

CCSE

Center for Computing
in Science Education



Using Computational Essays to Support Student Creativity and Agency in Science

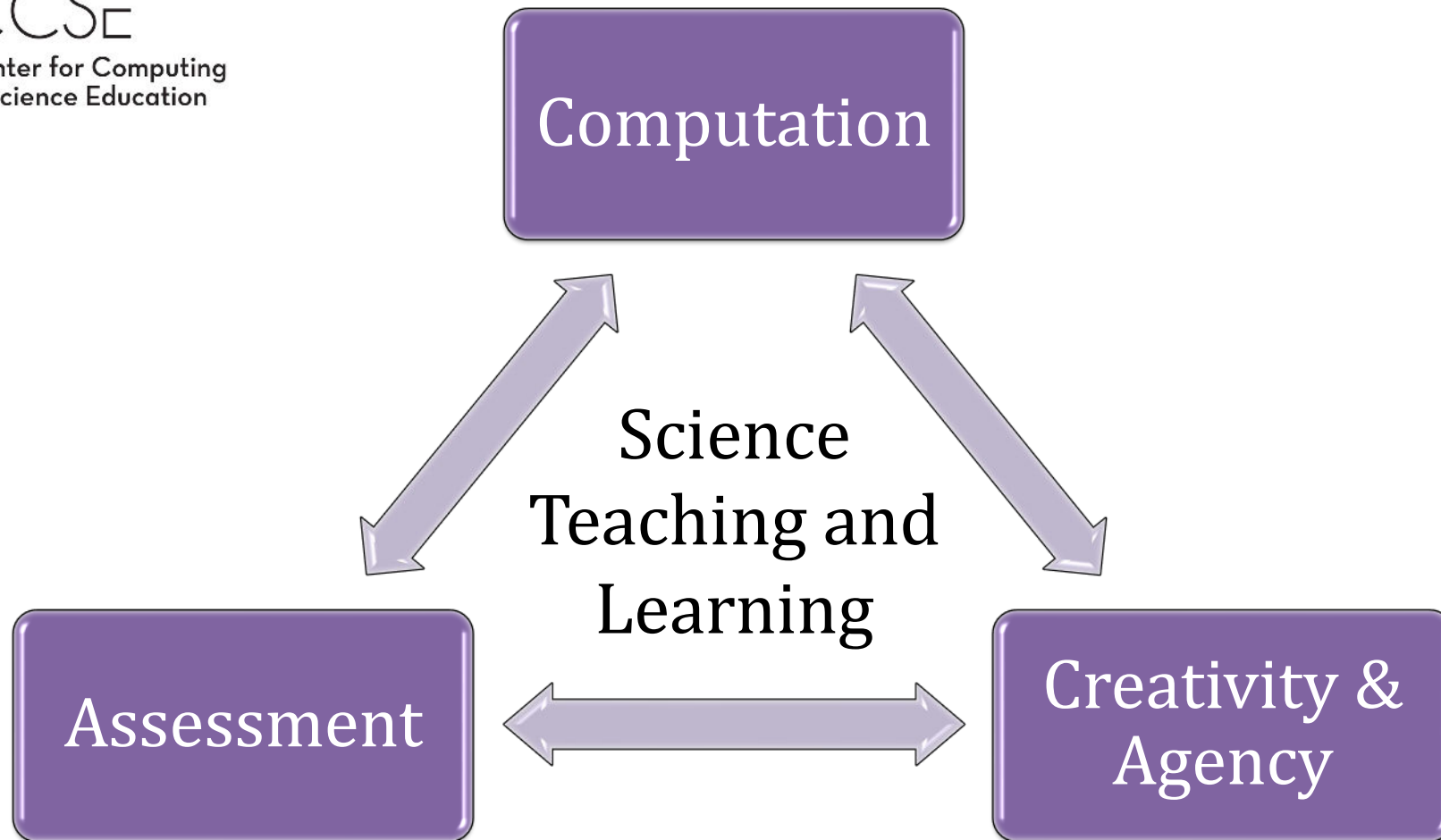
Tor Ole Odden
CCSE, University of Oslo
ProDaBi Seminar
April 19, 2023



UiO • Det matematisk-naturvitenskapelige fakultet



Centre for
Excellence in
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



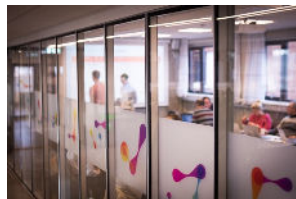
Faculty of mathematics
and natural science

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	



Center for Computing
in Science Education



(1 of 12 national centers)



CCSE
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in Science Education





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

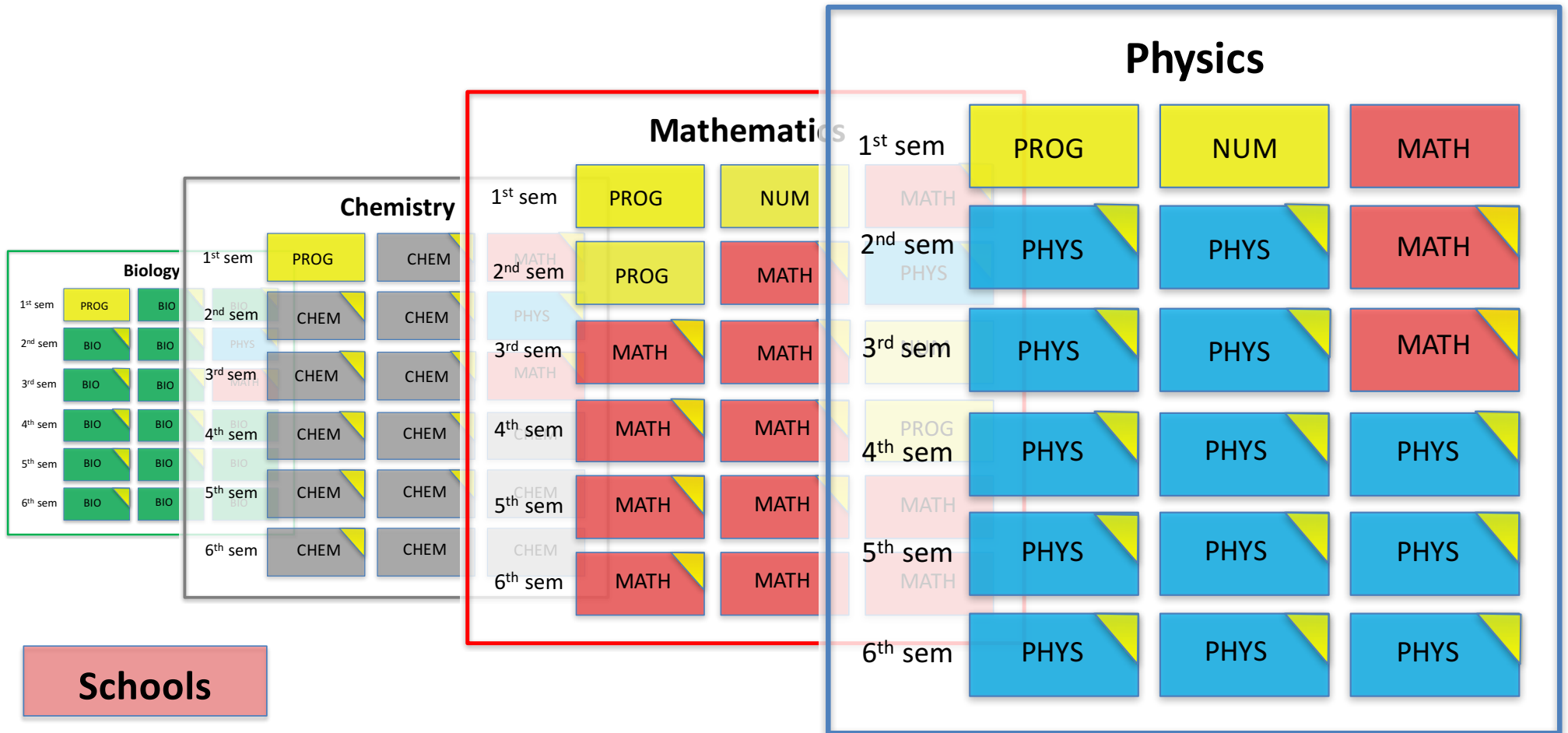
New content in
courses and
programs

Reorganization
of topics and ideas

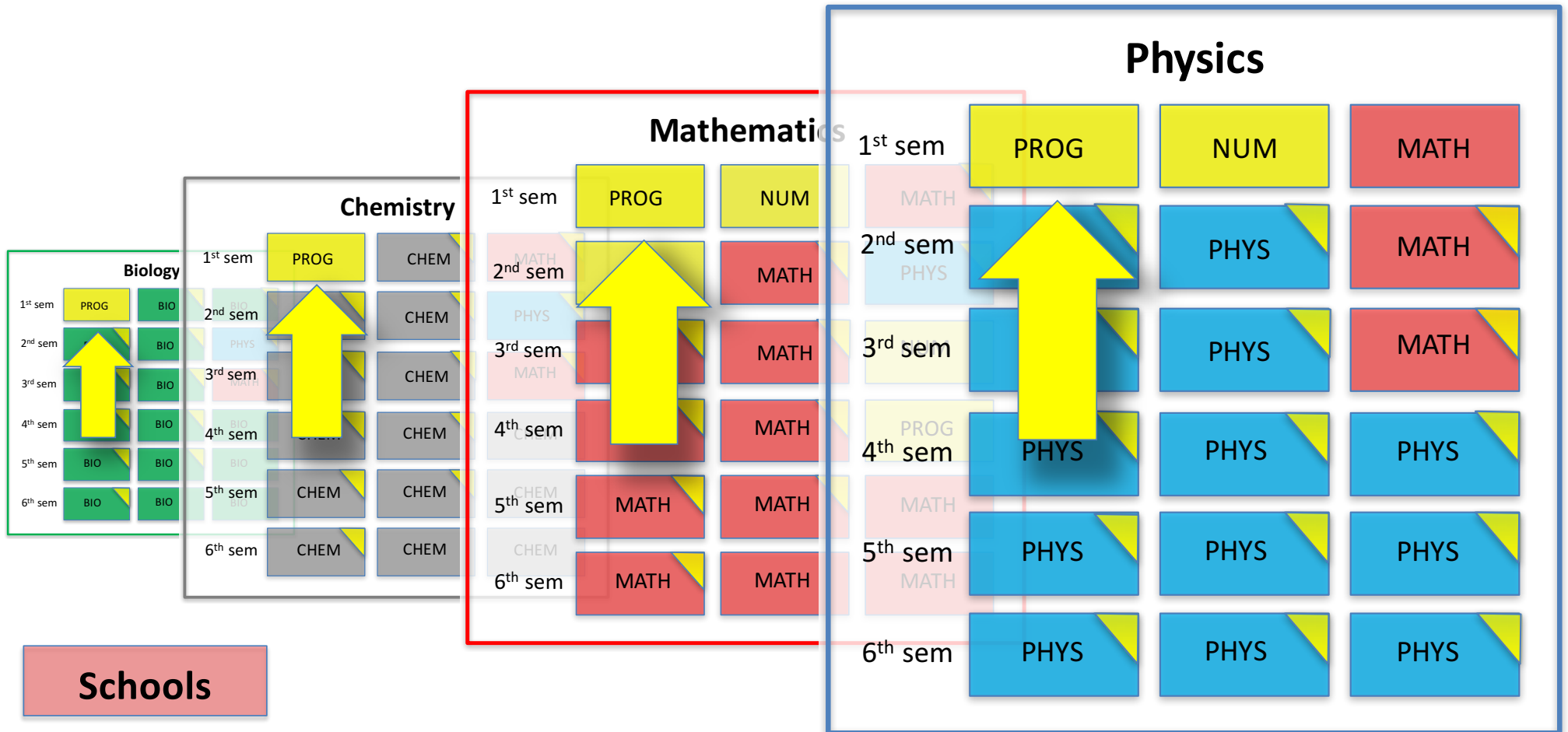
Creativity, agency,
and marketable
skills

Requires a cross-disciplinary educational collaboration

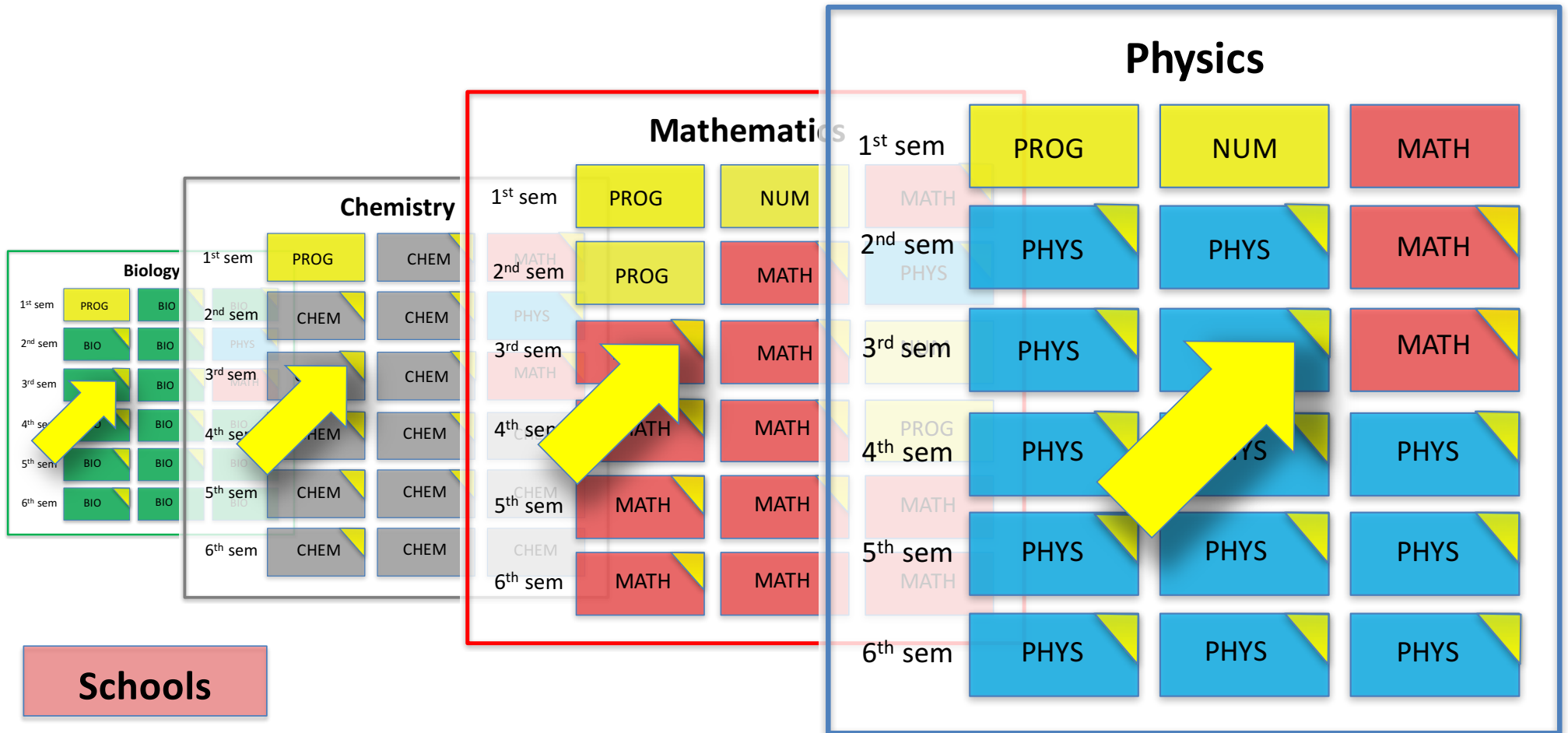
At the University of Oslo, programming is integrated in all science study programs and adapted to the disciplinary context



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Integration across departments

1 st sem	PROG	NUM	MATH
2 nd sem	PHYS	PHYS	MATH
3 rd sem	PHYS	PHYS	MATH
4 th sem	PHYS	PHYS	PHYS
5 th sem	PHYS	PHYS	PHYS
6 th sem	PHYS	PHYS	PHYS

MAT1100: Calculus

Week 5:

The derivative is defined

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

IN1900: Scientific computing

Week 6:

The numerical derivative is implemented in Python

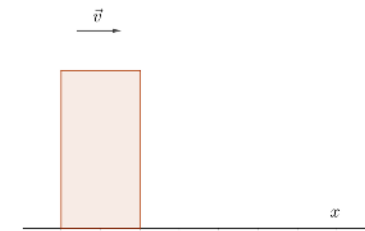
```
def dfdx(f, x):  
    h=1e-10  
    dfdx=(f(x+h)-f(x))/h  
    return dfdx
```

FYS1100: Mechanics and modeling

Week 8:

Use numerical derivatives to analyze motion

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

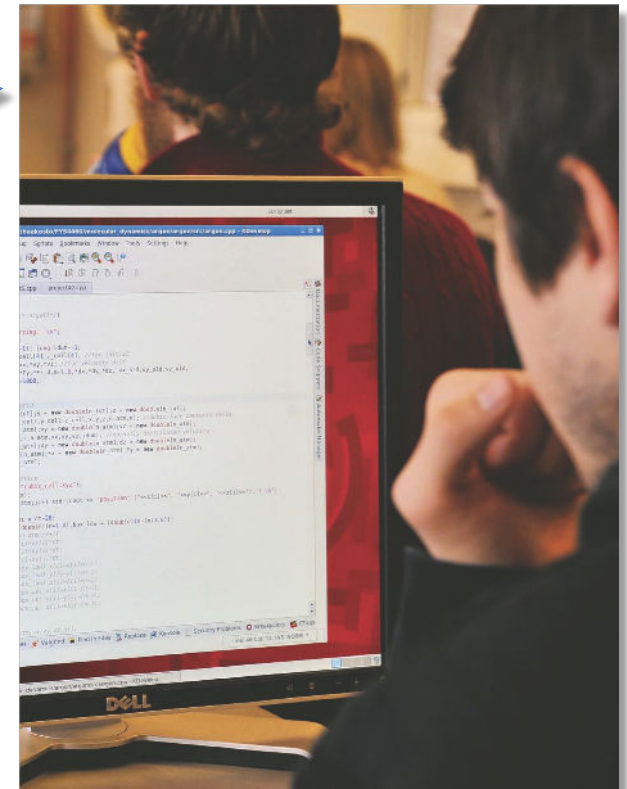


Programming is understanding



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

```
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

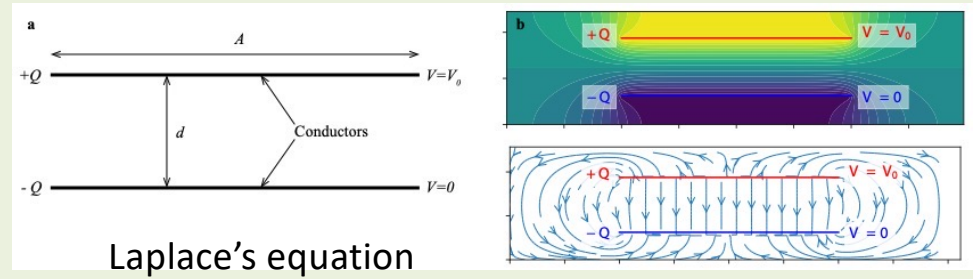


1 st sem	PROG	NUM	MATH
2 nd sem	PHYS	PHYS	MATH
3 rd sem	PHYS	PHYS	MATH
4 th sem	PHYS	PHYS	PHYS
5 th sem	PHYS	PHYS	PHYS
6 th sem	PHYS	PHYS	PHYS

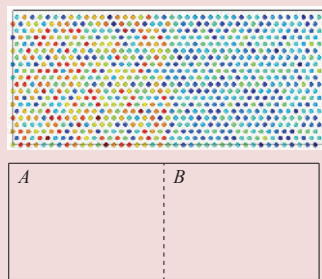
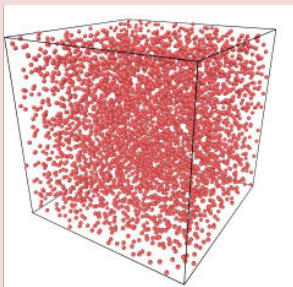
Mechanics



Electromagnetism

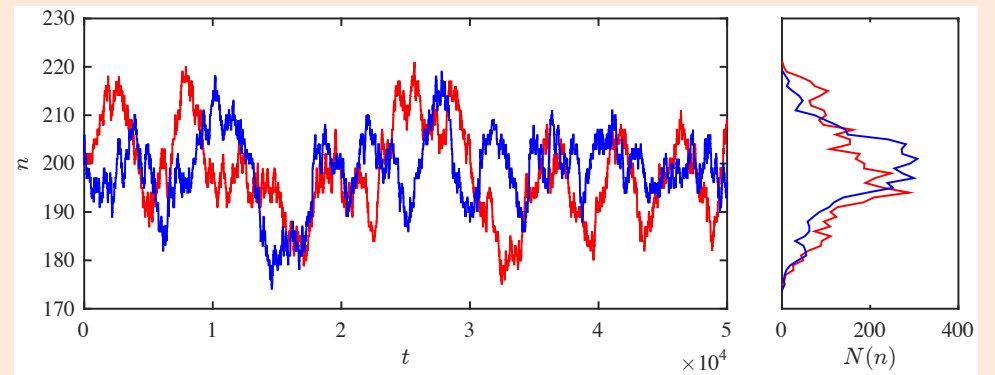


Statistical and thermal physics

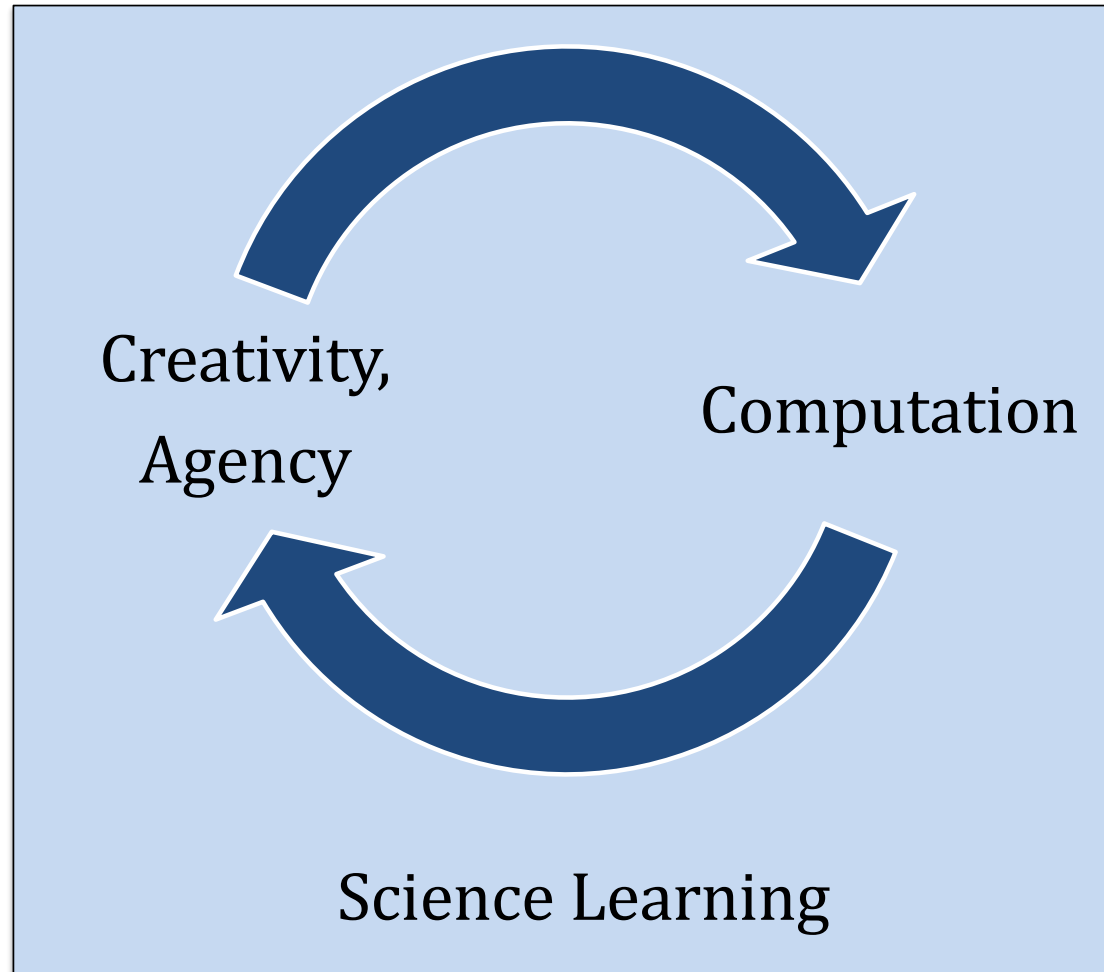


$$\begin{array}{rcccc}
 q_A & + & q_B & = & q \\
 N_A & + & N_B & = & N
 \end{array}$$

Statistics



Creativity and Agency in Science Learning

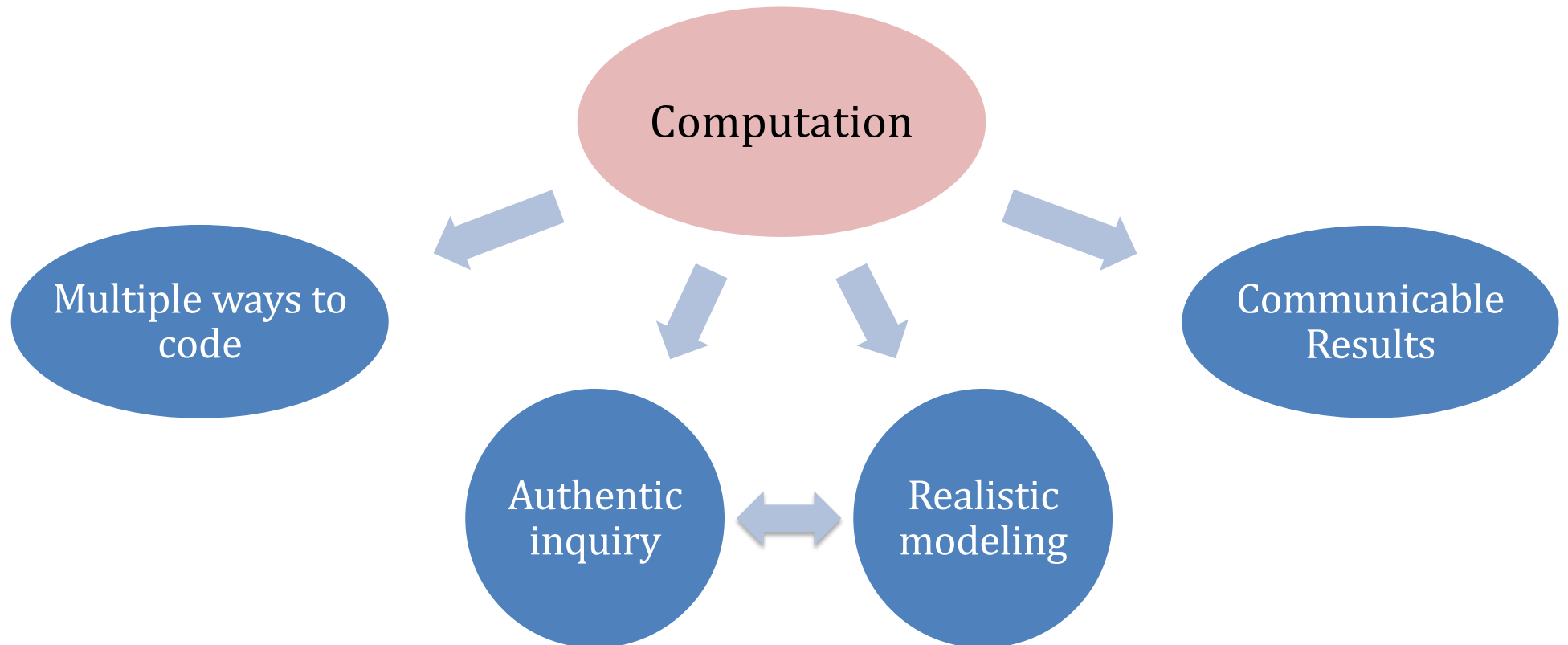


Epistemic agency

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

Live Code
Input & Output

Title and
Introduction

Importing packages

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 interpfd
from numpy.linalg import norm
```

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

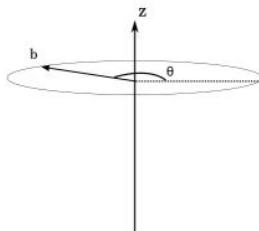
Now, we define some key constants, like the mass of a proton, the charge of a proton, and the magnetic constant μ_0 .

```
In [3]: # define key constants
m_p = 1.67E-27 # mass of proton: kg
q_e = 1.602E-19 # charge of proton: C
mu_0 = np.pi * 4.0E-7 #mu_naught
```

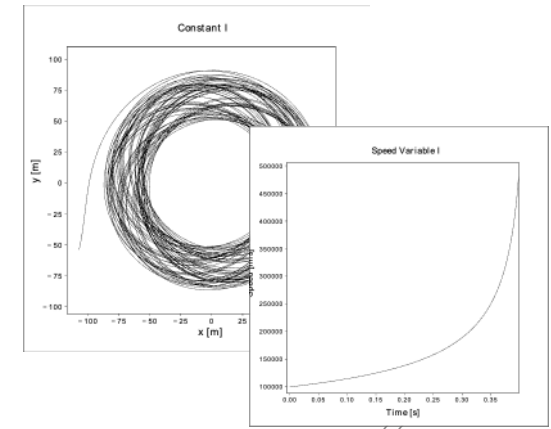
To create the magnetic field, we will consider two current carrying loops, both of radius a , placed a distance $2h$ apart along the z-axis. The loops are oriented such that the z-axis goes through the center of both loops. We will consider different types of current loops, but will begin by saying they both consist of wound, thin copper wire. The thickness and width of the loops are both considered negligible. 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

$$d\vec{B} = \frac{\mu_0 I}{4\pi} \frac{a - ab \cos(\phi - \theta)}{(a + b + h - 2ab \cos(\phi - \theta))^{\frac{3}{2}}} d\phi \hat{k}$$

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 somewhat hairy, we will solve it numerically. For reference, the figure below shows how the system is set up.



Model parameters



Other Examples of Computational Essays

Mathematica [5]

Simple Rules with Complex Behavior

Cellular automata are examples of programs defined by very simple rules. The most basic kind of cellular automaton consists of a row of black or white cells that are updated in a series of steps according to a definite rule that involves the immediate neighbors of each cell.

This represents the rule for a simple cellular automaton:

```
RulePlot[CellularAutomaton[150]]
```

Here is what happens if one runs this rule, starting from a single black cell:

```
RulePlot[CellularAutomaton[150], {{1}, 0}, 20, Mesh -> True]
```

Running it longer gives this nested pattern:

```
RulePlot[CellularAutomaton[150], {{1}, 0}, 250]
```

Many simple cellular automaton rules yield fairly simple—or at least regular—behavior. But some do not. My all-time favorite example of a rule that gives complex behavior is rule 30.

Annotations:

- General discussion:** Points to the introductory text about cellular automata.
- Input description:** Points to the code cell for the first RulePlot command.
- Input:** Points to the code cell for the second RulePlot command.
- Output:** Points to the resulting fractal pattern.

MATLAB Live Editor [6]

Integration

This example shows how to compute definite integrals using Symbolic Math Toolbox™.

Definite Integral

The value of the definite integral $\int_0^{2\pi} \sin(x) dx$ is 0. Use the dropdown below to try other trigonometric functions.

```
1 syms x
2 int(sin(x), 0, 2*pi)
```

ans = 0

Definite Integrals in Maxima and Minima

To maximize $F(a) = \int_0^a \sin(ax) \sin(x/a) dx$ for $a > 0$, first, define the symbolic variables and assume that $a \geq 0$:

```
3 syms a x
4 assume(a >= 0);
```

Annotations:

- General discussion:** Points to the introductory text about integration.
- Input description:** Points to the code cell for the definite integral calculation.
- Input:** Points to the code cell for the symbolic integral setup.
- Output:** Points to the resulting plot and the numerical answer 'ans = 0'.

Website with Trinket [7]

Part 2: The Collision

I could of course do a simple one-dimensional inelastic collision between the Nuvevo and Erus in which they stick together. Actually, that's a great case for an exam question, but I want to do better than that. Instead I will create something more realistic—a collision that is partly elastic (momentum, but not kinetic energy, is conserved) and it won't quite be in one dimension. I could write this out on paper, but I'll create a numerical calculation because it will look cool.

How do you model a collision? The basic idea is to let the two objects act like springs. When those objects are closer than the sum of their size (so that they overlap), you'll see a spring force pushing them apart. The more they overlap, the greater the spring force. Better yet, I can make this an inelastic collision by using a smaller spring constant when the two objects are moving away from each other. I've gone over the details of such a collision before.

Now for the collision. I have the Nuvevo heading straight toward Erus, but they aren't lined up exactly center-to-center. Here's how the collision will look. Note that Erus is spherical (technically wrong), and the Nuvevo is tiny in comparison. Click "play" to run and the pencil to see and edit the code.

```
1
2 # mass of erus
3 m = 8.7e5
4 # radius of erus
5 r = 2e3
6 erus = sphere(ox, vector([ 5*pi, 8, 0]), radius=r)
7 # radius of nuvevo
```

Annotations:

- General discussion:** Points to the introductory text about the collision.
- Input description:** Points to the code cell for the collision simulation setup.
- Input:** Points to the code cell for the collision simulation setup.
- Output:** Points to the resulting simulation output.

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:



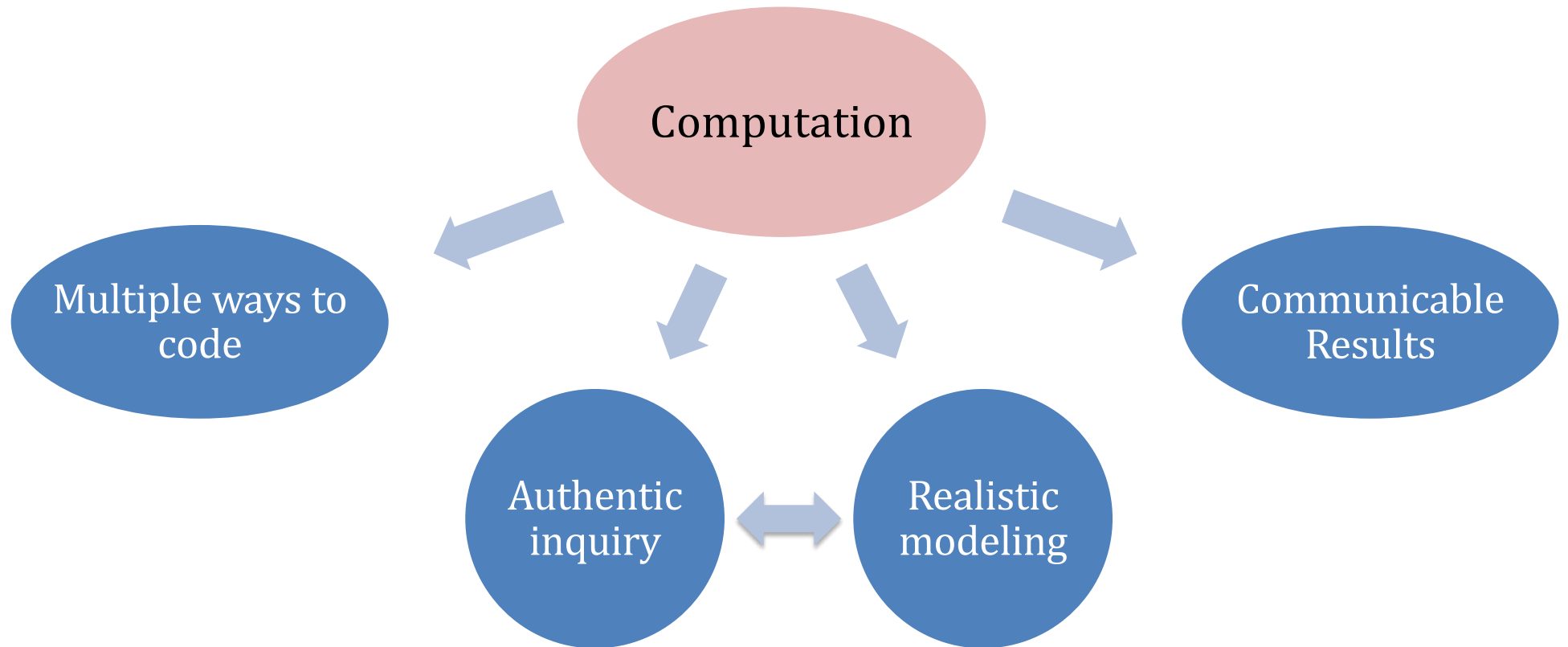
Summative Assessment

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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		0 points ←-----→ 4 points		

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

Students reported that the open-ended project
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!

What does it mean to fall into space?

We have a pretty good idea about what space is. It's everything up above the Earth. But where does Earth stop and space begin? The atmosphere disappears so gradually that there is no definite answer. An altitude of 100 km above sea level is often used to mark the beginning of space for space. This limit is called the Kármán line. This is the height you will be talking to in the next few paragraphs.

So what does falling mean? In physics, something is in free fall when it is affected only by gravity. This means that the object could be moving in any direction, as long as there are no other forces acting on it. We will not be looking at this kind of fall. Instead of gravity, we will be looking at a kind of anti-gravity. If, somehow, it is not the only force acting on the object, as we will find out at resistance, in our model.

In this essay we will define a formula for anti-gravity and a free stand, and use them together with the Euler-Cromer method to calculate the movement of the ball.

In [1]:

1. Import numpy as np #Always as useful for calculations
2. Import numpy.linalg.eigvalsh as eig #Eigenvalue gives us access to plotting curves for arrays

Anti-Gravity

Directly causes masses to attract. Objects as what makes it a ball with the Earth and applied to the ground. To calculate the force of gravity between two objects we use the formula: $F = \frac{GMm}{r^2}$ where G is the gravitational constant, M_1 and M_2 are the masses of the masses, and r is the distance between them. The gravitational force acts on both objects, and it always points from one object to the other, pulling them closer. The $\frac{1}{r^2}$ factor in the formula is essential to the behaviour of gravity as it means that gravity is much weaker when things are further apart.

But what if gravity pointed the other way? What if gravity pushed things away from each other? This is a very odd question, with many effects compared to our intuition of free-falling with everyday things. But it will be the focus of this essay. Gravity will instead only push you away from Earth.

What the mass represents is the attraction given by the formula $F = \frac{GMm}{r^2}$, where M is the mass of the ball and m is your mass, will push you off the face of planet given that you're outside.

and the anti-gravity you mean want to be used instead of your acceleration. Newtons second law together with our formula for anti-gravity gives us that $F = ma = \frac{GMm}{r^2} = \frac{GM}{r^2}m$

In [2]:

1. $G = 6.674 \times 10^{-11}$ #Gravitational constant
2. $R = 6.372 \times 10^6$ #Radius of the Earth
3. $R_{ball} = 0.075$ #Ball's radius on the Earth
4. #This function takes your current height above the ground and returns your current acc
5. def antiGravity(h):
6. return $G * M / (R + h)^2$
7. #Note that this function returns a positive acceleration, what will increase your acc
8. #If you were to add a mass sign here, you would have a function for normal gravity and
9. #You should try increasing gravity again and starting the ball up in the air to see how

Air Resistance

An resistance (also called drag) is the force which the air exerts on an object moving through it, acting in the direction opposite of the motion. As resistance is called makes, several fall slowly toward the ground. It is also what makes things stop when you push them.

The forces acting on the ball

In order to find the fastest possible way to get to know how the ball moves through the air, the things that affect the trajectory of the ball are the forces of the air, the force of gravity, and the force of the ball.

In [2]:

1. #The acceleration of the ball and velocity of the ball over time
2. #The acceleration of the ball over time
3. #The velocity of the ball over time
4. #The position of the ball over time

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:

