Three-Dimensional Learning in Introductory Physics for Life Sciences Laboratory Courses

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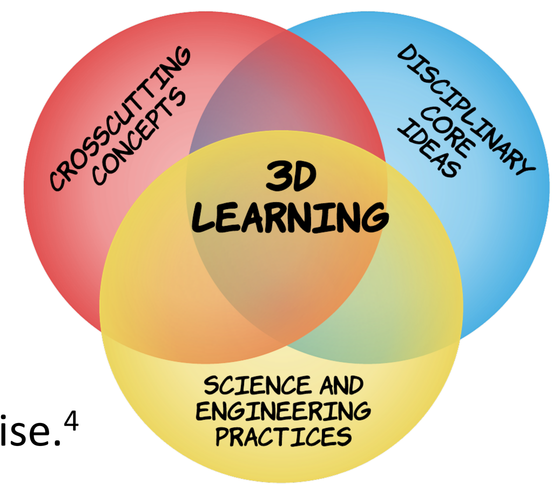
Three-Dimensional Learning

- Originated in the policy document *A Framework for K-12 Science Education* (2012)[1] and manifested in *Next Generation Science Standards* (2013).[2]
- **Disciplinary Core Ideas (DCIs)** – foundational disciplinary ideas that underlie and support understanding of common disciplinary topics
- **Science and Engineering Practices (SEPs)** –practices & skills scientists use to generate knowledge & build theories of the world
- **Crosscutting Concepts (CCCs)** – concepts that transcend disciplines to provide overarching explanatory power to scientific knowledge
- Recent studies suggest that 3D learning can be an effective framework for introductory undergraduate STEM courses.[3,4]
- Modifications to 3D learning structure, particularly the DCIs, are necessary when implementing at the undergrad level.[5]
- Physics courses have presented unique instructional challenges to 3D integration, though reformed courses hold more promise.[4]



IPLS Course Structure

Intro Physics Labs for Life Sciences (IPL[2]S)
- Course developed from project NEXUS IPLS labs[6]
- Group-focused, student-driven, inquiry-based investigations into biological phenomena through physical experimentation
- Student population is primarily pre-medical/life science majors

Lab 1: Kinematic analysis of zebrafish to study social behavior, metabolic processes, etc.

Lab 2: Analysis of fluid dynamical properties of macroscopic models of macro- and micro-scale biological systems

Lab 3: Analysis of microscopic stochastic motion to extrapolate to drug delivery, cellular structure and intracellular transport, etc.

Lab 4: Analysis of vesicle motion to investigate properties of molecular motor proteins in biological systems

Lab 5: Fluid dynamical analysis of capillary blood flow and its connection to circulatory systems

Lab 6: Kinematic analysis of microspheres subject to electric fields (electrophoresis), charge screening, etc.

Lab 7: Investigating biological samples' fluorescent properties and atomic structure via spectroscopy

Lab 8: Design and analysis of passive electronic model of axon signal transport

Integrating 3D Learning into IPLS Course

Scientific Practices:
- Initial course development prioritized SEPs and their alignment with IPLS experiments; further alignment occurred through integrating a modified *Argument-Driven-Inquiry* (ADI), an instructional model shown to align with SEPs.[7]
- ***Evidence of SEPs in course identified through student engagement in experimental tasks (e.g. microscopy, computational analysis)***

Disciplinary Core Ideas:
- DCIs were developed uniquely for our course through consultation with course faculty and disciplinary experts, based on DCIs developed as part of 3D-LOP/3D-LAP project.[8]
- Course-specific DCIs were integrated via explicitly chosen physical/biological phenomena underlying experiments (e.g. Lab 6 – Electrophoresis involves electric fields, integrates PCI 4 and 5)

Crosscutting Concepts:
- CCCs integrated implicitly into curriculum (e.g. lab manuals and slides) and instructor-student interactions through pedagogical training.[9]
- ***Evidence of CCCs in course identified through class observations of student-student dialogue and analysis of written lab reports.***

Disciplinary Core Ideas Alignment

	Disciplinary Core Ideas	Student Examples
Physics Core Ideas (PCI)	(1) Interactions can cause Changes in Motion (2) Conservation and Interactive Transfer of Physical Quantities (e.g. energy, mass) (3) Entropic Nature of Energy (4) Interactions are Mediated by Fields (5) Non-Interactive Transfer of Physical Quantities (e.g. energy, momentum)	*"The point of efficiency is to* ***transfer as much of the energy we put in, into the outcome we desire without losing energy to other sources such as sound or heat****. If we have inefficient molecular motors, we consume more energy than we need in order to complete a task."* **(PCI 2)** (Lab 4 Student Report) *"A greater* ***signal propagation*** *occurs when* ***membrane resistance is increased and axon resistance is decreased****. … It is clear that as membrane resistance is increased and axon resistance is decreased, the exponential curve of the graph is smaller."* **(PCI 5, BCI 5)** (Lab 8 Student Report)
Biology Core Ideas (BCI)	(1) Physical and Chemical Basis of Life (2) Matter and Energy (3) Cells - Biological Building Blocks (4) Biological Systems (5) Biological Structure and Function (6) Hereditary Information Flow, Exchange, and Storage (7) Evolution	*"In this experiment we were studying molecular motors. These motor proteins within our cells help us in transporting necessary materials as well as aide in* ***genetic replication****.* ***(BCI 6)*** *The task at hand was to figure out how efficient these molecular motors are and how much energy they use to do their job.* ***(BCI 2, CCI 3)*** *This is important because this affects every living organism, we all have these motor proteins with in us working 24/7."* (Lab 4 Student Report)
Chemistry Core Ideas (CCI)	(1) Atomic/Molecular Interactions (2) Atomic/Molecular Structure/Properties (3) Energy	*"Based on charge screening, the idea that particles in* ***an ionized solution will neutralize the charge by being attracted to and surrounding them****, we aim to determine the effect of salinity on the effective charge of the silica bead."* **(CCI 1)** (Lab 8 Student Report)

Scientific Practices Alignment

Scientific Practices ⇨ / Lab Sequence Activities and Description ⇩	Asking Questions	Developing and Using Models	Planning & Carrying Out Investigations	Analyzing and Interpreting Data	Using Mathematics & Computational Thinking	Constructing Explanations	Engaging in Argument from Evidence	Obtaining, Evaluating, & Communicating Information
Warm-up Activity – Activity-based introduction to scientific concepts and experimental techniques.			✓	✓	✓	✓		
Development of Research Question and Design Plan – Groups develop research question, plan experiments.	✓	✓	✓					
Investigation – Groups collect and analyze data to complete experiments and answer Research Question.	✓	✓	✓	✓	✓	✓	✓	
Investigative Check – Groups present scientific arguments and results to TA or LA for feedback.	✓					✓	✓	✓
Jigsaw Presentation Session – Groups split, present their scientific argument and results to peers.	✓					✓	✓	✓
Group Feedback and Argument Revisions – Groups reconvene, discuss feedback, make final revisions.			✓	✓	✓	✓	✓	✓
Drafting Lab Report – Students individually draft their lab reports in class. Students complete their reports at home after Peer Review.						✓	✓	✓
Peer Review - Students participate in a double-blind peer review process, providing (receiving) constructive feedback to (from) peers.	✓						✓	✓

Crosscutting Concepts Alignment

Crosscutting Concepts
Patterns; Cause and Effect; Scale, Proportion, and Quantity; Systems and System Models; Energy and Matter; Structure and Function; Stability and Change
Student Examples
"In conclusion, as temperature increases, Brownian motion also increases. This makes sense because an increase in temperature also leads to greater kinetic energy of the water molecules in which the microspheres are suspended in." **(Energy and Matter; Scale, Proportion, and Quantity)** (Lab 3 Student Report)
"Our claim is that decreasing the resistance of the [axon] membrane decreases the length at which the signal can travel. … the thicker the membrane is, the harder it is for ions to leak out through the membrane; thus, the signal can travel farther. … [Y]ou want to increase membrane thickness and decrease the radius of the axon in order to get the greatest membrane resistance. This explains why our nerves are myelinated." **(Structure and Function)** (Lab 8 Student Report)
"In the video, the fish seemed to be avoiding an aggressive fish by quickly swimming away. … [W]e asked the question: how does the escape speed of the threatened zebra fish compare to the resting speed? … Ou[r] data shows that in response to a threat, the fish escape by increasing speed significantly." **(Cause and Effect)** (Lab 1 Student Report)
"We could not actually measure signal transmission in real nerves; … we used a simple circuit model with a voltage source that would provide us with similar information. This lab has … biological implications because everyone relies heavily on their nerve's ability to send signals … " **(Systems and System Models)** (Lab 8 Student Report)

Acknowledgements and References

This material is based upon work supported by the National Science Foundation Grant No. 1938721 and Graduate Research Fellowship Program Grant No. 1747505. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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