Changing students' approach to learning physics in undergraduate gateway courses

Calvin Kalman, Concordia University, Calvin.Kalman@concordia.ca
Marina Milner-Bolotin, University of British Columbia
Bruce Shore, McGill University
Gyoungho Lee, Seoul National University
Gul Unal Coban, Dokuz Eylul University
Xiang Huang, Concordia University
Ahmed Ibrahim, McGill University
Xihui Wang, McGill University
Mandana Sobhanzadeh, Mount Royal University
Wahidun Khanam, Concordia University

Challenges for Students:

Textbooks seem to be written in students' native language and seemingly all that is required is to understand the meaning of the special scientific vocabulary.

This works to the extent of going to France and being taught that chaise is the word for chair, maison is the word for house and so on, but nothing else.

Without grammar, you have great difficulty communicating "where is my hotel; the Louis V?".

For many students in the introductory gateway course, although individual words are understandable, the sentences appear to take the form of an unknown language.

A second major problem is that students enter gateway science courses with certain preconceived beliefs about the nature of science **knowledge and learning**.

Most students have no notion that science could be learned more *effectively* yet in different ways other than how they usually learn it.

If a student believes that knowledge in science should come from a teacher or authority figure, and the class activities require more independent thought than direct intervention, there is epistemological conflict.

Likewise, if a student comes in thinking that physics consists of a bunch of equations to be memorized, and the instructor focuses more on concepts, there is conflict.

We have developed **a suite of activities**, the Reflective Writing Tool (Kalman, Aulls, Rohar, & Godley 2008, Kalman, & Rohar 2010), the conceptual-conflict collaborative group exercises and the critique writing exercises (Kalman & Aulls, 2003; Kalman, Milner-Bolotin, & Antimirova (2009)).

Reflective Writing Tool

Get students to metacognitively examine the material in their textbooks before it is discussed in class

Instructions

Many of you may have experience that during discussion with others, you can clarify your ideas. Speaking to others is always helpful to obtain a better understanding. The idea of doing reflective writing is to construct a self-dialogue about what you have read. The main difference between summary and reflective writing is that in a summary you write down what you already have in your mind during your reading, while in doing reflective writing you question what you read and relate it to other concerns.
DON'T just pick up important sentences or ideas from the textbook and give me a list!

To do it, first finish reading the material, at the same time, you may underline, highlight, or even do summarization. Then close your book, and rethink about what your have in your brain, at the same time, write down your rethinking rapidly. Don't pay attention to grammar, it's not formal writing, but jotting. Write down your own understanding of concepts, relationship among those concepts, or even relationship of the material to former chapters and your former knowledge from other disciplines and life experience.
Don't worry if what you are writing is right or not. Marking is not based on that.

Collaborative Group Intervention

Groups are formed and roles are assigned: Time Keeper, Critic, Facilitator, Recorder and Presenter

Groups are asked to solve a conceptual problem

The groups write down their solutions.

Next the instructor invites 2-3 groups to present their solution to the entire class

The instructor facilitates an all class discussion.

A vote is taken on the various alternatives.

The instructor helps the students to resolve the conflict with the help of experimental aids.

Comparison of the Effectiveness of Collaborative Groups and Peer Instruction in a Large Introductory Physics Course for Science Majors
Calvin S. Kalman, Marina Milner-Bolotin, and Tetyana Antimirova
Canadian Journal of Physics 88, (5), 325-332, 2010.

Two equally experienced instructors (two of the paper authors) T & M were teaching an introductory first year physics course for science majors in a large public university in Toronto. Students were randomly assigned to the two sections of the course taught by T (N=110) & M (N=148).

Modified Peer Instruction

Students work in small groups (of 2-3) to figure out conceptual questions

A clicker question is posed

↓

Students work individually for about a minute to figure out the answer that they submit using clickers

↓

Students' responses are displayed to the class without revealing the correct answer

↓ (left branch)

Many of the students answered incorrectly.

↓

Students work in groups of 2-3 to discuss the question.

↓

Students resubmit individual answers using clickers.

↓

↓ (right branch)

Most of the students provided a correct response. Correct answer revealed.

↓

An instructor leads a summary discussion with the class: the reasons for correct answer as well as the reasons for choosing the incorrect answers are elicited from the students.

Final Exam Question	Score section T	Score section M	Activity type Section T	Activity type Section M
Final Q13	64.10%±5.5%	55.08%±4.6%	CG (T)	PI (M)
Final Q11	46.15%±5.7%	49.15%±4.6%	PI (T)	CG (M)
Final Q5	71.79%±5.1%	56.42%±4.5%	CG (M)	PI (T)

Only the students who wrote all the assessments were included in the data analysis:

For Section T: 54 students
For Section M: 77 students

In this experiment, it was necessary not only to alternate the concepts, but also to eliminate the effect of different professors in the two classes.

Table 1: Interventions in two sections (T and M) of the introductory calculus-based mechanics course. Each section is exposed to both the conceptual conflict collaborative group method (CG) and modified peer instruction method (MPI).

Concept \ Instructor	T	M
A. Vertical 1-D motion with constant acceleration: objects thrown from the edge of a cliff.	CG (T)	MPI (M)
B. Inertia & graphical representation of motion: sandbag dropped from ascending balloon	MPI (T)	CG (M)
C. Newton's second Law: Forces on a body in a moving elevator	CG (M)	MPI (T)
D. Free fall versus motion in the presence of air resistance: Vertical motion of bodies dropped from a high tower	MPI (M)	CG(T)

In the **critiques** [Kalman, C. S., Morris, S., Cottin, C. & Gordon, R. (1999)], students are required to present arguments in favor of both their personal scientific concepts and the scientific explanation described by the instructor, with the aid of supporting experiments at the end of the conceptual conflict collaborative group activity.

They must also clearly indicate which position is verified by experimental evidence (with references to the evidence.)

At most 5% of students still insist that their personal scientific concept is correct.

These students are asked to see the instructor.

TABLE I. Studies comprising program of research

	Setting/Population	Methods	Purpose
Study 1 (1999) Kalman, Morris, Cotton & Gordon	Concordia University – 2 groups of students in two successive years	-Quantitative	Explore the collaborative-group exercise as a stand-alone activity.
Study 2 (2004) Kalman, Rohar & Wells	Concordia University - 2 later groups of students in two successive years	-Quantitative -Students taught by a different instructor than in Study 1 **Year 1**: as in Study 1, collaborative group utilized without follow-up of critique exercise **Year 2**, Collaborative- group exercise followed up by critique exercise	Modifications were made to the interventions explored in Study 1: Conceptual conflict model (using collaborative group exercises) was enhanced by the introduction of the writing-to-learn exercise ("critique")
Study 3 (2008) Kalman, Aulls, Rohar, & Godley	Concordia University -Sample of students from Study 2, year 2	-Qualitative	Analyze the reflective writing activity
Study 4 (2009) Kalman,Milner-Bolotin, M., & Antimirova	Ryerson University -2 groups of students in a single semester	-Quantitative	Comparison of the conceptual conflict collaborative group method with peer instruction
Study 5 (2010) Kalman, & Rohar	Marianopolis College and Champlain College compared with study 3.	-Qualitative	Analyze the reflective writing activity

Study 6 (2012) Huang & Kalman [51]	University and College. 2 groups of students in a single semester	- Quantitative scores on a - - Survey; interview transcripts and students' writing products	Explore if reflective writing enables students to approach science textbooks in the manner of a hermeneutic circle
Study 7 (2011) Lee, Ha, & Kalman [56]	University	- Analyzing group discussions and written student responses	Analysis of a lesson from a hermeneutic perspective
Study 8 (2014) Kalman, Milner-Bolotin, Shore, Aulls, Charles, Lee, Antimirova, Coban, Lopes Coelho, Kaur Magon, Huang, Ibrahim, & Wang (the present study)	University and College 4 groups of students in a single semester. [2 groups at each institution]	- Rubrics on writing products plus qualitative analysis of the pre- and post-interviews	Explore if the whole set of reflective-writing activity, reflective-write-pair share, collaborative- group exercise and critique exercise can change the way students learn and exceed the outcomes of stand-alone studies

Study Objectives:

We attempt to bring students to recognize that mechanics can be viewed as a coherent "framework".

A coherent framework is a highly ordered knowledge structure that embraces concepts, methods of applying concepts to solve problems, etc. It contains a coherent set of interrelated big ideas.

As students learn, they relate new material to the material that they feel they already understand and in the process accommodate the new material within the framework.

We do not attempt to determine if any single activity is more effective than lectures or more effective than another kind of activity.

The purpose of this study was to investigate if and how the **combined** implementation of reflective-writing activities, critique-writing activities, and reflective write-pair-share combined with conceptual-conflict collaborative-group exercises **could change students' approach to learning physics over and above the impact of each approach undertaken alone, and also enhance their learning**.

Specifically the first objective is to help students to recognize the importance of concepts in learning physics.

The second objective is to get students to change their learning approach to situate concepts within a framework.

Thirdly, to get them to review all their concepts and ask how they fit into the framework presented in the textbook and by their instructor.

This investigation was conducted at two different institutions over a three-year period. At Institution A, a comprehensive university, classes were relatively large sections (over 100 students each) of a typical calculus-based course in mechanics. At Institution B, a community college, there were relatively small classes (about 32 students each) of a typical algebra-based introductory course in mechanics, electricity, and magnetism.

The two institutions used different textbooks and had different formats.
All sections considered in this experiment at each institution were taught by the same instructor who was not part of the research team that authored this paper.

The first year of the project (spring 2009-fall 2010) was devoted to development of Rubrics to examine reflective writing, critiques and interviews that utilizing courses in the fall 2010 semester.

Inter-rater reliability for the rubrics was tested with actual data before the final coding of responses began. Every available written submission from the students in winter and spring 2011 was circulated to the authors so that each writing product was evaluated by two or three different evaluators

We collected data during spring 2011 through winter 2012. Altogether, two sections in spring 2011 and two sections in fall 2011 were utilized at institution B a total of 120 students.

A further two sections in winter 2011 and one section in winter 2012 comprising 200 students were utilized in institution A.

In institution B in fall 2011 one section (experimental groups) was exposed to all three of the target activities. The other section (control group) was asked to submit only summary writing of textual material before coming to class.

Results:

The Final Exams scores between the experimental and control groups have been compared.The experimental group the students in the group had significantly lower initial FCI scores with a relatively strong effect size than those in the summary-writing (comparison) group, $F(1,48) = 26.01$, $p < .0001$, $\eta^2 = .35$. This means that the two groups differed on scientific beliefs before the study began and this should be controlled statistically. Because there was no systematic reason for this difference in the assignment of students to sections, it was justified as a covariate.

The unadjusted **mean of the experimental group on the final exam score was 42.47, and that of the summary-writing group was 36.35, differing by 6.12**. After adjusting for the covariates (especially the impact of the FCI), the difference was reduced to 2.70 in favor of the experimental group (not much different in scale from the difference at Institution A).

This difference was significant, $F(3, 48) = 9.04$, $p < 0.0001$, and the effect size, $\eta^2 = .36$, was relatively strong.

The experimental group appeared to overcome their initial disadvantage reflected in the FCI scores and surpassed the comparison group in actual course performance as well as in their thinking processes as shown in the qualitative (interview) data.

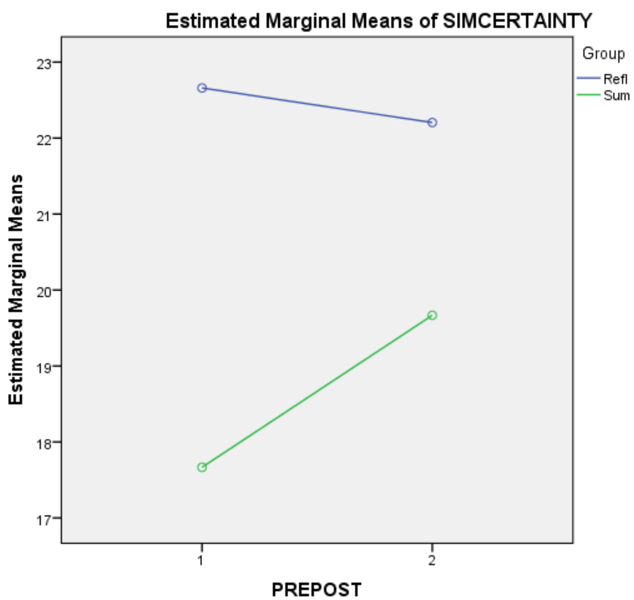
Was there epistemic change in students in the experimental group and control group after taking the course for one semester

Before and after the intervention, the participants of both groups were asked to fill out the *Discipline-focused Epistemological Beliefs Questionnaire* (Hofer, 2000) adapted for the domain of physics.

We could only use data for those students who actually chose to fill out the questionnaire adapted for the domain of physics (DFEBQ) at the beginning and end of the course from the experimental group (*n* = 44) and control group (*n* = 15).

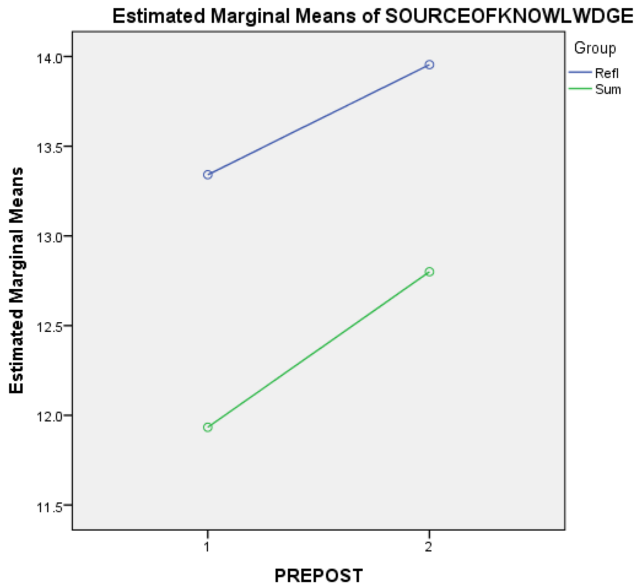
In the DFEBQ, the four epistemic belief dimensions are Certainty/Simplicity, Justification of Beliefs, Source of Knowledge, and Attainability of Truth

A 2 (group condition, i.e., reflective, summary) x 2 (time, i.e., pre, post) x 4 (epistemic beliefs--simplicity and certainty, source, justification, attainability) GLM Repeated Measures analysis was conducted to compare the effect of one semester intervention on students' epistemic beliefs in two different conditions: reflective writing versus summary writing.

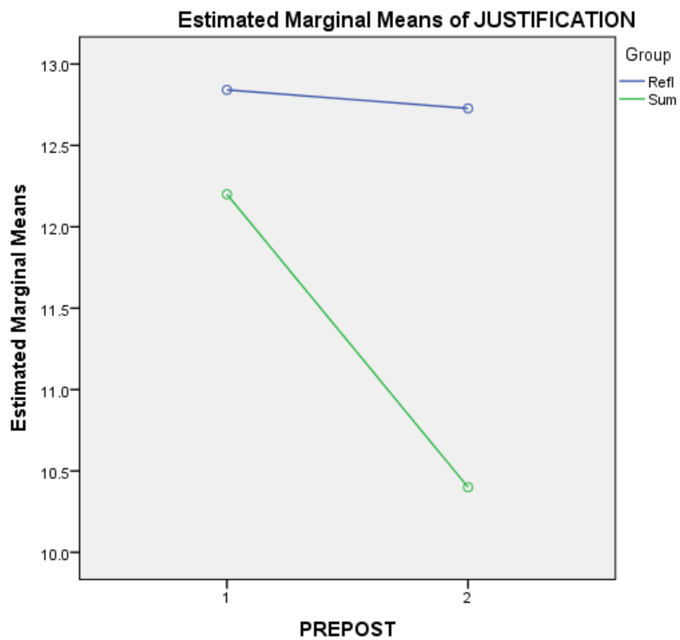


in the dimension Simplicity/Certainty, the reflective-writing group developed their epistemic beliefs toward a more advanced level, whereas the summary-writing group showed the opposite trend.

This was in the direction of what we expected, although the change was not significant. If true, that means students from the reflective-writing group, given time, came to believe that knowledge is complex and evolving instead of being simple and fixed.

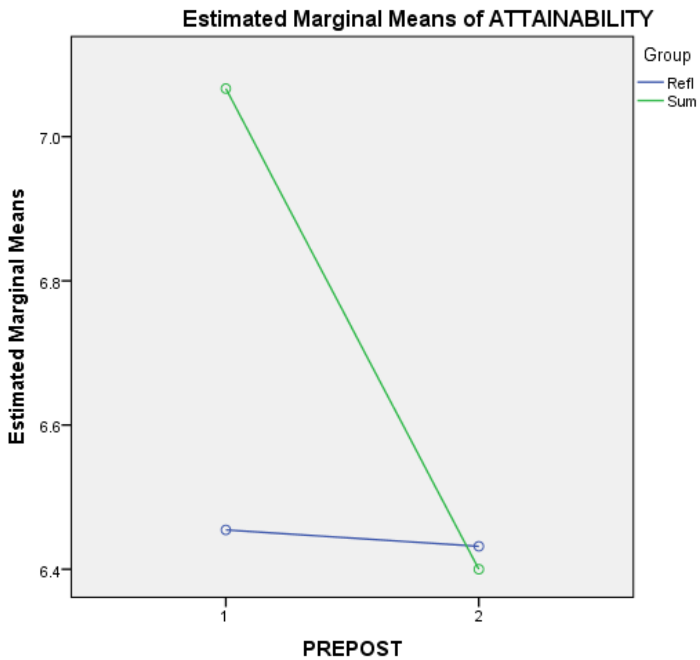


In the dimension of Source of Knowledge, both groups tended to believe that knowledge is handed down by authorities more and more, which means their beliefs did not develop but became less sophisticated.



In, both groups' epistemic beliefs become less advanced, with the summary-writing group experiencing a bigger setback than the reflective-writing group.

Justification of Knowledge refers to the knower's evaluation or estimation of their knowledge in relation to the authority's knowledge. The difference between the size of the changes was significant.



In Attainability of Truth both groups had growth in their beliefs, with the summary group having a bigger change than the reflective group, which means both groups saw knowledge as more attainable.

Although this change was not significant, it was in the direction we expected.

For the fall 2011 and winter 2012 data we had developed a set of rubrics to analyze the data

Students at institution B did not exhibit as much anxiety about the course as those in institution A both at the beginning and end of the course.

Two out of five students in institution A reported the course as challenging, whereas five of eight students at institution B reported the course as challenging on both the pre- and post-tests.

At both institutions some students exhibited changes in how they viewed learning. Students categorized this as “Seeing concepts from different perspectives” (five students) and “Seeing physics (or other knowledge) as more than a collection of facts, having a relational structure” (five students).

“Have you changed the way you learn as a result of taking this course?”.
Four out of five students in institution A and at least three out of eight students in institution B responded positively:

The ways in which this occurred differed from student to student, but all of these students reported “less reliance on the textbook.”

“Why do you think the professor has given you this activity, reflective writing?”:
four of five students in institution A responded “identifying important ideas”
four “Thinking about what you are learning.”
Three “Integrating ideas”
Three “recognition that disagreements can be good.”
Five of eight in institution B reported “identifying important ideas” Three “Thinking about what you are learning”.

Overall, this study had potential access to data 346 students.

34 critiques made available for students in winter 2011 and spring 2011. Nine of these products were from six experimental-group students at Institution A, and 25 critiques were written by 25 students at Institution B. Forty-three more critiques from a further 11 students in institution A in winter 2012.

Institution B: by a wide margin, the largest number of responses, 52 of 129, were scored as the maximum 3. The mean rating was 2.14.

Institution A: similar but less positively skewed.

Students who engaged in critique-writing activities acquired the skill to write critiques that reflected ability to identify key concepts and other target performance of the present study.

Reflective-writing activity

We analyzed 249 reflective-writing products for winter 2012 and fall 2012 students

Typical results

Table VIII. Institution A Winter 2012.
Ratings of the Writing Products (Maximum Possible = 3)

	Fluent, students' own words	Identifies concepts, own words	Relates concepts to previously studied concepts	Relates concepts to life experiences	Identifies conflicts with own ideas
Student 17 Ch4(1-3)	1.3	1	1.3	0.3	0.3
Student 17 Ch4(4-6)	3	3	2.7	2.3	1
Student 17 Ch5	2.3	2	2.3	2.3	1
Student 17 Ch6	2.3	3	3	3	0.3
Student 17 Ch7	3	3	2.7	2.7	1.3
Student 17 Ch8	2.7	2.3	2.3	2.3	3
Student 17 ch11-12	1	1.7	1	2	0.7
Student 19 Ch4(4-6)	3	2.3	0.3	0	0.3
Student 19 Ch5	3	3	3	3	0
Student 19 Ch6	3	3	3	3	2
Student 19 Ch7	2.7	2.7	1	3	0
Student 19 Ch8	1.3	1.3	0.3	3	0
Student 19 ch11-12	3	3	0	3	0

Interviews

Students were asked what they had done at the beginning, middle and end of the course to learn physics.

Students doing summary writing reported that that they were doing the same activities at all three times; typically- reading the textbook, summary writing and attending the tutorial session.

In the reflective writing group a typical student reported that at the beginning of the course he was looking for direct examples of how to solve the particular problem.

By the middle of the course, he was trying to think of the points he needed to take out of the chapters and write notes about them.

More details emerged that students had actually changed their ways of learning.

One student stated: "I don't know if I'm older or anything but now I don't just want to copy and paste equation but to actually understand."

He was now more systematic: "Not just memorizing it; actually understanding. To actually apply it and to know how it actually works."

Another said "I kind of noticed that I am being forced to maybe change the way I think about things

"The course has developed new ideas and ways of seeing things."

Conclusions:

The main results of this study were the changes in students' approaches to learning physics, especially as revealed in the interviews. Final examination results were a bonus that added insight that complemented the main objectives of the study.

Although traditional problem-solving was not specifically targeted by the experimental course activities, it improved as a spin-off of the suite of interventions given to the experimental group, most notably at Institution B.

Because the students in the experimental group had come to think of the course in terms of a framework, they most likely had developed a paradigm approach to solving problems rather than relying on treating each problem type as a domain of its own (with a plug-in formula). This could explain their higher achievements on the end-of-course examination.

Conclusions:

Administration of the *Discipline-Focused Epistemological Beliefs Questionnaire* showed that the novice science learners become more expert-like and saw knowledge as interconnected as a result of having participated in the intervention.

Analysis of the results based on the rubrics showed that that the students in the experimental group were able to identify concepts and relate them to previously studied concepts within the course and to their own life experiences.

They came to the realization that some ideas/facts/data presented in the textbook are in conflict with the students' own ideas.

Most of them were also successful in discussing the conflict.

In doing the critiques, faced with scenarios taken from two different frameworks, all but one of the students were able to justify the point of view of their framework.

Conclusions:

In the interviews, students typically stated that they were "thinking about some of the concepts we are taught for problem solving."

in the 2012 interventions when students stated that they viewed learning as "Seeing concepts from different perspectives" (five students) and "Seeing physics (or other knowledge) as more than a collection of facts, having a relational structure" (five students)

In the critiques, faced with scenarios taken from two different frameworks, all but one of the 28 students were able to justify the point-of-view of their framework. In seven of the 12 critiques, the student writing the critique was also able to evaluate arguments based upon a framework that was different from the one chosen by the other student. In most of the critiques, the students could justify the Newtonian point of view suggested in the assignment. These outcomes indicated that most of the students in the experimental group had come to appropriately place the science presented in the course in the context of a Newtonian framework.

Implications for Physics Teaching

Implementing the pedagogical strategies discussed in this paper has the potential to help instructors in introductory physics courses to empower their students in learning science by learning how to learn. It can help them move from template-driven to paradigm-driven thinking in the subject matter, even in gateway courses. It can help them perform better. Moreover success in courses resulting from acquiring such strategies can help retain students beyond gateway courses in science.

It is important to use a combination of activities--the suite is more effective than any of the single activities on its own--and to make participation compulsory. The activities should be built into the evaluation system

Thanks!!