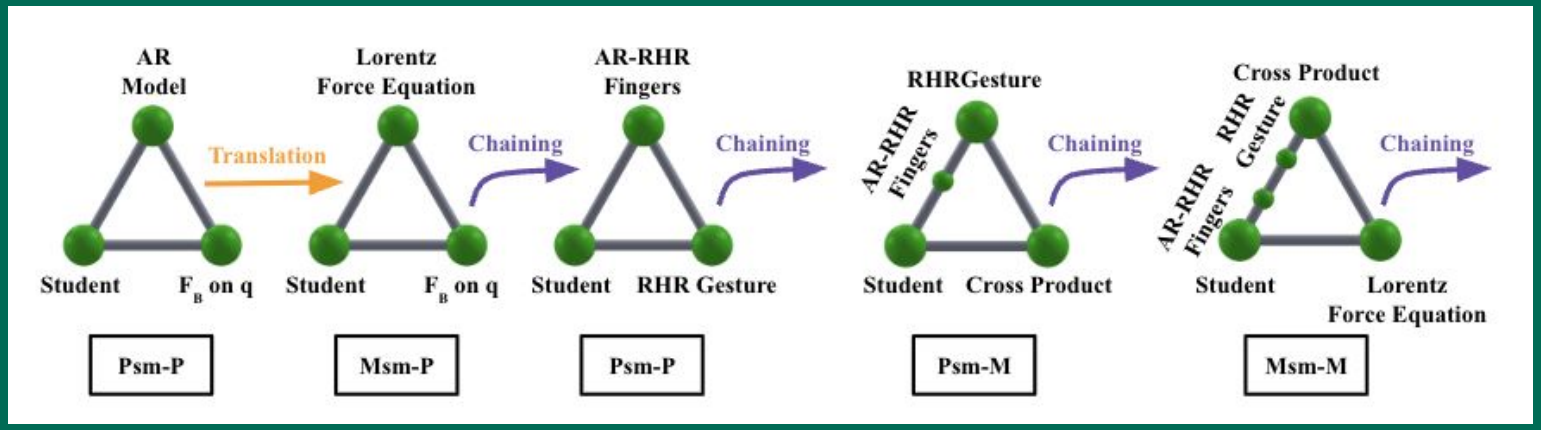
Student

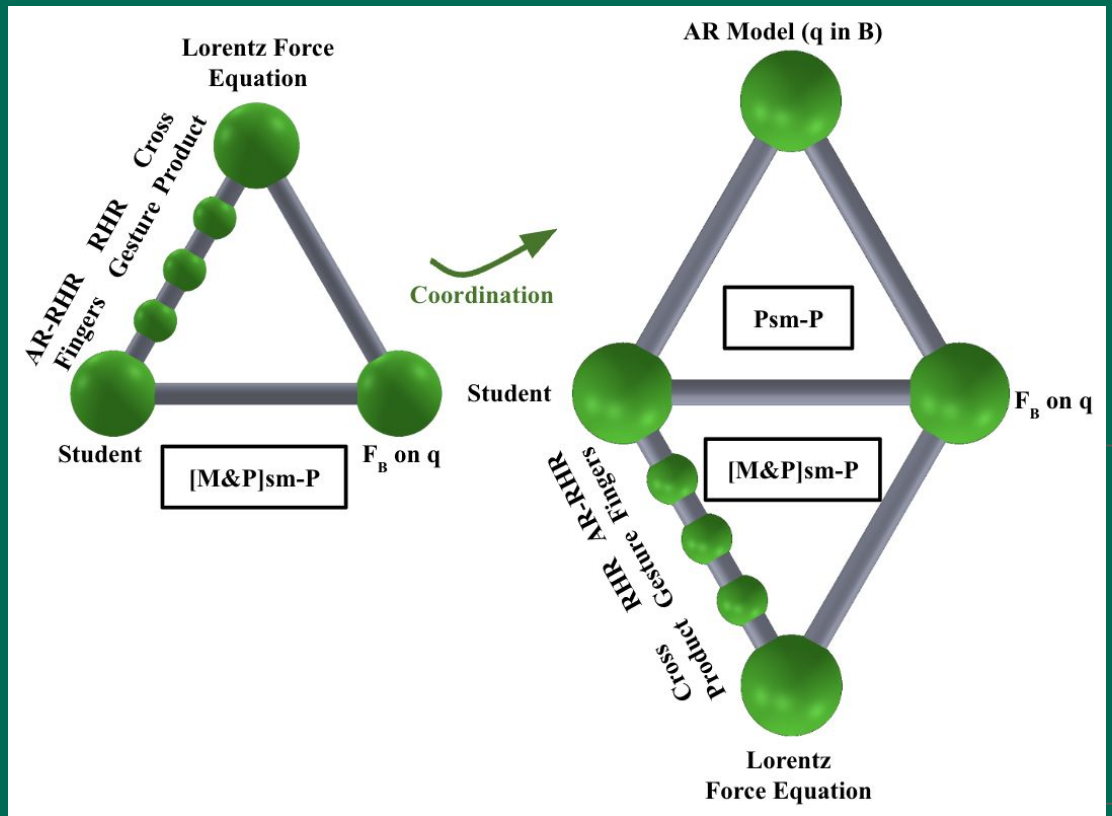
Lorentz Force Equation

$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$



MSM: Putting it all together





NSF IUSE Study

- Final goal of the grant is to test the Apps and lessons at other institutions.
- Are You Interested?
  - Run one or more of the lessons in your classroom as an in-class activity or homework activity
  - Student and instructor survey or pre/post assessments
  - IRB approved study - through your institution or mine
  - Contact Michele McColgan for more information
    - mmccolgan@siena.edu

Thanks for Listening!

- Questions?
- Contact info: Michele McColgan mmccolgan@siena.edu

PERC Proceedings

- M. McColgan, G. Hassel, N. Stagnitti, J. Morphew, and R. Lindell, Augmented Reality to Scaffold 2D Representations of 3D Models in Magnetism, presented at the Physics Education Research Conference 2023, Sacramento, CA, 2023
- M. McColgan, G. Hassel, and K. Pashayi, MSM Framework: AR Model of the Force on a Charge Moving in a Magnetic Field, presented at the Physics Education Research Conference 2024, Boston, MA, 2024

ASEE Proceedings

- McColgan, M., Morphew, J. W., Hassel, G., Bennett, J. A., & Kelly, M. C. (2024). Understanding magnetism concepts through augmented reality: A qualitative analysis. In ASEE 2024 Conference Proceedings, Portland, OR, June 23-26. https://peer.asee.org/47004
- Bennett, J., Morphew, J. W., & McColgan, M. (2024). Embodied learning with gesture representation in an immersive technology environment in STEM education. In ASEE 2024 Conference Proceedings, Portland, OR, June 23-26. https://peer.asee.org/47233
- McColgan, M., & Hassel, G. E., & Pashayi, K., & Morphew, J., & Bennett, J. A. (2025), MSM Framework: Augmented Reality Models of 3D Vectors.In ASEE 2025 Conference Proceedings, Montreal, Quebec, Canada, June 22-25. https://peer.asee.org/56981

MARVLS: Apps & Lessons

MARVLS QR Codes

MARVLS: Physics I Mechanics App Store

MARVLS: Physics I Mechanics Google Play Store

MARVLS AR for Physics 2 App Store

MARVLS AR for Physics 2 Google Play Store

MARVLS: Quantum Computing App Store

MARVLS: Quantum Computing Google Play Store

MARVLS: Plasma Physics App Store

MARVLS: Plasma Physics Google Play Store

MARVLS AR Chemistry App Store

MARVLS AR Chemistry Google Play Store

MARVLS Lessons & Answers

Lessons for MARVLS:
Physics I Mechanics App

Lessons for MARVLS AR for Physics 2 App

Lessons for MARVLS:
Quantum Computing App

Answers for Lessons for MARVLS:
Quantum Computing App

Lessons for MARVLS:
Plasma Physics

Merge Cube Template
(for best results print on card stock)

MARVLS: Apps & Lessons

https://docs.google.com/document/d/1VU_dLoBgyvD-drUofh88chdHWC-VN7HNhiwawKsypuA/edit?usp=sharing