SUCCESSFULLY IMPLEMENTING INQUIRY-BASED LABS: A CASE STUDY FOR A COLLEGE WAVES AND MODERN PHYSICS COURSE

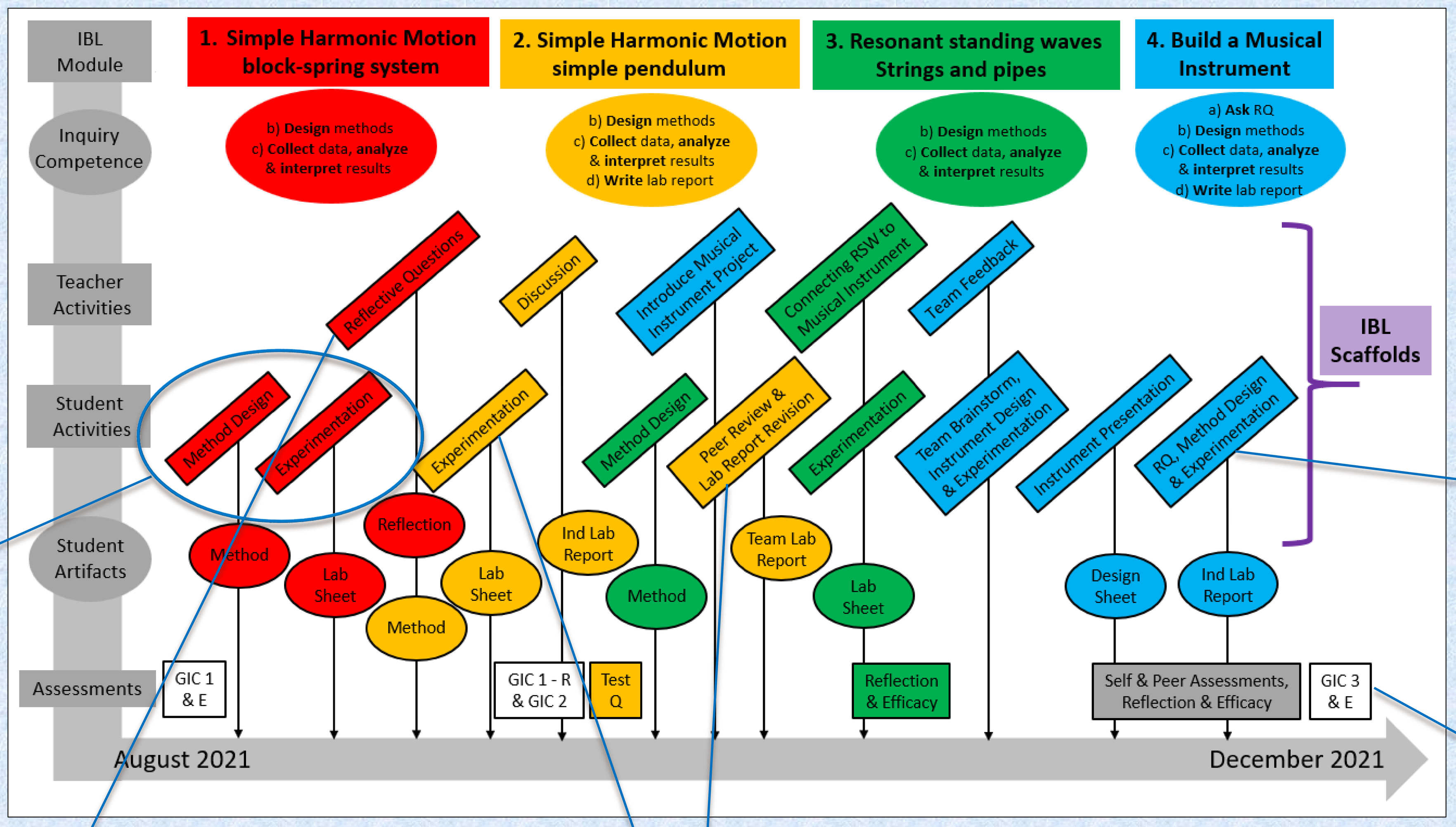
Elizabeth S. Charles[1], Kevin Lenton[2], Rhys Adams[2], Michael Dugdale[3], Sean Hughs[3], Karl Laroche[2], Caroline Cormier[4], Véronique Turcotte[4], and Chao Zhang[5]

Overview

Inquiry-based instruction is a form of active learning that scaffolds investigation of authentic problems. It relies on collaborative activities that engage students in discipline-specific practices that promote the use of high-level cognitive skills – analysis, decision-making, and evaluation. Inquiry-Based Laboratory (IBL) extends this approach to lab experimentation. Compared to traditional labs, IBL requires students to make decisions that are critical to the process – what methods to use, what data to collect, etc. We report on a case study conducted in Fall 2021, featuring a design focus IBL implementation in a college Waves and Modern Physics course. The case study spanned the 15-week semester with students' scientific reasoning assessed at three points: pre-test, immediate posttest, and delayed posttest. Students showed improvements in their scientific reasoning with positive changes to their epistemic beliefs – i.e., thinking more like scientists.

Mapping the Inquiry-Based Labs over a semester of a Waves and Modern Physics course

Based on the Blanchard et al. (2010) model for levels of inquiry, four IBL modules were developed, each with its set of inquiry competencies and scaffolds. In the fourth module, students had to design a musical instrument.



Given the context of a hanging block-spring system, you need to experimentally research the following two research questions:

1) Does the amplitude of the motion affect the period of the motion?
2) Does the mass of the hanging block affect the period of the motion?

Your goal is to prepare the "methods" (or "procedures") that will allow an experimenter to answer the research questions.

You should work in teams of 4 students (two pairs per team; Rhys will provide more instructions in class). You will have equipment available if you wish to experiment during the lab session. You can prepare multiple methods per research question if you wish.

Week 1 – Prepare "Method Design" and some "mess about" in the lab.
Week 2 – Perform experiment. Collect data, analyze & interpret results.

Working in pairs, you need to submit by the end of class:

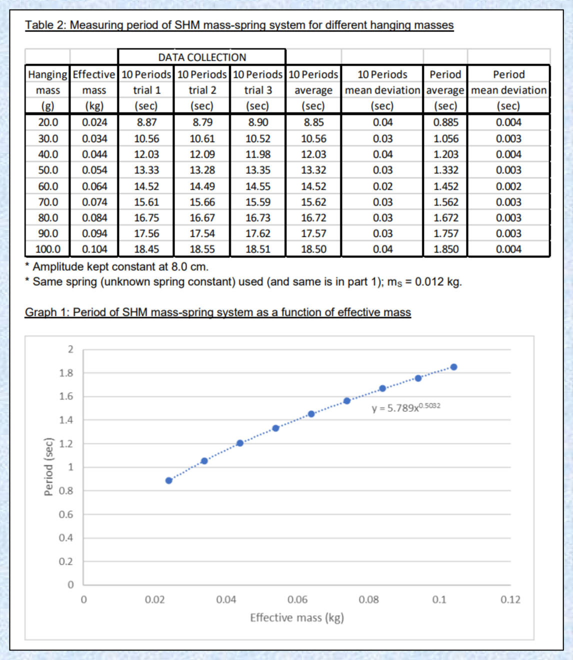
1) The procedure chosen to perform these experiments. Highlight all modifications between the assignment submission and what was actually done during this lab period.
2) The data collected.
3) The data analysis.
4) The answers to the two research questions.
5) Any comments that you wish to share regarding your procedures, analysis, etc.

Reflection on procedure. "Expert" analysis provided to students.

i) Reflect and describe the procedures they think provided the expert data.

ii) They reflect (compare/contrast) between this new procedure AND the one they used for their experiment.

iii) Prompt them to prepare a new "methods" for a SHM based simple pendulum experiment.



SHM research questions Q2

Read the "SHM research questions - data and analysis" pdf provided in our course LEA space. With respect to Table 2, Graph 1 and its analysis that allows to answer the research question, "Does the mass of the hanging block affect the period of the motion?"; please provide what you think is the procedure/methods that led to the data collection and analysis.

Discipline: Physics
Categories: Reflection, research methods
Student answers: 36

Perform experiment. Collect data, analyze & interpret results.

Provided to all: Data set, lab report guidelines & assessment rubric.

i) Individual Lab Report.
ii) Peer Assessment.
iii) Final Team Lab Report.

Given the context of a simple pendulum, you need to experimentally research the following two research questions:

1) **Does the maximum angular displacement of the motion affect the period of the motion?**
2) **Does the length of the pendulum affect the period of the motion?**

Working in pairs, you need to submit by the end of class:

1) The procedure chosen (from the myDALITE assignment) to perform these experiments. Highlight all modifications between the assignment submission and what was actually done during this lab period.
2) The data collected.
3) The data analysis.
4) The answers to the two research questions.
5) Any comments that you wish to share regarding your procedures and analysis, including a comparison to what you did today to what you did last week (for the block-spring experiment).

		AMPLITUDE (degrees)																	
		5 Trial 1	5 Trial 2	5 Trial 3	10 Trial 1	10 Trial 2	10 Trial 3	15 Trial 1	15 Trial 2	15 Trial 3	25 Trial 1	25 Trial 2	25 Trial 3	35 Trial 1	35 Trial 2	35 Trial 3	45 Trial 1	45 Trial 2	45 Trial 3
LENGTH (m)	0.20	9.01	8.48	8.81	9.11	9.05	8.67	9.04	9.82	9.73	9.92	9.72	10.20	9.55	10.58	10.43	10.08	9.94	10.62
	0.40	12.61	12.70	12.21	12.63	13.28	12.10	13.10	13.33	12.98	13.12	13.35	13.33	12.91	13.50	13.37	13.56	13.64	13.71
	0.60	15.91	15.65	15.93	15.82	16.00	15.57	15.64	16.15	16.20	16.57	16.02	15.91	16.60	16.75	15.77	16.53	17.22	16.82
	0.80	18.20	18.05	17.53	18.05	18.10	17.48	18.19	18.69	18.55	18.26	18.91	18.82	18.76	19.11	18.62	19.03	19.21	19.88
	1.00	20.08	20.97	19.93	19.86	20.17	20.57	20.53	20.90	20.33	20.57	21.03	20.97	20.94	21.12	21.32	21.95	21.53	21.42
	2.00	29.15	28.00	28.52	29.12	28.84	28.25	29.69	29.53	29.20	29.05	30.15	29.97	30.52	30.11	30.62	30.85	31.11	29.88
	5.00	44.89	45.33	44.90	45.05	44.41	44.81	45.12	44.57	46.06	46.15	45.91	46.29	46.45	46.10	46.65	47.18	47.37	48.48

Summary of deliverables, each student will:

1. Build a musical instrument.
2. Present and play their musical instrument in class (November 29). You should be able to link your experiments to your final product and be able to comment on the instrument's potential and limitations.
3. Complete the Instrument Specification Sheet (December 1).
4. Conduct an experiment(s) based on a research question(s) and prepare a lab report (December 5).
5. Complete a "Peer and Self Assessments and Learning Reflection" (this document will be provided to you). You will have the opportunity to assess your work and contributions for the group, and to assess your peers' work and contributions (December 8).

CHALLENGE: Each student will build, present, and play a musical instrument.

Constraints and guidelines:

- Your instrument must be STRING or PIPE based. You may have 1+ string(s) OR pipe(s).
- You must play a simple medley using at least 3 frequencies (or notes). It does not have to sound good (but it would be nice if it does)!
- Your instrument must be made with household and/or recycled items. You should not have to purchase anything, but if you do, you cannot spend more than $10.
- You will have to present and play your instrument for the class (during class time) and/or submit a short video.
- You will report on your design (e.g., desired fundamental frequency(ies)), experimental procedure(s), research and knowledge transfer enabling you to build your instrument. There will be an "Instrument Specification Sheet" (this will be provided to you) to fill out and you will have to prepare a "Lab Report" based on a research question (of your choice) based on your instrument (further instructions will be provided to you).
- No prior musical knowledge is necessary for this challenge.

GIC = "George's Ice Cream" activity ("Physics by Inquiry: An Introduction to Physics and the Physical Sciences" by L. C. McDermott & "Development of procedural skills in science through the use of an interactive database: an example from designing experiments" by M. Papaevripidou & C. P. Constantinou).

George wanted to examine of the colour of the wrapper of specific ice cream affects the time it takes ice cream to melt. In order to answer this question, he performed the following test:

He bought several ice creams with different colour wrappers, measured each ice cream's mass as it is shown in the table below, and put all together in a freezer. He then removed all of the ice cream from the freezer at the same time, placed them all on his car's front dashboard, and measured the time it took each ice cream to melt.

	Flavour	Wrapper Colour	Mass (g)	Melting Time (min)
1	Lemon	White	80	8
2	Lemon	Brown	80	8
3	Chocolate	Green	100	6
4	Chocolate	Yellow	120	9
5	Vanilla	Blue	120	11
6	Strawberry	Black	120	12

According to George's test and his measurements, can you say whether the colour of the ice cream's wrapper affects the melting time? Explain your reasoning, mentioning which of the above measurements you used to reach your conclusion.

Assume that you are a scientist working for the company producing these ice cream bars. Their main concern is to maximize the amount of time the ice cream bars can remain sold outside of a fridge. The company realizes that there may be many research questions. You must propose one specific research question to help the company address their concern, and design a methodology (procedure/methods) appropriate for answering your question. Write your answer as if you are speaking to your colleague.

The company produces the following types of ice cream bar flavours, sizes and varieties:

Flavour	Wrapper Colour	Available sizes (g)	Varieties	Special ingredients
Lemon	White	80, 160	Regular	Regular: None
			Sugar-free	Sugar-free: sucralose and binding agents
Chocolate	White	80, 160	Regular	Regular: none
			Chunky	Chunky: chocolate chips
Strawberry	White	80, 160	Regular	Regular: Pieces of strawberry
			Sugar-free	Sugar-free: sucralose and binding agents
Vanilla	White	80, 160	Regular	None
Double chocolate	White	80, 160	Regular	Pieces of fudge

E = Topic-Specific Epistemic Beliefs Questionnaire ("Dimensions of topic-specific epistemological beliefs as predictors of multiple text understanding" by H. I. Strømsø, I. Bråten, and M. S. Samuelstuen).

The questionnaire measures four different dimensions of epistemological beliefs about the topic of climate:

- Certainty of knowledge about climate
- Simplicity of knowledge about climate
- Source of knowledge about climate
- Justification for knowing about climate

Issues concerning climate are highly topical and often mentioned in the media. We can read daily about issues such as climate change, pollution of the atmosphere, global warming, extreme weather, rise in ocean levels, and melting of ice in polar regions. This is material that we often encounter in newspapers and magazines, as well as on TV and radio. Most people who do research on climate have a background in natural science, for example in physics, chemistry, biology, or meteorology. The following questions concern knowledge about climate and how one comes to know about climate. There are no right or wrong answers to these questions; it is your personal beliefs that interest us. Use the scale below to answer the questions. If you strongly agree with a statement, circle 10; if you strongly disagree, circle 1. If you more or less agree with a statement, circle the number between 1 and 10 that best expresses your belief.

		Strongly disagree									Strongly agree
1.	Climate researchers can find the truth about almost everything concerning climate.	1	2	3	4	5	6	7	8	9	10
2.	When I read about issues concerning climate, the author's opinions is more important than mine.	1	2	3	4	5	6	7	8	9	10
3.	With respect to climate problems, I feel I am on safe ground if I only find an expert statement.	1	2	3	4	5	6	7	8	9	10

Results – George's Ice Cream

PRE-TEST:

- Majority of students could recognize that the variables were not controlled.
- Most inferred there was a dependent variable (DV), but none used the term DV.
- Most recognized that mass was a confounding variable, but none used the term.
- Half tried to explain why the results are muddled BUT did not clearly explain not being able to draw any conclusions from the data.
- Some students talked about the data that have patterns and tried to draw some conclusions even when there are so many confounding variables.
- Less than 10% explicitly said that there was insufficient data and that the experiment was flawed.

DELAYED POST-TEST:

- ALL students were able to explain the need to control variables and were able to distinguish DV and IVs (though only a few named them as such).
- All students suggested there is confounding but less than 25% stated it clearly enough to be able to code it as such (these students stated it as the need to make separate experiments).
- Main improvement – the need for more trials and suggesting a reason why.
- Half the students were explicit about needing more data to make better conclusions.

In summary: there is a modest improvement in their explanation of the problem with George's experiment, but there appears to be more confidence in making their claim.

Results – Epistemic Beliefs Questionnaire

Q43: "The only thing we know for certain about climate problems, is that nothing is certain"

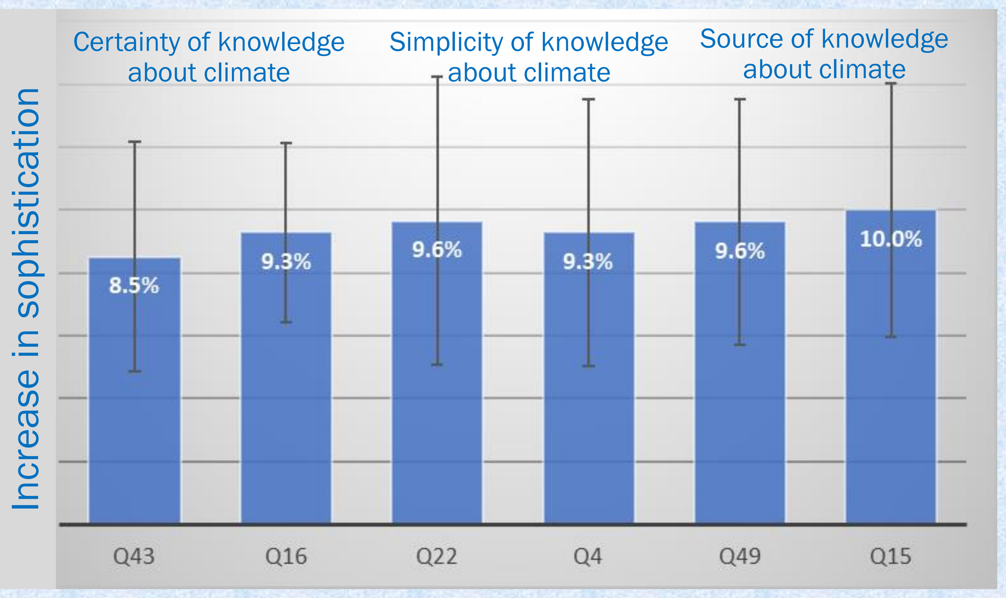
Q16: "Within climate research, truth is unchanging" (Reversed scale; improvement shown)

Q22: "Knowledge about climate consists of highly interrelated concepts rather than an accumulation of facts"

Q04: "Within climate research, facts are more important than theories" (Reversed scale; improvement shown)

Q49: "When I read about issues related to climate, I try to form my own understanding of the content"

Q15: "Ordinary people have no basis for speaking about issues concerning climate" (Reversed scale; improvement shown)



Conclusions

- Incorporating IBL in a semester-long course is feasible for college/university courses.
- Students showed improvements in their scientific reasoning with positive changes to their epistemic beliefs.
- Designing IBL takes macro and micro level planning.
- Zone-of-Proximity scaffolding is critical to successful implementation of IBL.
- Giving students opportunities to explore and make decisions could be the first step to transition into IBL.

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[1] Dawson College, 3040 Sherbrooke St W, Montreal, Canada, H3Z 1A4
[2] Vanier College, 821 Sainte Croix Ave, Montreal, Canada, H4L 3X9
[3] John Abbott College, 21275 Lakeshore Dr, Sainte-Anne-de-Bellevue, Canada, H9X 3L9
[4] Collège André-Laurendeau, 1111 Rue Lapierre, Montreal, Canada, H8N 2J4
[5] McGill University, 845 Sherbrooke St W, Montreal, Canada, H3A 0G4

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Corresponding e-mails: echarles@dawsoncollege.qc.ca, adamsr@vaniercollege.qc.ca

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