CCSE
Center for Computing in Science Education

Using Computational Essays to Support Student Creativity and Agency in Science

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ProDaBi Seminar
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UiO : Det matematisk-naturvitenskapelige fakultet

Centre for Excellence in Education

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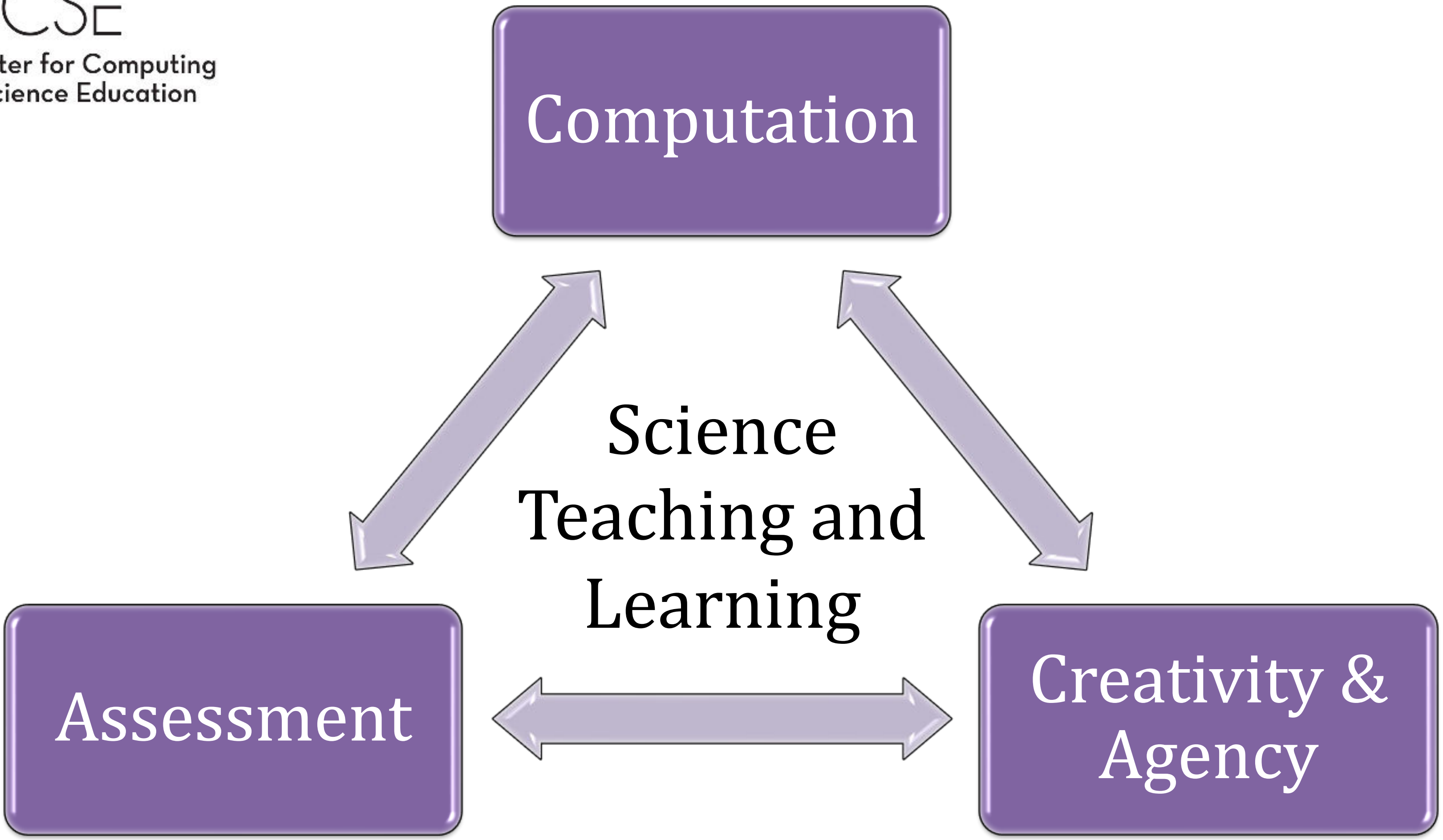
Center for Computing in Science Education



UiO : University of Oslo

UNIVERSITY OF OSLO AND THE CCSE

Welcome to the University of Oslo

Established 1811

3 campuses & 2 museums

27000 students & 6600 employees

3100 courses, 227 study programs

Welcome to the Center for Computing in Science Education

Faculty of mathematics and natural science

Law	Math and Nat. Sci.
Medicine	Education
Humanities	Odontology
Social sciences	Theology

Department of physics

(48 faculty, 200 PhD students)

Mathematics	Bioscience
Physics	Astronomy
Chemistry	Pharm. Science
Geoscience	Technology syst.
Computer Science	

CCSE

Center for Computing in Science Education

SENTER FOR FREMRAGENDE UTDANNING

(1 of 12 national centers)





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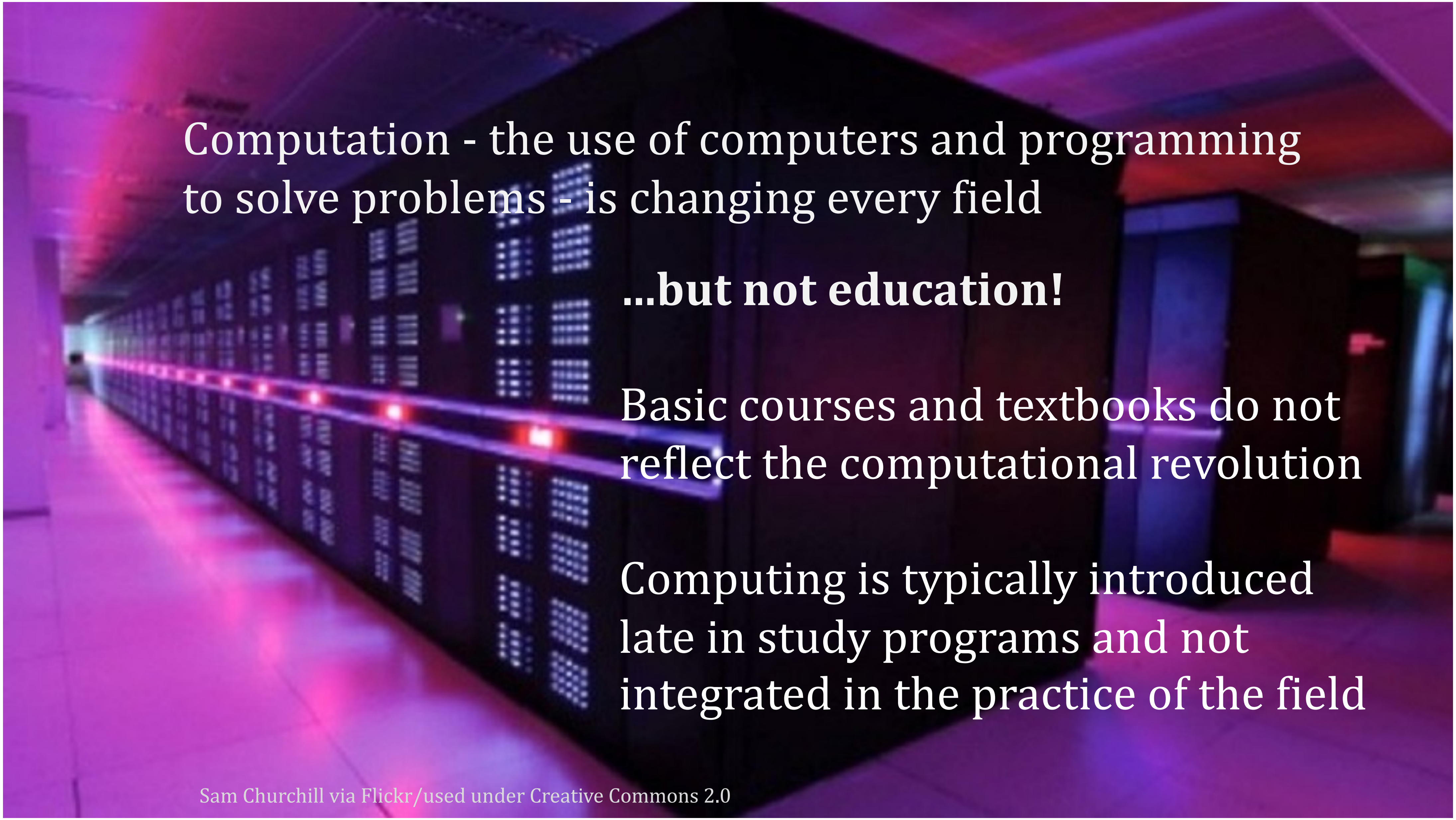
CMSE



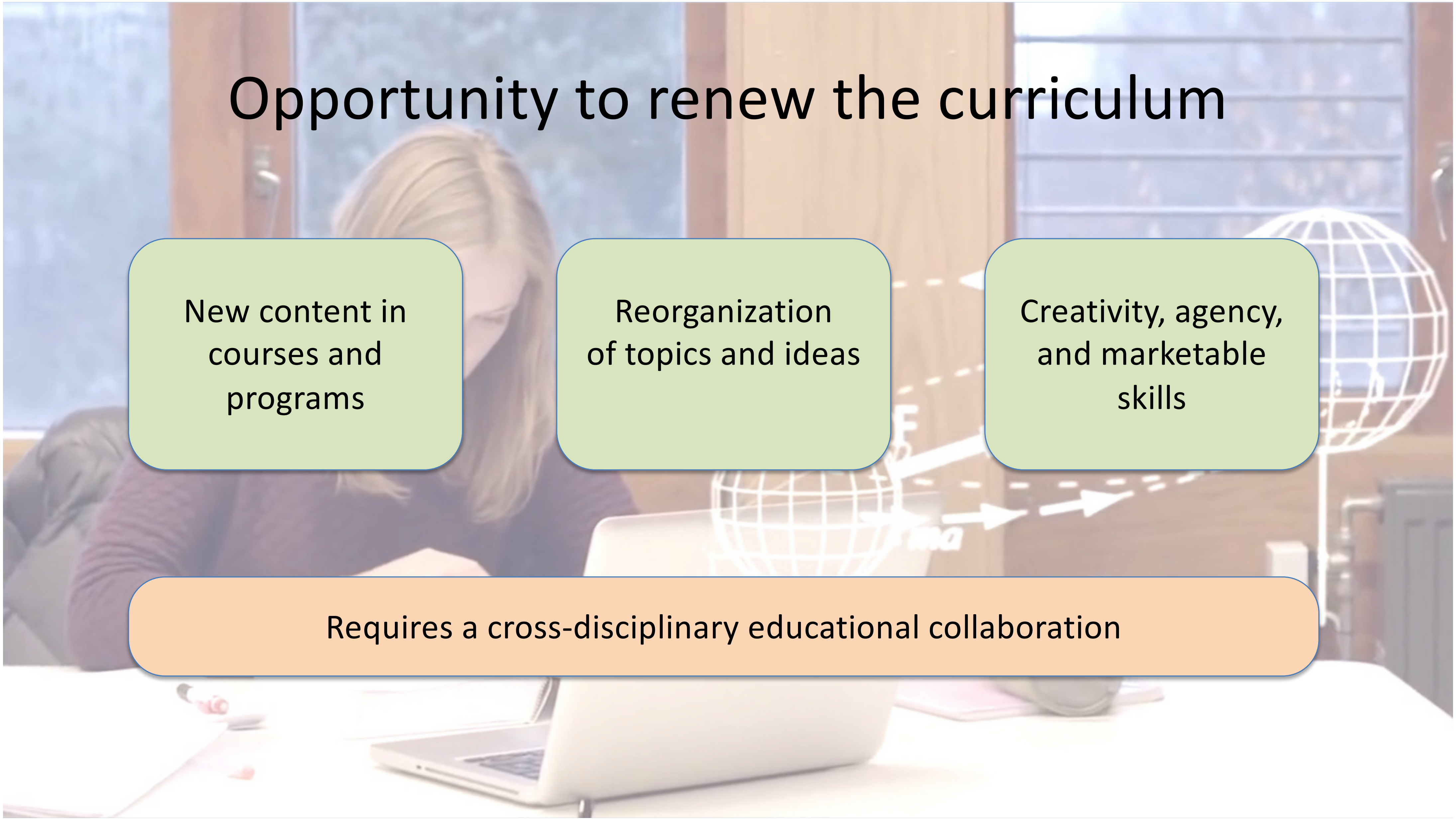
Computation - the use of computers and programming to solve problems - is changing every field

...but not education!

Basic courses and textbooks do not reflect the computational revolution

Computing is typically introduced late in study programs and not integrated in the practice of the field

Opportunity to renew the curriculum



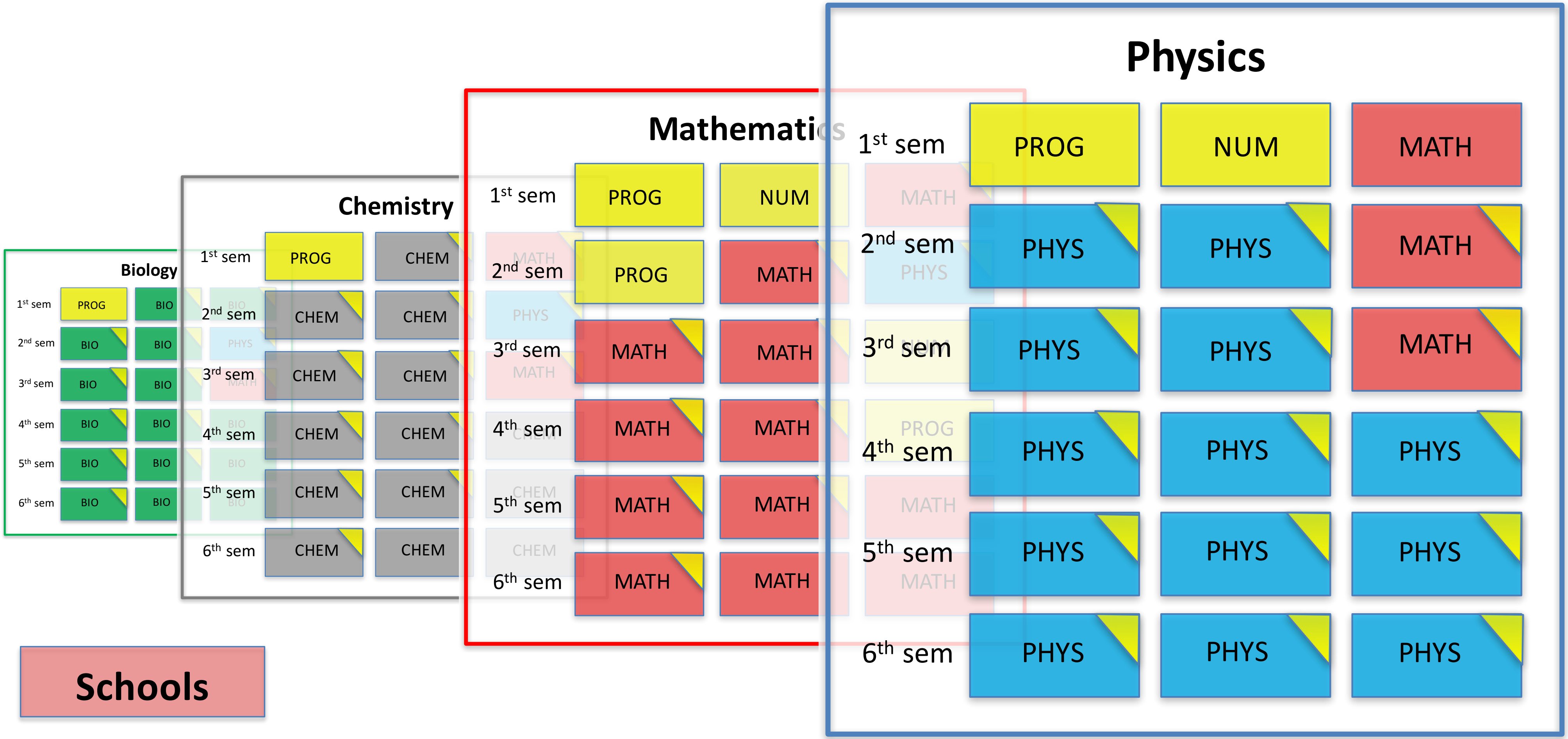
New content in courses and programs

Reorganization of topics and ideas

Creativity, agency, and marketable skills

Requires a cross-disciplinary educational collaboration

At the University of Oslo, programming is integrated in all science study programs and adapted to the disciplinary context



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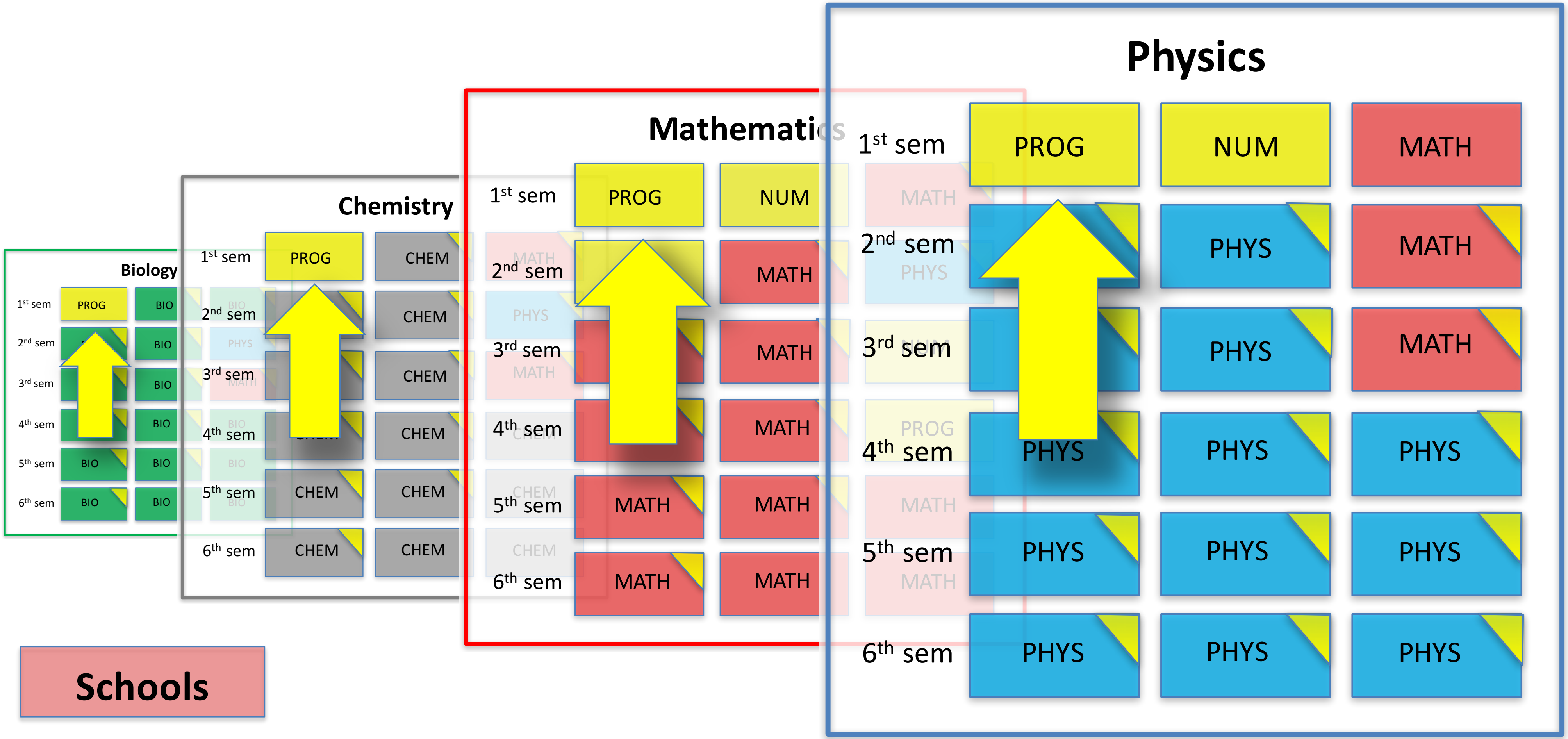

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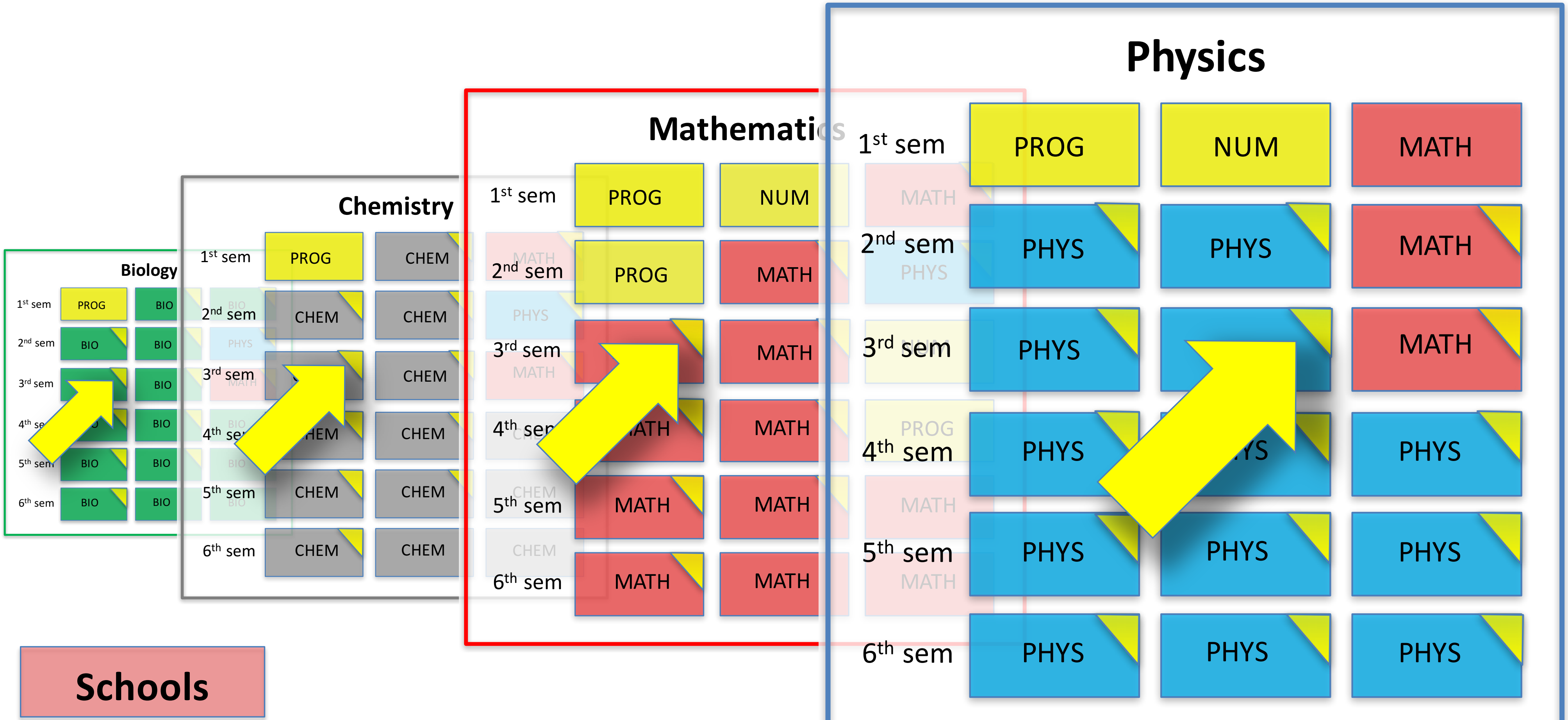
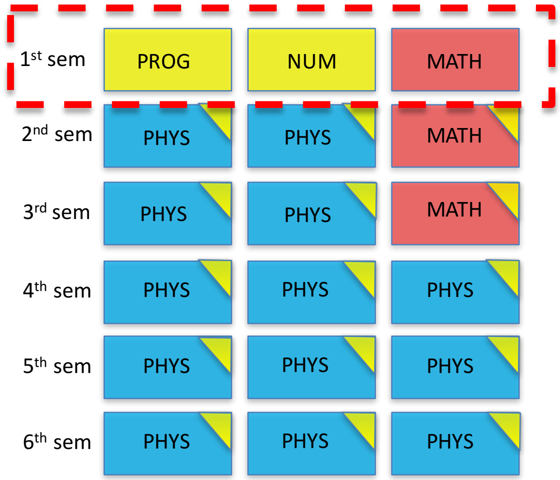


Integration across departments



MAT1100: Calculus

Week 5:
The derivative is defined

$$\frac{df}{dx} = \lim_{\Delta x \to 0} \left(\frac{f(x+\Delta x) - f(x)}{\Delta x} \right)$$

IN1900: Scientific computing

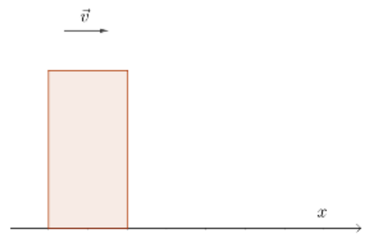
Week 6:
The numerical derivative is implemented in Python

```
def dfdx(f,x):
  h=1e-10
  dfdx=(f(x+h)-f(x))/h
  return dfdx
```

FYS1100: Mechanics and modeling

Week 8:
Use numerical derivatives to analyze motion

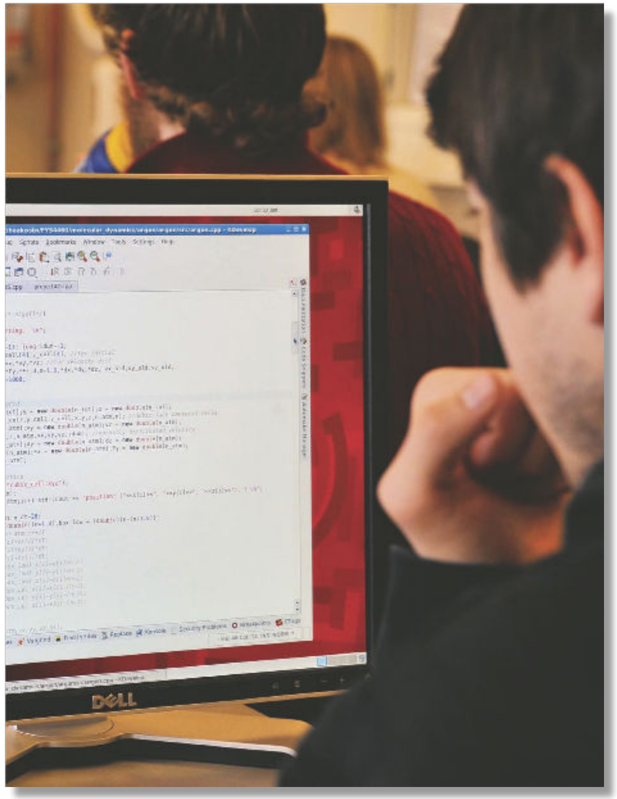
$$\frac{df}{dx} = \left(\frac{f(x+\Delta x) - f(x)}{\Delta x} \right) + O(\Delta x)$$



Programming is understanding

$$F = \begin{cases} -k(x+d) & x < -d \\ 0 & x > -d \end{cases}$$

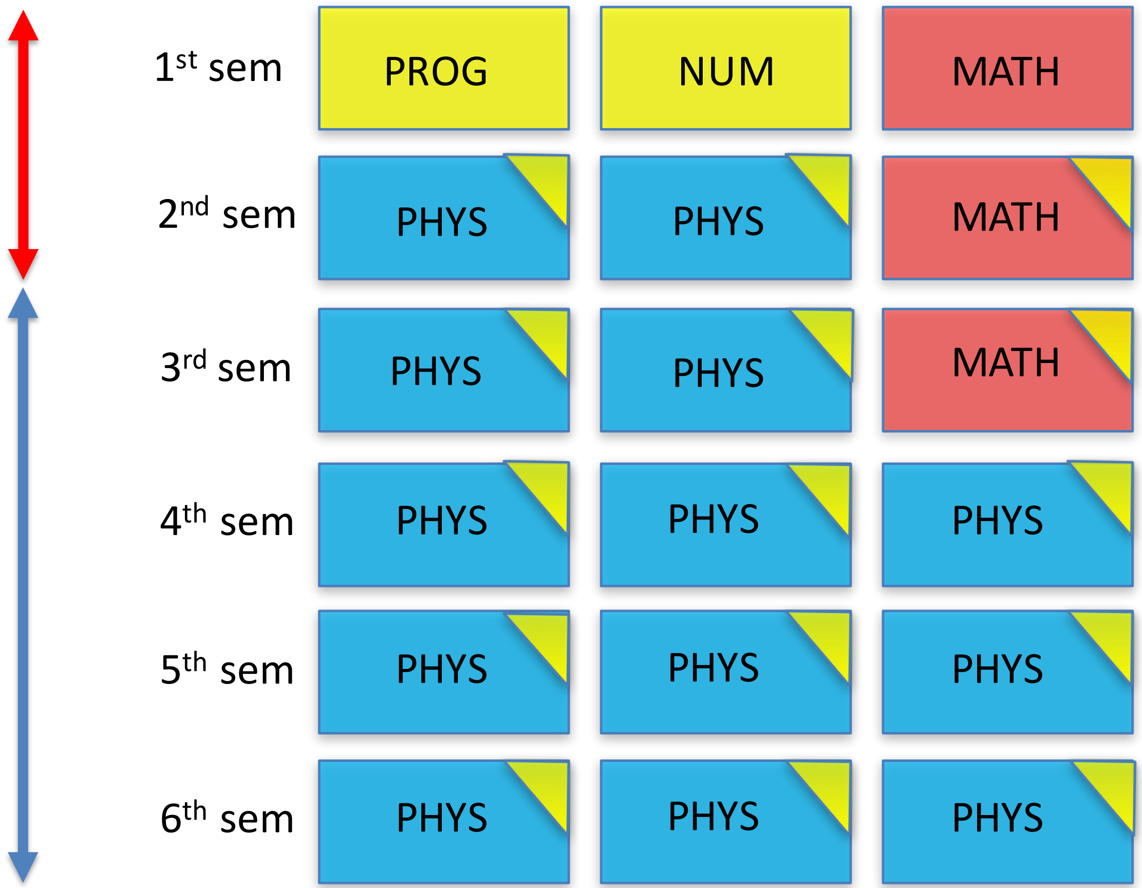
```
if (x[i]<-d):
    F = -k(x[i]+d)
else:
    F = 0.0
```



From skills to student agency

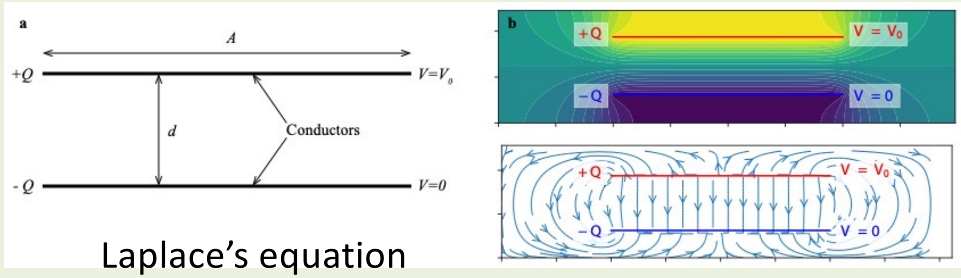
Fundamental skills

Creativity,
authenticity,
realistic problems,
student agency

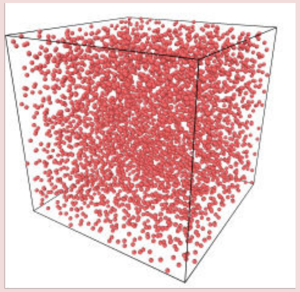


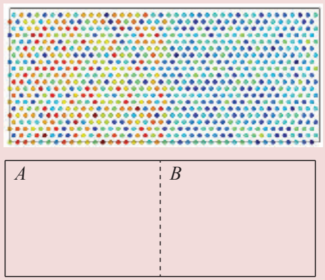
Mechanics

Electromagnetism



Statistical and thermal physics

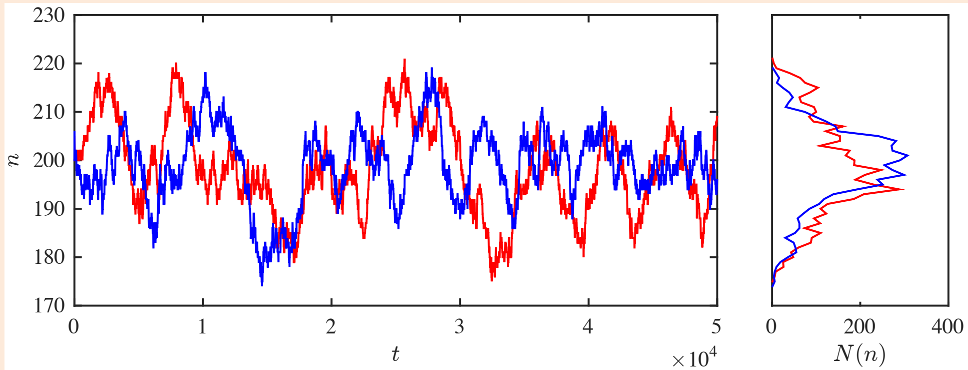


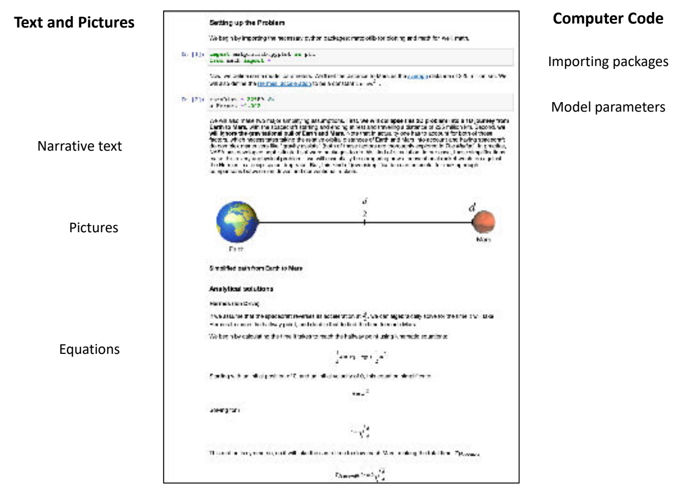


$q_A + q_B = q$

$N_A + N_B = N$

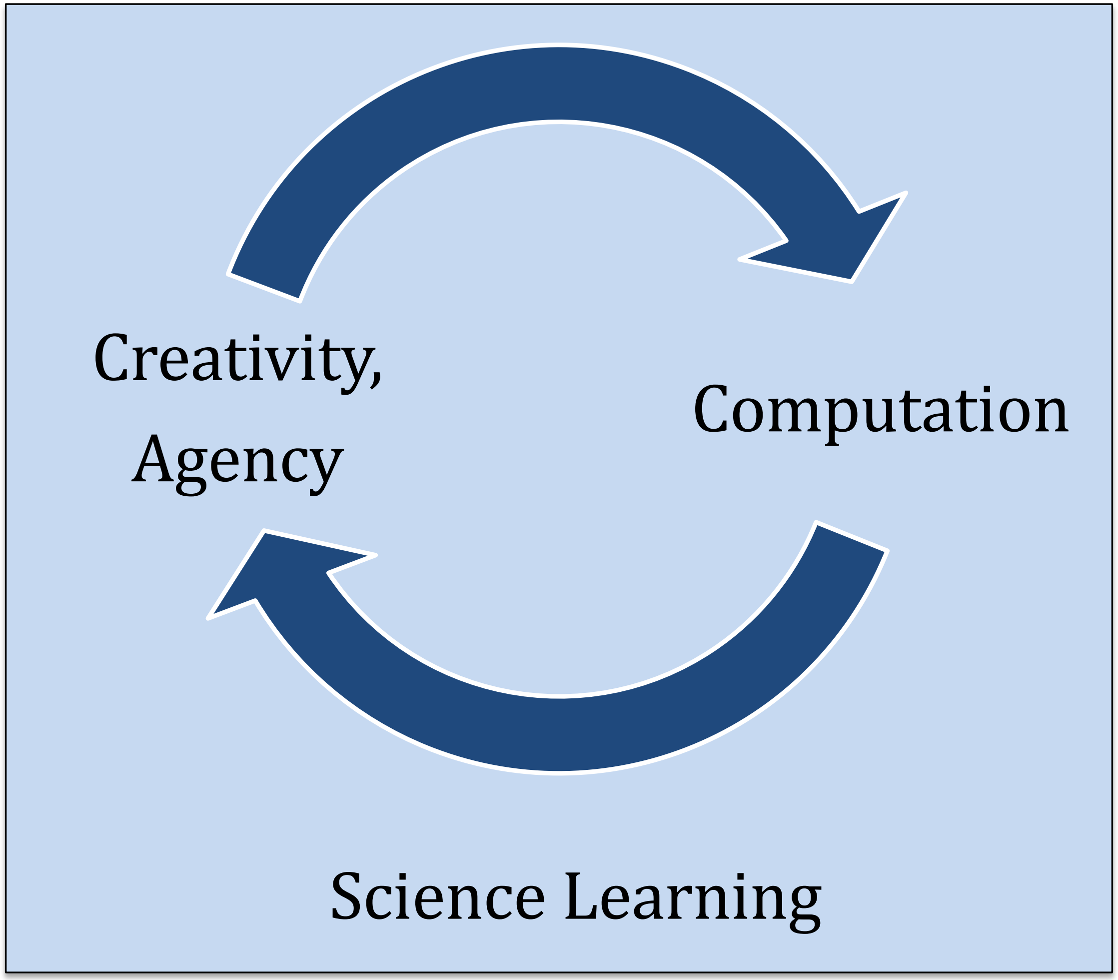
Statistics





COMPUTATIONAL ESSAYS AT THE UNIVERSITY OF OSLO

Creativity and Agency in Science Learning

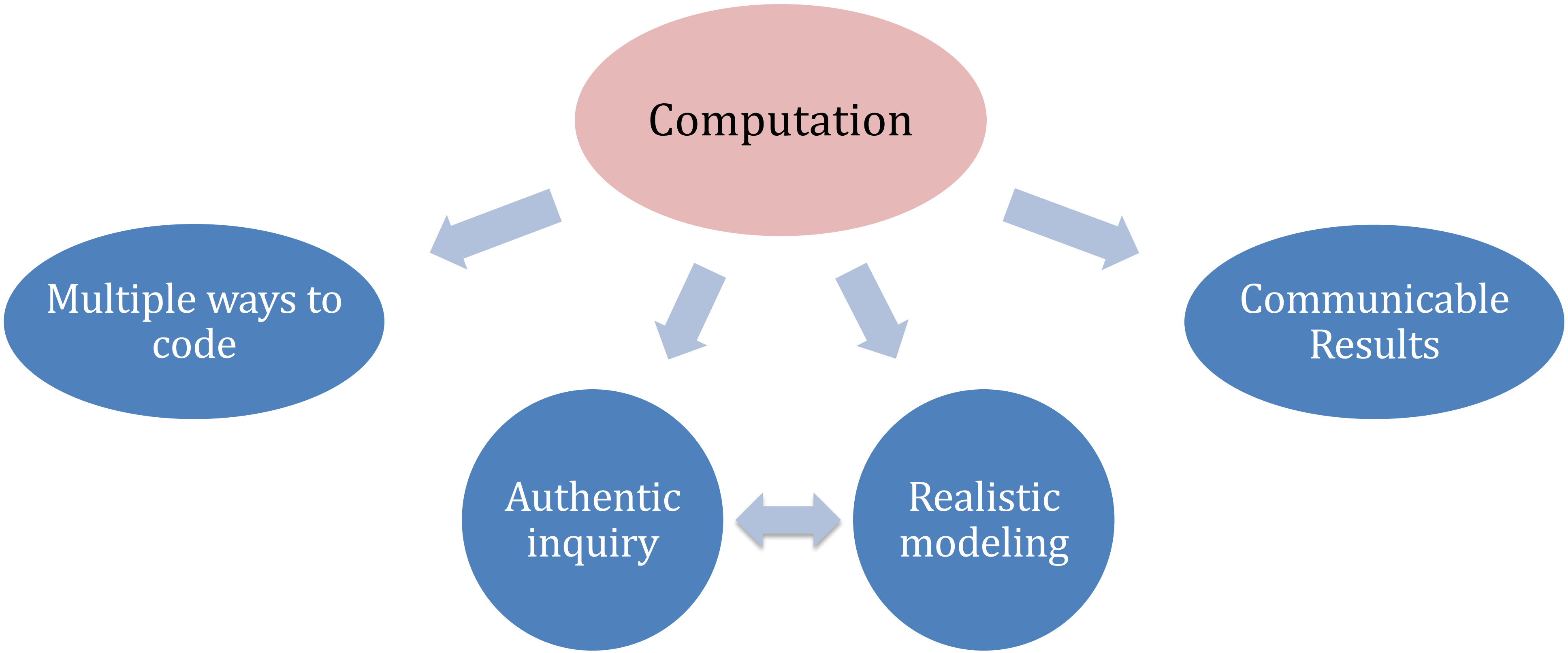


Epistemic agency

Epistemic Agency: the ways in which students take control and ownership of their own scientifically-authentic processes of learning and inquiry.

Epistemic agents: "individuals or groups who take, or are granted, responsibility for shaping the knowledge and practice of a community" [3].

Computation and Student Agency



Computational Essay (Computational Narrative)

A written document that uses both **writing** and **code** to present an argument, explain an analysis, or tell a story

[4]

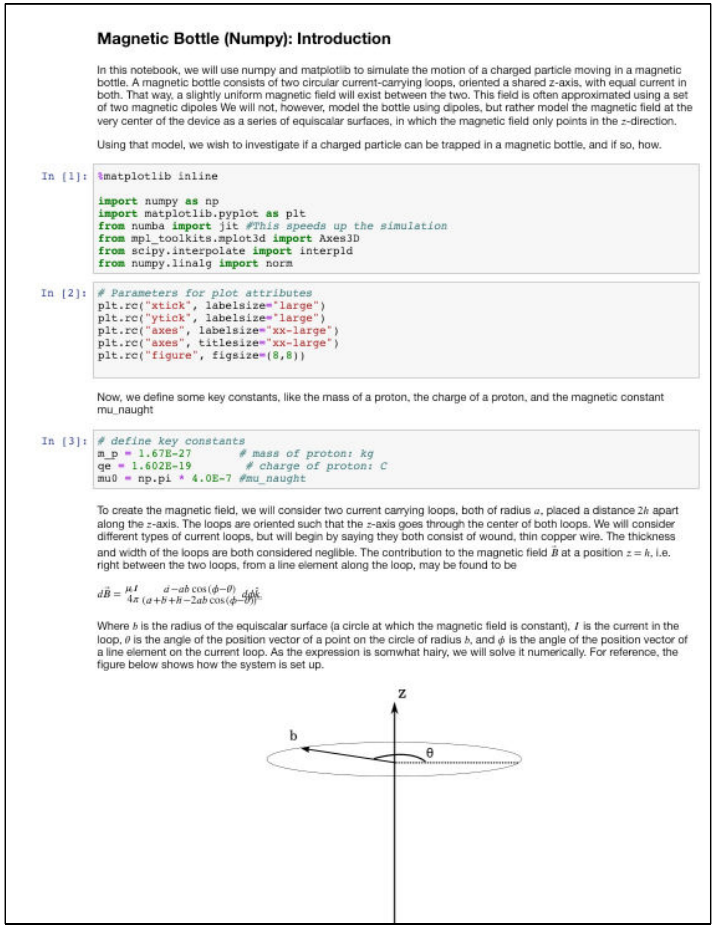
Computational Essays

Narrative text

Title and Introduction

Text and Equations

Pictures and Diagrams



Magnetic Bottle (Numpy): Introduction

In this notebook, we will use numpy and matplotlib to simulate the motion of a charged particle moving in a magnetic bottle. A magnetic bottle consists of two circular current-carrying loops, oriented a shared z-axis, with equal current in both. That way, a slightly uniform magnetic field will exist between the two. This field is often approximated using a set of two magnetic dipoles We will not, however, model the bottle using dipoles, but rather model the magnetic field at the very center of the device as a series of equiscalar surfaces, in which the magnetic field only points in the z-direction.

Using that model, we wish to investigate if a charged particle can be trapped in a magnetic bottle, and if so, how.

In [1]:
```
%matplotlib inline

import numpy as np
import matplotlib.pyplot as plt
from numba import jit #This speeds up the simulation
from mpl_toolkits.mplot3d import Axes3D
from scipy.interpolate import interpld
from numpy.linalg import norm
```

In [2]:
```
# Parameters for plot attributes
plt.rc("xtick", labelsize="large")
plt.rc("ytick", labelsize="large")
plt.rc("axes", labelsize="xx-large")
plt.rc("axes", titlesize="xx-large")
plt.rc("figure", figsize=(8,8))
```

Now, we define some key constants, like the mass of a proton, the charge of a proton, and the magnetic constant mu_naught

In [3]:
```
# define key constants
m_p = 1.67E-27        # mass of proton: kg
qe = 1.602E-19        # charge of proton: C
mu0 = np.pi * 4.0E-7 #mu_naught
```

To create the magnetic field, we will consider two current carrying loops, both of radius a, placed a distance $2h$ apart along the z-axis. The loops are oriented such that the z-axis goes through the center of both loops. We will consider different types of current loops, but will begin by saying they both consist of wound, thin copper wire. The thickness and width of the loops are both considered neglible. The contribution to the magnetic field $\vec{B}$ at a position $z = h$, i.e. right between the two loops, from a line element along the loop, may be found to be

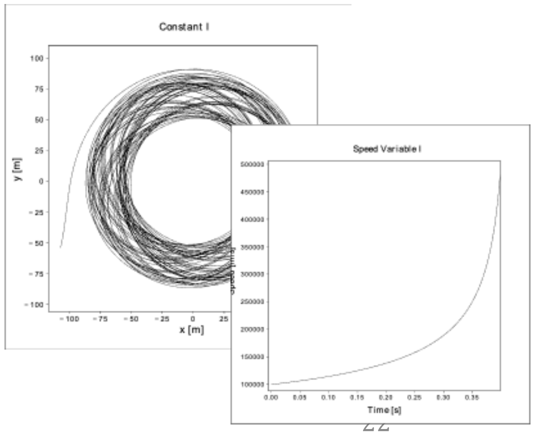
$$d\vec{B} = \frac{\mu I}{4\pi} \frac{a - ab\cos(\phi-\theta)}{(a+b+h-2ab\cos(\phi-\theta))} d\phi\hat{k}$$

Where b is the radius of the equiscalar surface (a circle at which the magnetic field is constant), I is the current in the loop, θ is the angle of the position vector of a point on the circle of radius b, and ϕ is the angle of the position vector of a line element on the current loop. As the expression is somwhat hairy, we will solve it numerically. For reference, the figure below shows how the system is set up.

Live Code Input & Output

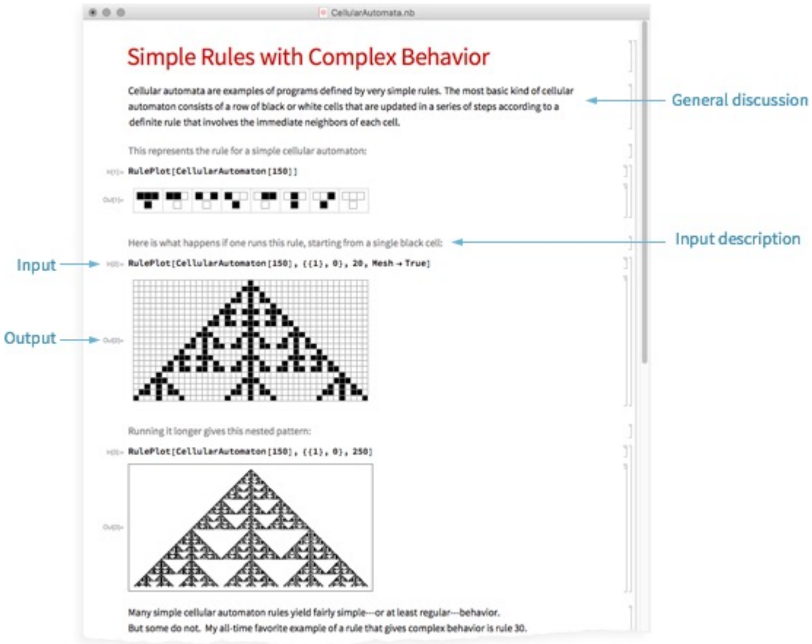
Importing packages

Model parameters

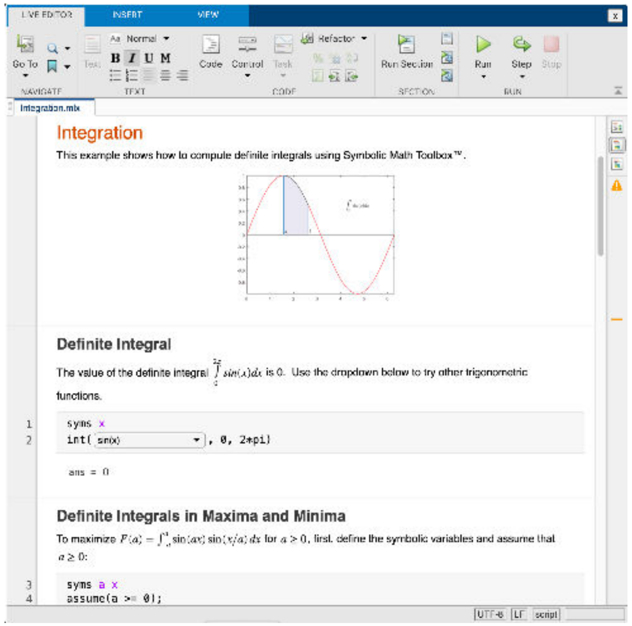


Other Examples of Computational Essays

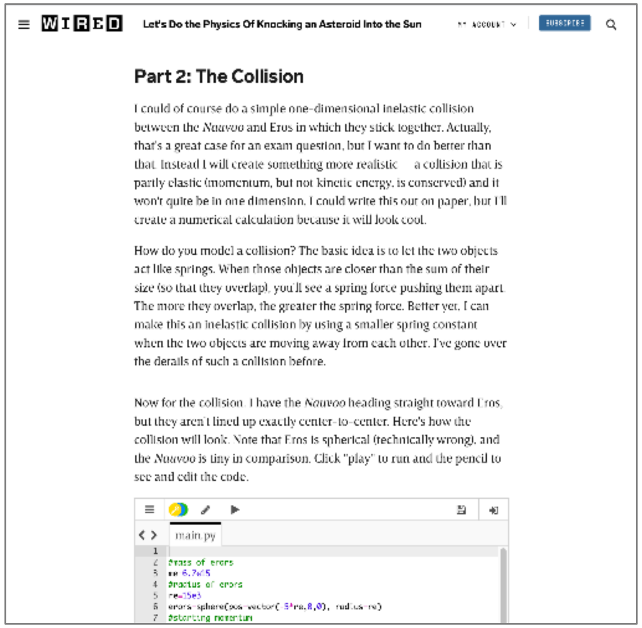
Mathematica [5]



MATLAB Live Editor [6]



Website with Trinket [7]



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Computational Essay Design

Challenge: "Use a computational simulation to investigate a problem that you find interesting. Then, write a computational essay about what you've learned"

Essay Topics (Electricity & Magnetism):

- Railgun-powered train lines
- Cyclotrons for cancer therapy
- Automated car lane control using magnetic fields
- Northern lights
- Lightning safety in cars
- Friction on ions in nerve cells

...and many more!

Essays available at:

Summative Assessment

Requirement	Points	Novice Competence	Developing Competence	Mastering Competence
Investigation Question	4	No question, or question could be answered using the example code as given (without modification)	Investigation question is not physical and/or answerable by tweaking variables in example code	There is an investigation question, it is physically meaningful, and it requires significant additions to the example simulation to answer
		0 points ←--→ 4 points		
Coding	4	Code either doesn't work or is just the unmodified example	Code works, but only small changes have been made	Code works and there are significant additions to the code
		0 points ←--→ 4 points		
Physics in the Simulation	4	No additional physics has been added to the given simulation	Physics principles from E&M have been used to augment the simulation, but they are not clearly explained	Physics principles from E&M have been used to augment the simulation, and it is clear how they were derived and applied in the code
		0 points ←--→ 4 points		
Conclusion	4	No conclusion	Conclusion only states the results and does not justify their meaning or reasonability	Conclusion describes results, interprets their meaning, uses them to answer investigation question, and justifies their reasonability
		0 points ←--→ 4 points		
Written Report	4	No report, or report is uninformative and/or does not change the given notebook.	Report is sparse, does not adequately explain the code or steps of the investigation, and/or includes no pictures or diagrams. Little use or documentation of external sources.	Report clearly explains the steps of the investigation, is fleshed out with at least 1 picture or diagram. External sources are used and cited.
		0 points ←--→ 4 points		

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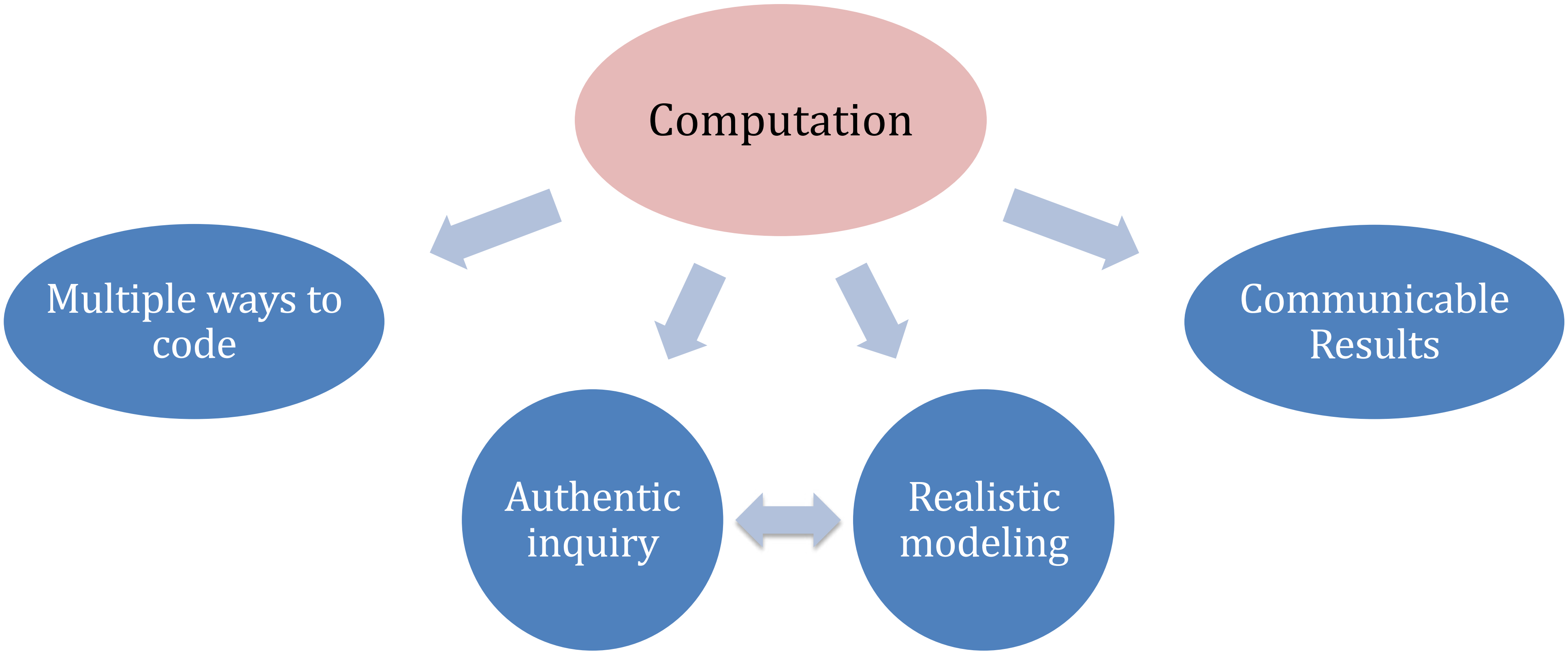
Computation and Student Agency



Creativity and Authenticity

Students report that working with computation
feels more **creative** and **authentic:**

I take these subjects because they don't require anything from me, in a way, I can just solve the problems and be done with it, and that's comfortable. But the fact that it requires some creativity is—it maybe becomes closer to the way it is to actually do physics. And I feel like this assignment here—that is, it recreates the situation where one has to invent something, one has to find something to figure out, in a way. It's not often that we encounter that in our STEM courses here. So, it's a little bit of a breath of fresh air, creatively speaking. (translated)

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Creativity and Motivation

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was **positive** and **motivating**:

Honestly I think this is better than the obligs in a way because I think we pushed ourselves harder here than we would with those assignments. Because then you have an endpoint like, okay, I've done what the program or what the assignment asked me to do and here's the program. But now when we finished something it was like 'this is really cool to actually see. What else can we do?'

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Impact of Educational Design?

Training in object-oriented programming
↓
Code efficiency

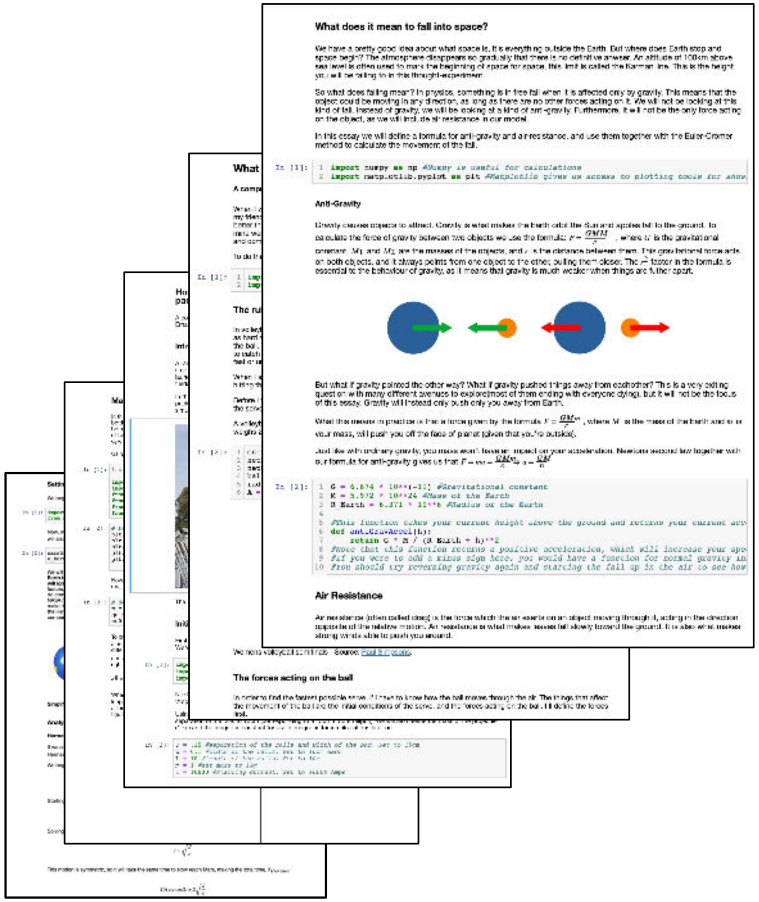
Physics simulations
↓
Assumptions and Limitations

Training in code readability, notebooks
↓
Organized, documented code

Completely open-ended project
↓
Novel investigation questions, external sources

Next Steps!

- Continued research on students’ **epistemic agency** [3]
- **Peer feedback** and iterative assessment
- Computational essays across **disciplines**
- Portfolio assessment!



Thank You!

References:

1. diSessa, A. A. (2000). *Changing minds: Computers, learning, and literacy*. MIT Press.
2. Odden, T. O. B., Lockwood, E., & Caballero, M. D. (2019). Physics Computational Literacy: An Exploratory Case Study Using Computational Essays. Physical Review Physics Education Research, 15(2), 20152.
3. Stroupe, D. (2014). Examining Classroom Science Practice Communities: How Teachers and Students Negotiate Epistemic Agency and Learn Science-as-Practice. Science Education, 98(3), 487–516.
4. https://www.theatlantic.com/science/archive/2018/04/the-scientific-paper-is-obsolete/556676/
5. https://writings.stephenwolfram.com/2017/11/what-is-a-computational-essay/
6. https://uk.mathworks.com/products/matlab/live-editor.html
7. https://www.wired.com/2017/03/lets-physics-knocking-asteroid-sun/

Computational Essay showroom:

NOKUT The Research Council of Norway