Computation as a Tool for Physics Learning

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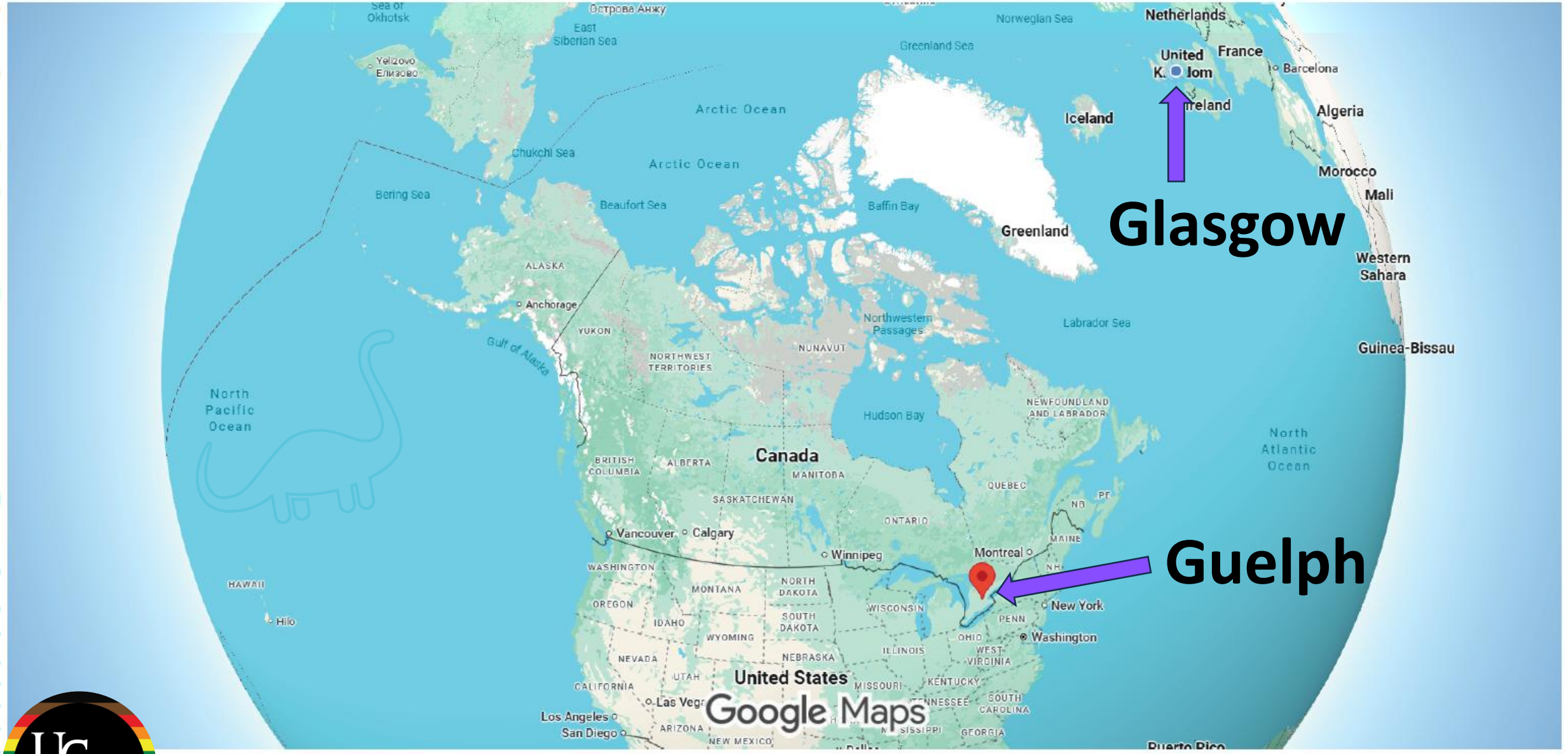
Advisor: Prof. Michael V. Massa

APE Birthday

October 29, 2025


Glasgow
Guelph
Google Maps
Map data ©2025 Google, INEGI
1000 km
Canada
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Morocco
Mali
Western Sahara
Guinea-Bissau
Arctic Ocean
Baffin Bay
Labrador Sea
Hudson Bay
Greenland Sea
Norwegian Sea
Bering Sea
Chukchi Sea
Beaufort Sea
Gulf of Alaska
North Pacific Ocean
North Atlantic Ocean
Northwestern Passages
ALASKA
Anchorage
YUKON
NORTHWEST TERRITORIES
NUNAVUT
BRITISH COLUMBIA
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MANITOBA
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Calgary
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WISCONSIN
ILLINOIS
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INDIANA
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KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
WEST VIRGINIA
PENN
MAINE
NH
NB
PE
Los Angeles
San Diego
Las Vegas
Puerto Rico

UG PHYSICS

Land Acknowledgement

Divergence

$$\vec{\nabla} \cdot \vec{V} = \frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} + \frac{\partial V_z}{\partial z}$$

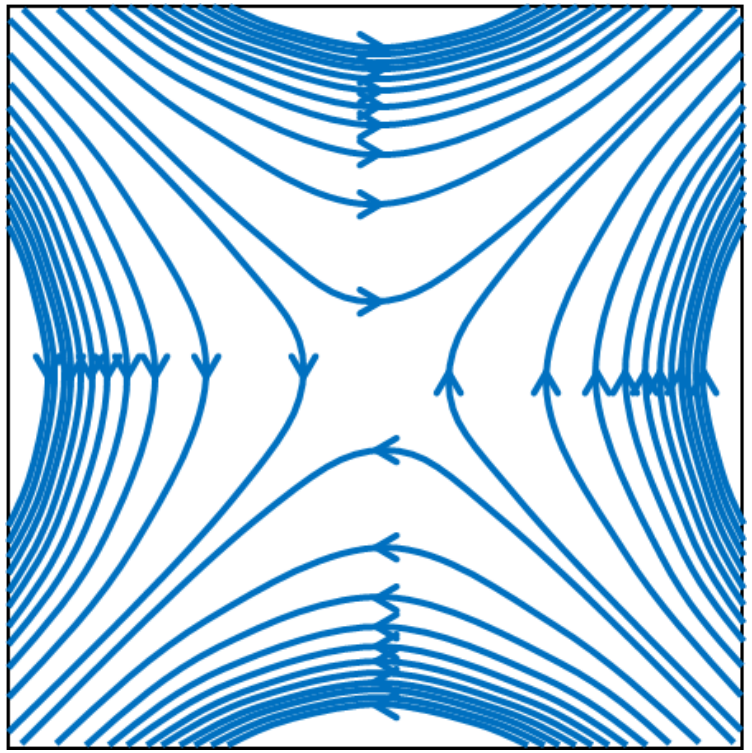
"…measure of how much the vector v **spreads out (diverges)** from the point"

Curl

$$\vec{\nabla} \times \vec{V} = \left(\frac{\partial V_z}{\partial y} - \frac{\partial V_y}{\partial z}\right)\hat{\imath} + \left(\frac{\partial V_x}{\partial z} - \frac{\partial V_z}{\partial x}\right)\hat{\jmath} + \left(\frac{\partial V_y}{\partial x} - \frac{\partial V_x}{\partial y}\right)\hat{k}$$

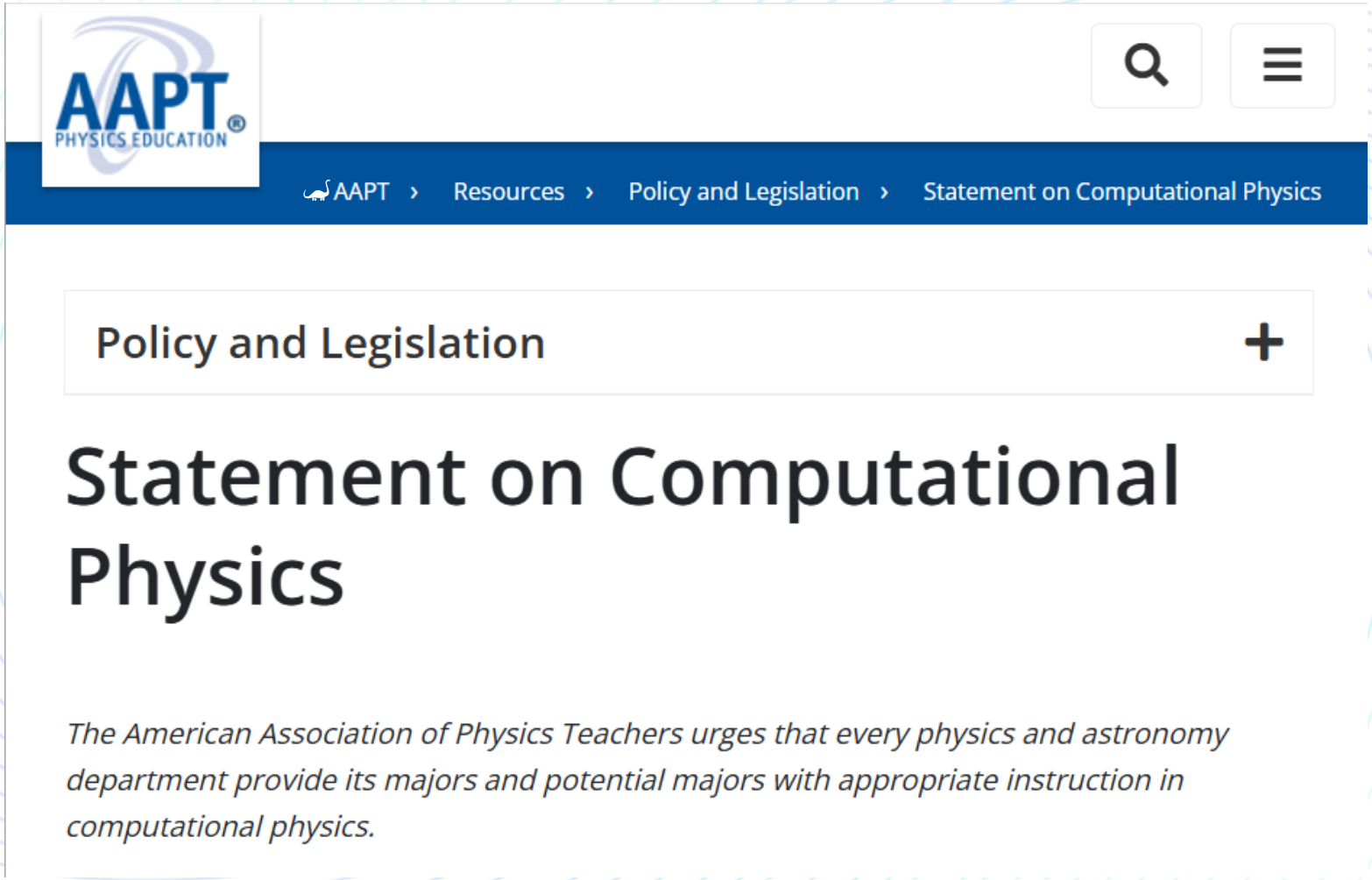
"…measure of how much the vector v **swirls** around the point"

Griffiths, D. "Introduction to electrodynamics." 2013



Is there divergence?

Is there curl?



American Association of Physics Teachers. (2011). Statement on Computational Physics. https://www.aapt.org/resources/policy/statement-on-computational-physics.cfm

Benefits of Computational Physics Exercises

Sand, O.P., et. al. "How computation can facilitate sensemaking about physics: A case study" *2018 PERC Proceedings*; https://doi.org/10.1119/perc.2018.pr.Sand

Research Question

How do computational exercises impact physics learning?

Pre-quiz

Tutorial

Computation exercise

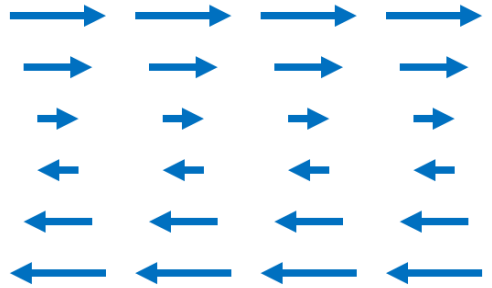
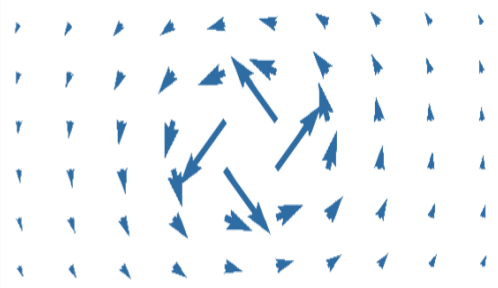
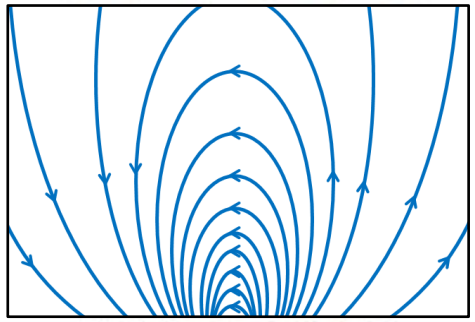
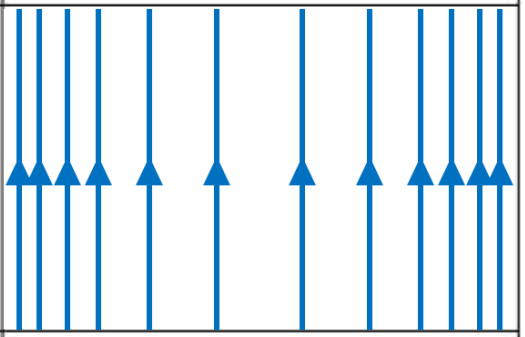
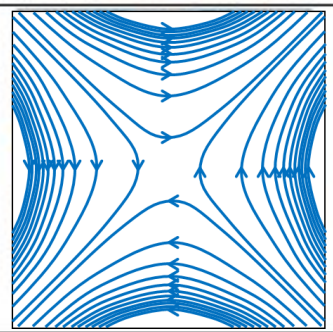
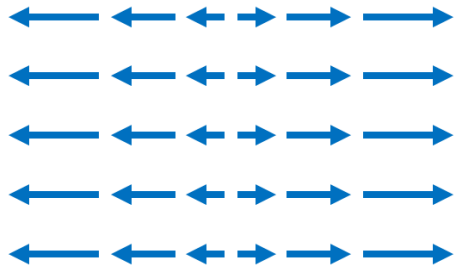
Post-quiz

Is there divergence?

S E N

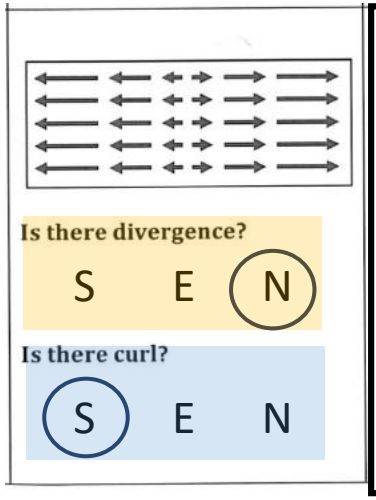
Is there curl?

S E N

#	Vector Fields	#	Vector Fields
1		5	
2	$\vec{F} = (y, x)$	6	$\vec{F} = A\vec{r}$
3		7	
4		8	

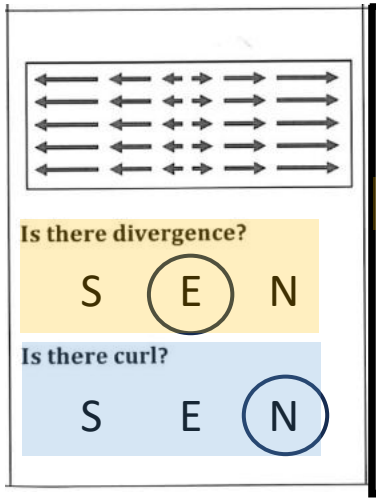
These fields were designed to catch common misconceptions and difficulties

Pre-quiz



"The field lines do not spread out, but they do change direction in the middle of the graph which makes me think that there is non-zero curl there."

Post-quiz

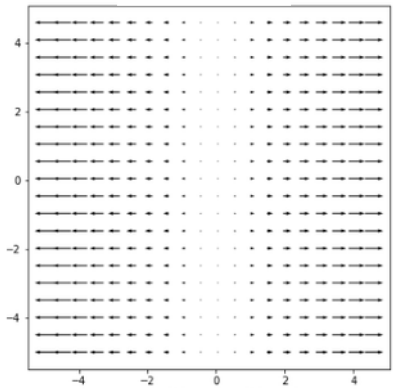


"Divergence: 0 nowhere. dVy/dy = Vy = 0 everywhere, but dVx/dx is non-zero at all places. Curl: 0 everywhere. Again, dVy/dx = Vy = 0 everywhere. Also, the x component is constant in y, implying dVx/dy is 0 everywhere."

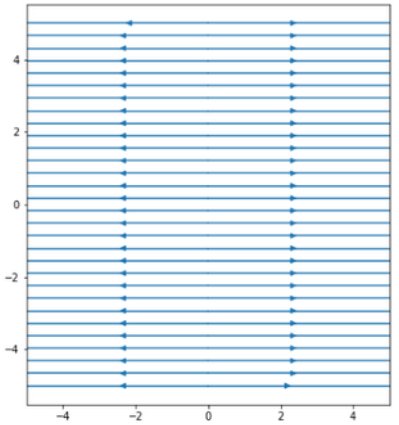
Computation Exercise

```
def Field8(x,y):
    Vx = x
    Vy = np.zeros(x.shape)
    return Vx, Vy
```

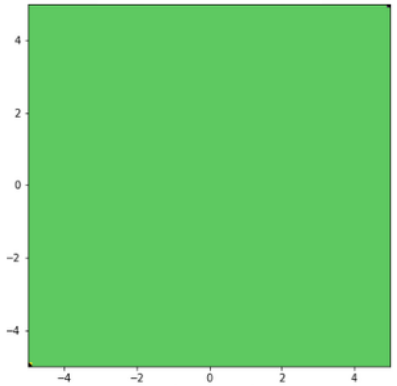
Vector Plot



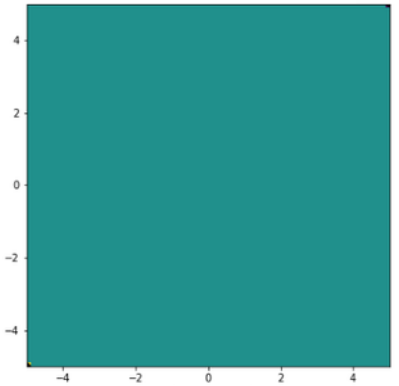
Field Line Plot

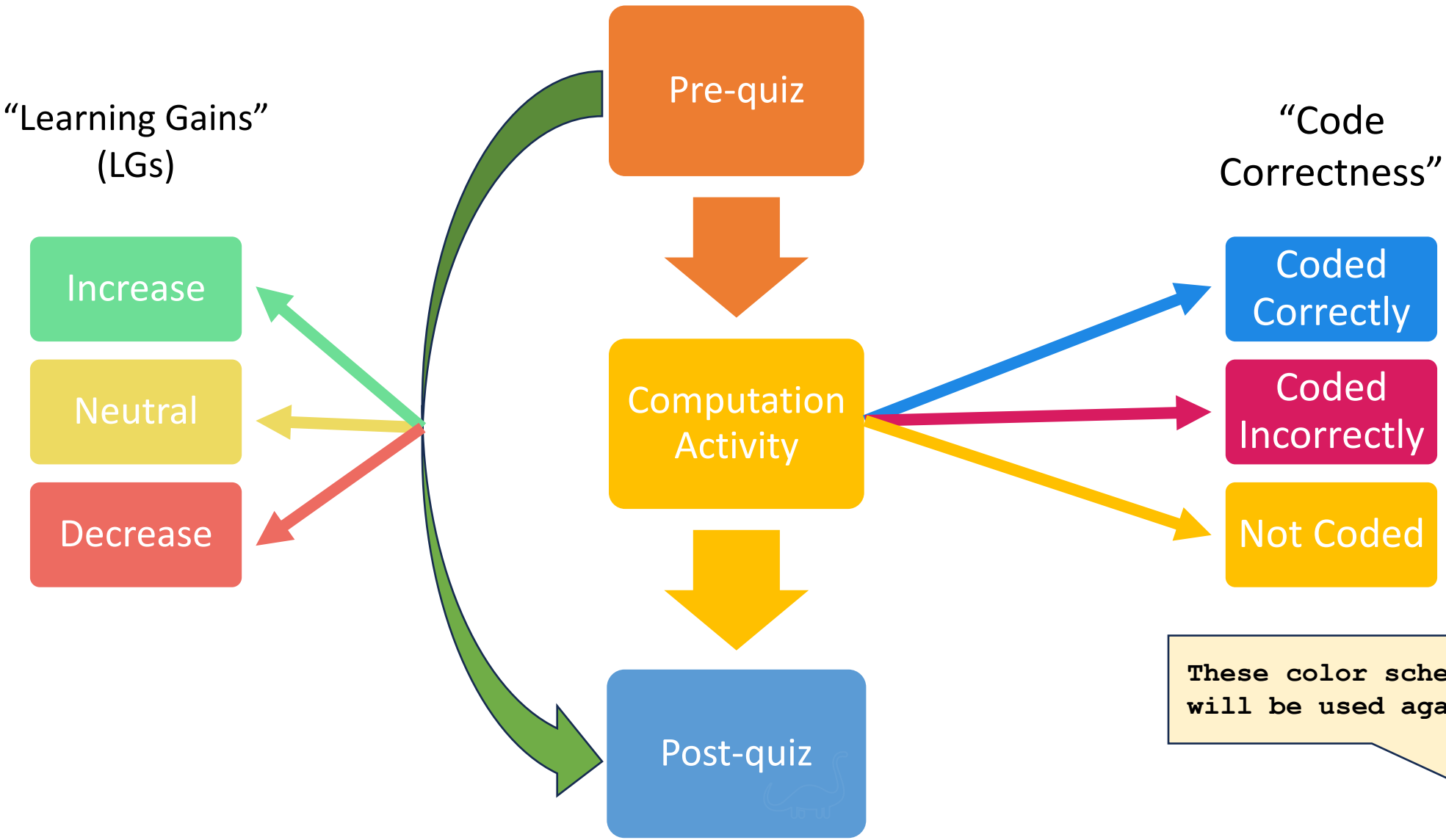


Divergence

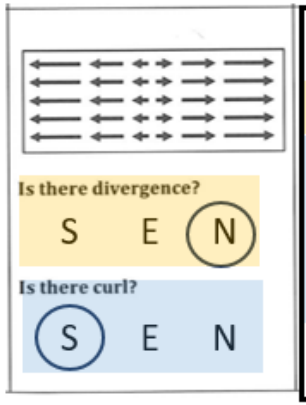


Curl



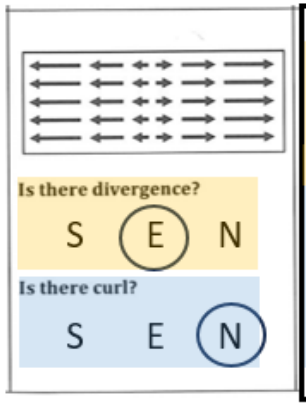

"Learning Gains" (LGs)
Increase
Neutral
Decrease
Pre-quiz
Computation Activity
Post-quiz
"Code Correctness"
Coded Correctly
Coded Incorrectly
Not Coded
These color schemes will be used again!

Pre-quiz



"The field lines do not spread out, but they do change direction in the middle of the graph which makes me think that there is non-zero curl there."

Post-quiz



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Computation Exercise

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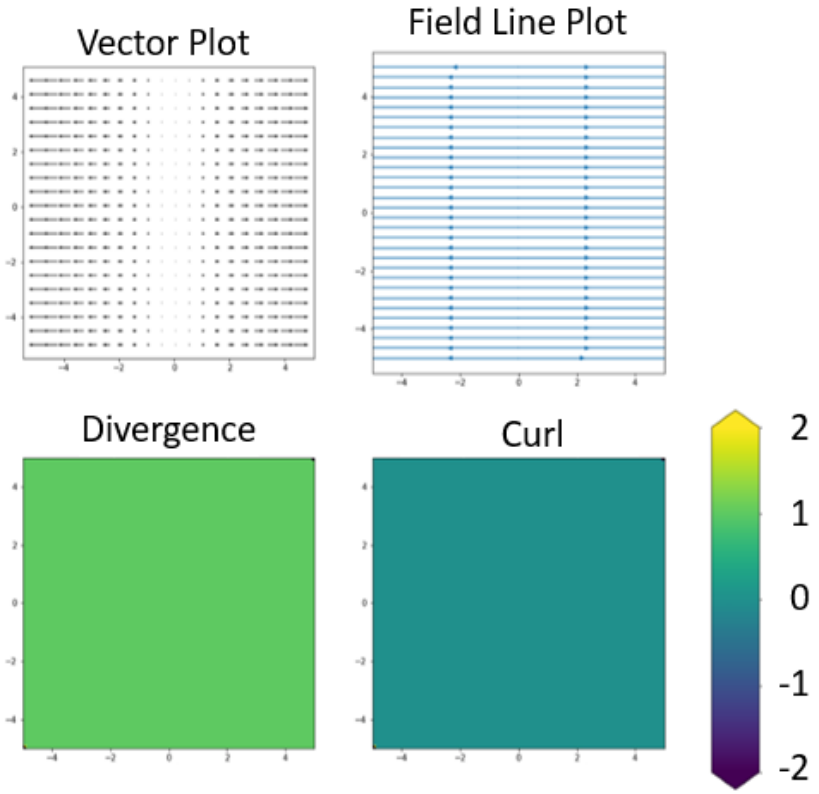


<u>Learning Gains</u>

Divergence: Increase

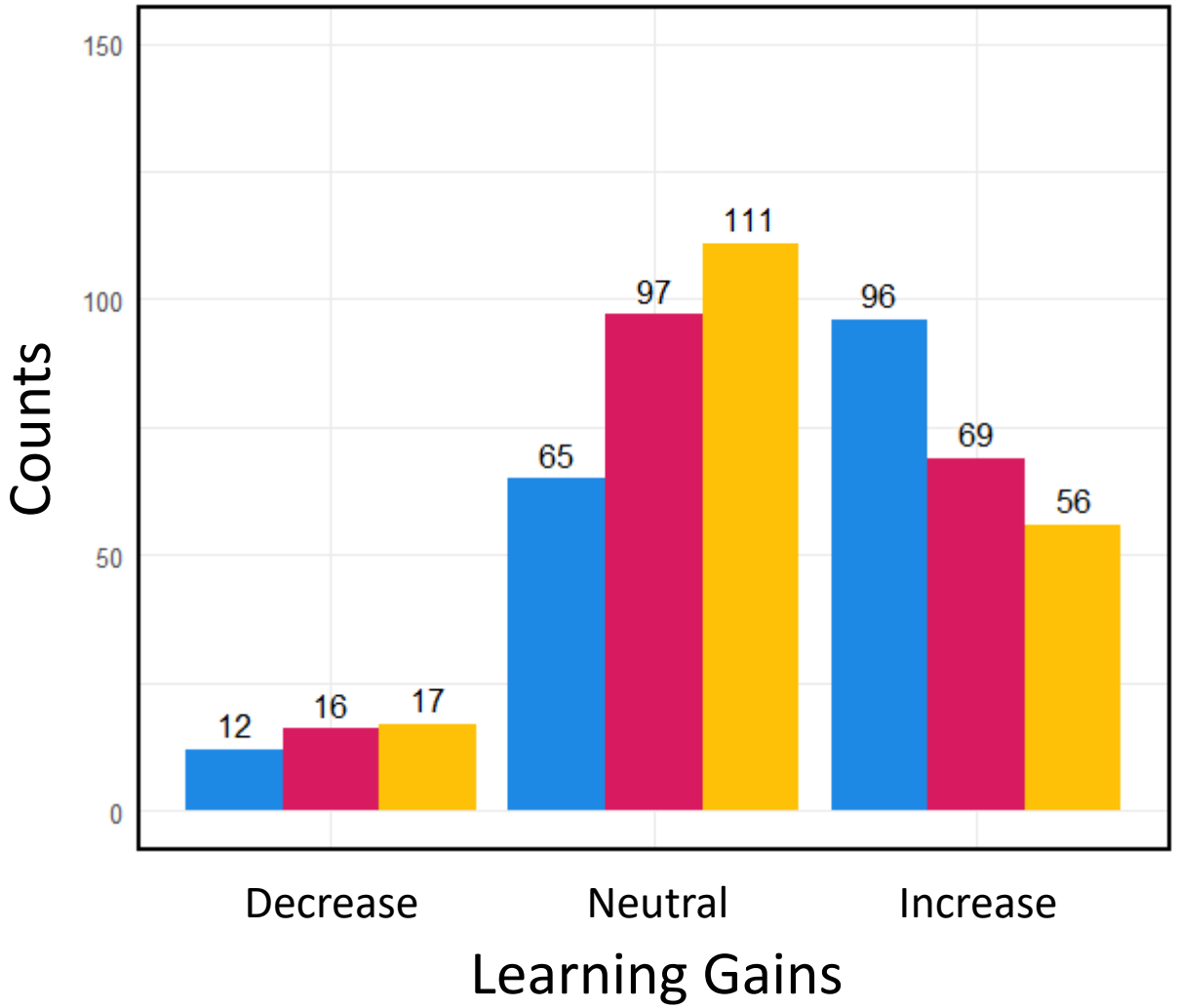
Curl: Increase

<u>Code Correctness</u>

Coded Correctly

Code Correctness

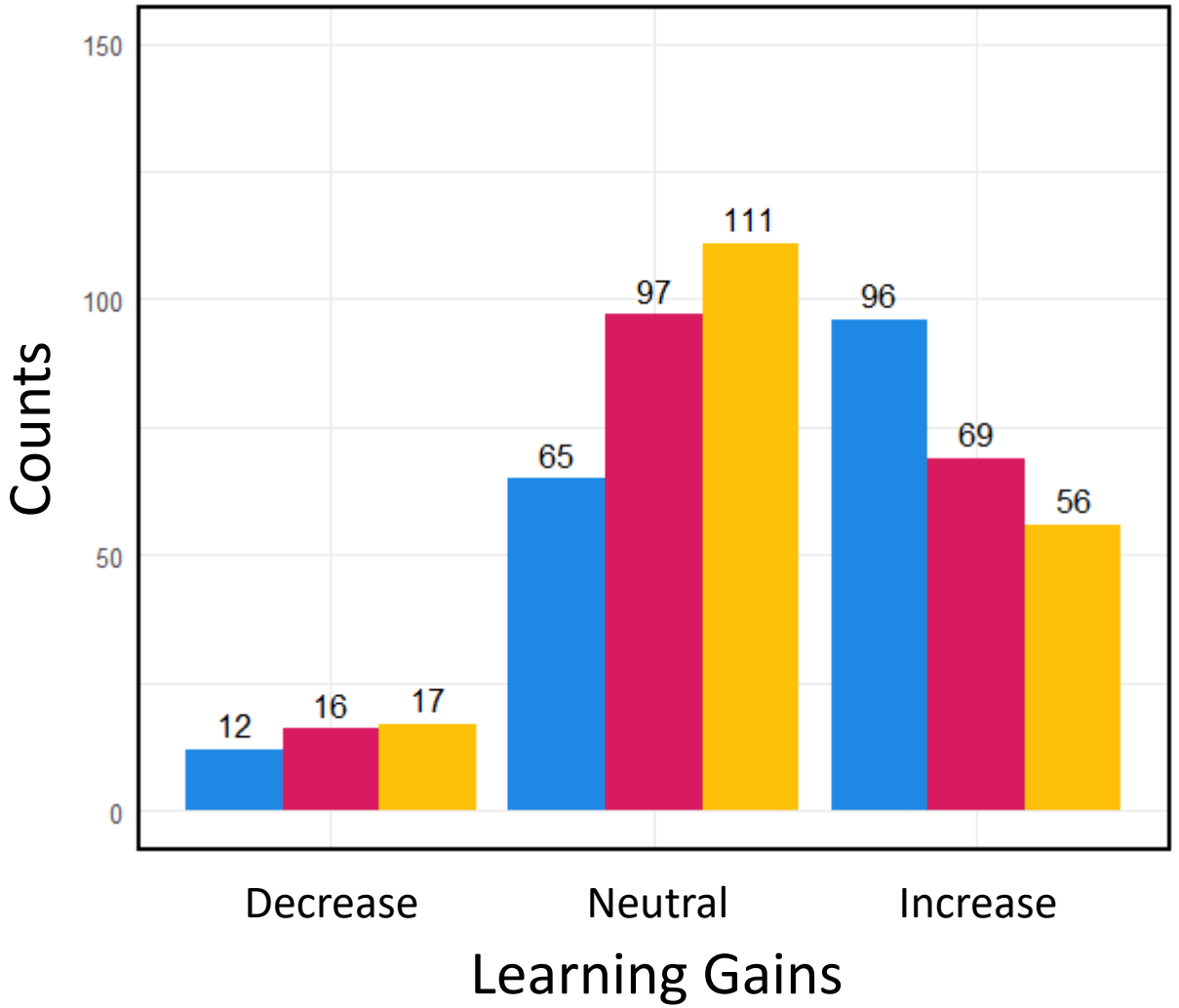
$$\ln\left(\frac{P(LG \leq l|X)}{P(LG > l|X)}\right) = \zeta_l - \eta_{Incorrect}X_{Incorrect} - \eta_{Not\ Coded}X_{Not\ Coded}$$



Base Model			
N	539		
Parameter	**Coeff.**	**Std. E**	**Signif.**
Code Category: Incorrect	-0.67	0.21	** 0.0014
Code Category: Not Coded	-0.93	0.21	*** 8.9×10^{-6}

Code Correctness

$$\ln\left(\frac{P(LG \leq l|X)}{P(LG > l|X)}\right) = \zeta_l - \eta_{Incorrect}X_{Incorrect} - \eta_{Not\ Coded}X_{Not\ Coded}$$



Engaging with the Computation Exercise corresponded to neutral/positive Learning Gains. They were most positive when Coded Correctly.

Coding Incorrectly did not negatively impact learning.

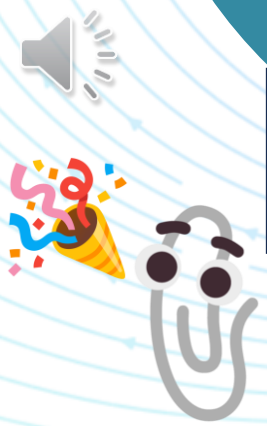
How do computational exercises impact physics learning?

1. Coding activity → Increased learning gains
2. Coded Correctly → Higher chance of positive learning gains
3. Coded Incorrectly ≠ Negative learning gains
4. Switch from qualitative to more quantitative
5. All tools were used more correctly, especially when Coded Correctly
6. Increased representational competency and fluency

Conclusion

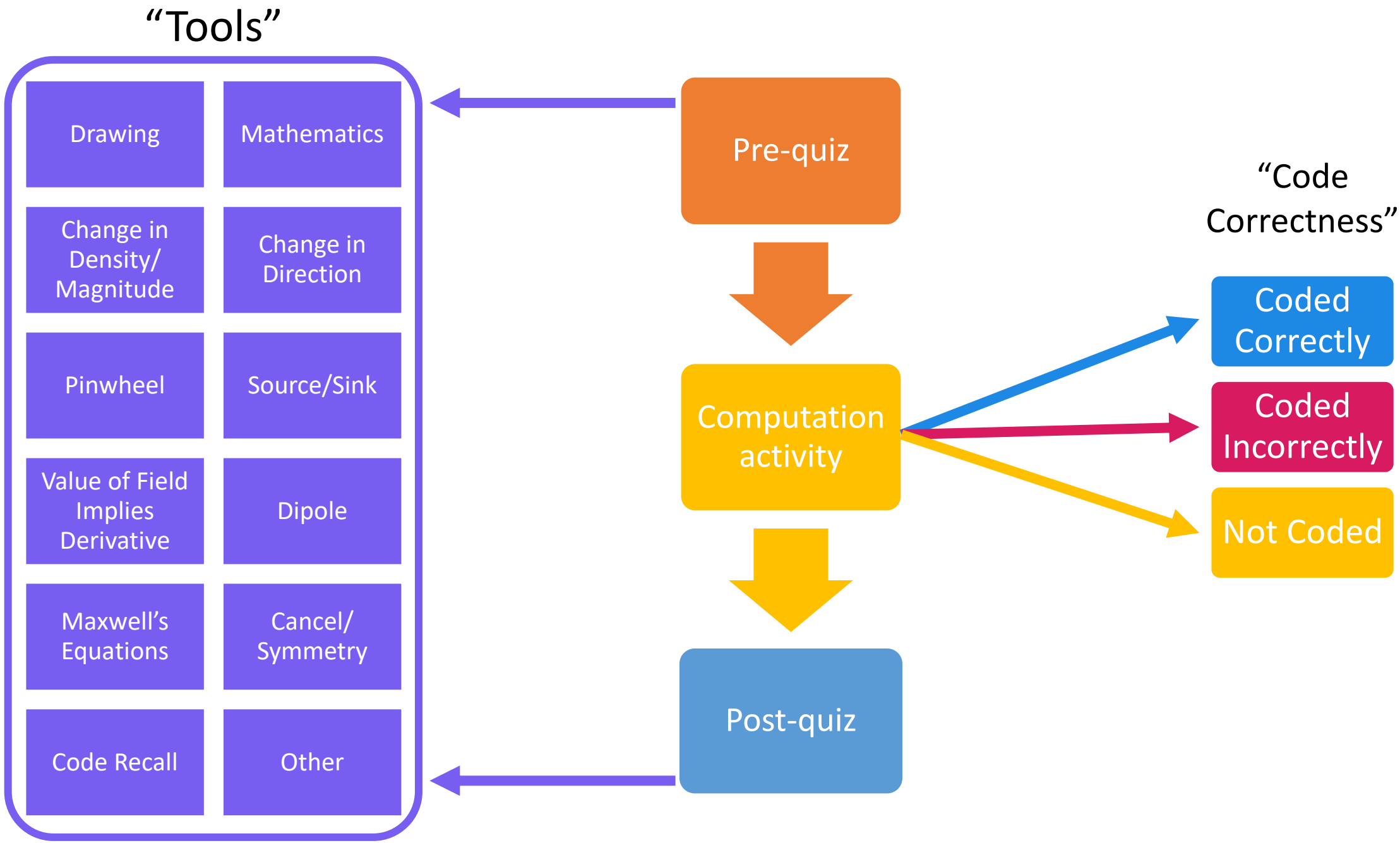
Computational physics activities show promise as tools for physics learning

Thank you!
What can I clarify?

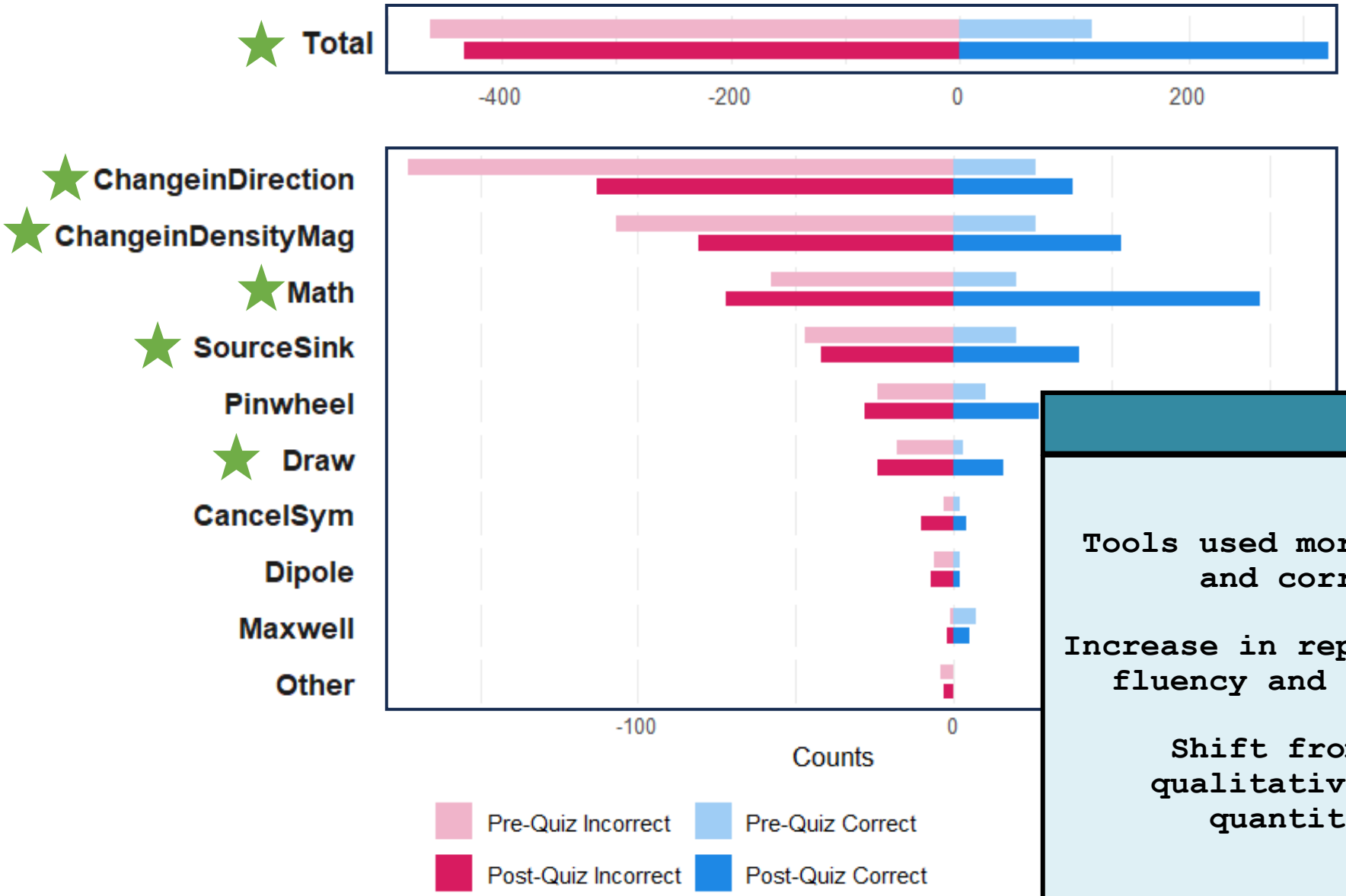


Thank you to Mike Massa, Martin Williams, and Owen Butler

Backup Slides


"Tools"
Drawing
Mathematics
Change in Density/ Magnitude
Change in Direction
Pinwheel
Source/Sink
Value of Field Implies Derivative
Dipole
Maxwell's Equations
Cancel/ Symmetry
Code Recall
Other
Pre-quiz
Computation activity
Post-quiz
"Code Correctness"
Coded Correctly
Coded Incorrectly
Not Coded

All Derivatives

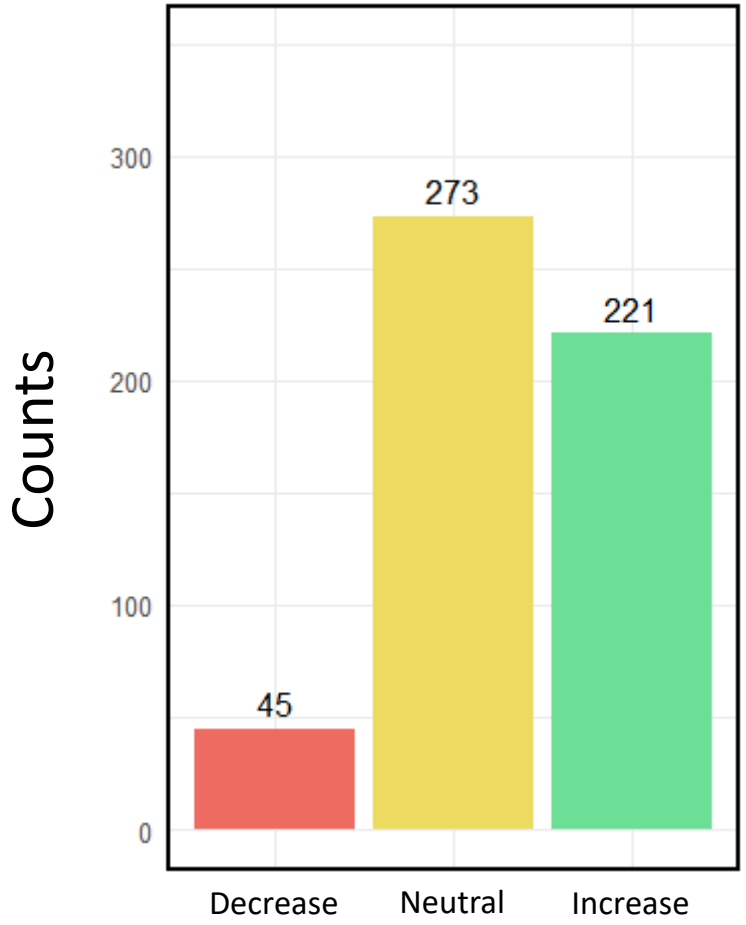


Tools used more frequently and correctly.

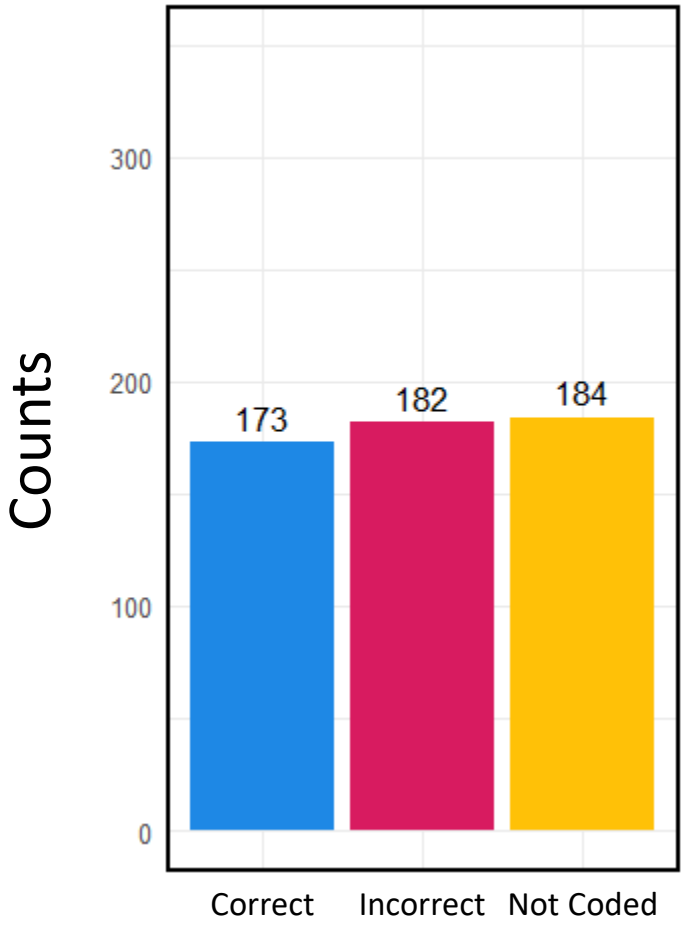
Increase in representational fluency and competency.

Shift from mostly qualitative to more quantitative.

Learning Gains

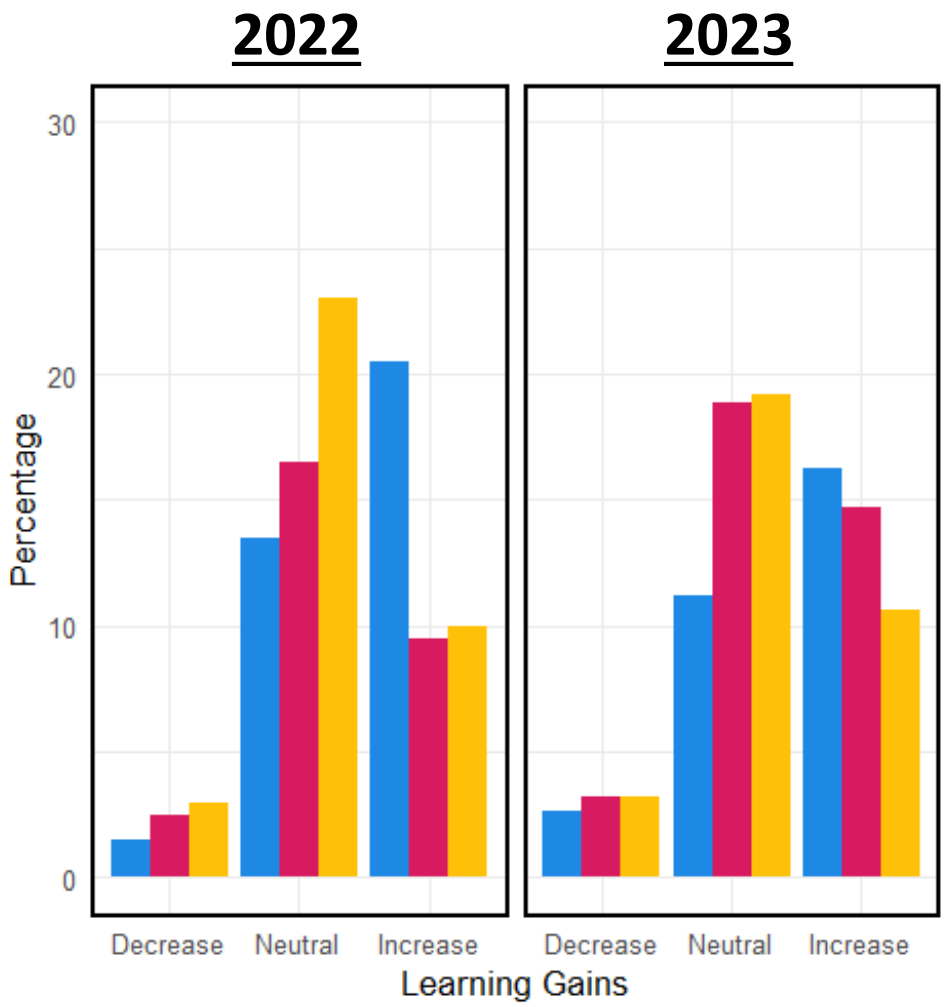


Coding Correctness



Remember! Students only needed to code 5/8 Fields.

Year



Base Model + Year			
N	539		
Pseudo-R^2	0.02		
Parameter	**Coeff.**	**Std. E**	**Signif.**
Code Category: Incorrect	-0.67	0.21	** 0.0014
Code Category: Not Coded	-0.94	0.21	*** 8.8×10^{-6}
Year: 2023	0.04	0.17	0.83