Changing students' approach to learning physics in undergraduate gateway courses

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ABSTRACT

This study investigated if and how a combined set of specially developed activities – a) reflective writing, (b) critique-writing activities, and (c) reflective write-pair-share combined with the collaborative conceptual-conflict group exercises–can help students change their approach to learning physics and their actual learning. Each of these activities was previously successfully tested as a stand-alone activity. We also developed new rubrics for evaluation of the impact of the activities. Data were collected at two different institutions over a two-year period. At each institution the same instructor taught students in two sections. At the first, a comprehensive university, classes were relatively large sections (over 100 students each) in a typical calculus-based course in mechanics. At the second, a community college, there were relatively small classes (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. Measured outcome variables included student interviews and writing products. Students in the experimental groups better identified key concepts, related concepts to their own prior understanding of the same and other concepts, and used a paradigm-based rather than template-based approach to solving new problems. Moreover, the experimental teaching approach had a significant positive impact on students' final examination results in one of the settings. The *Discipline-focused Epistemological Beliefs Questionnaire* was administered at the beginning and end of the semester. Overall, results in the dimension of simplicity/certainty showed that novice science learners become more expert-like after the one-semester intervention, beginning to see physics knowledge as interconnected and evolving, which can be better learned by relating to their prior knowledge and their life experience. The same trend of development was also found with their beliefs in the attainability of truth: students believe more and more that truth is attainable. The main results of this study are the changes in students approach to learning physics.
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I. BACKGROUND

It has been long established that closing the novice-expert gap is one of the most difficult tasks in science teaching [1,2,3,4,5]. Many novice science learners view science as loosely connected pieces of information to be separately learned, in contrast to the web of meaningful interconnections perceived by science experts [6, 7-10]. Elby [11] suggested that a holistic mode is required for meaningful learning. Students do not conceive of science in terms of a coherent theoretical framework. The students' paradigm, in the Kuhnian sense, is that the subject-matter consists of solving problems using a tool kit of assorted practices. "The professor classifies the problems in terms of physics concepts, while the students classify them by situations" [11] (p. 85).

A coherent theoretical 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 assimilate the new material within the framework.

The novice-expert gap is not necessarily reflected by students' science grades or their ability to solve standard quantitative end-of-chapter problems [12, 13]. It is reflected in the approach to learning and also in the quality of the connections among related concepts [14]. More successful students use such expert-like strategies more often and more effectively [15,16, 17]. Teacher-centered instructional methods, such as traditional lectures, are largely ineffective in helping students acquire expert-like science skills and behaviors [18, 19, 20] or to appreciate the nature of science [21, 22]. It is the purpose of this research project to create a learning environment in which students can both succeed in undergraduate science courses and develop meaningful approaches to learning in physics and other sciences as well as other transferrable skills vital for productive participation in a modern society.

We had previously developed and validated the activities in our suite: the Reflective Writing Tool [23, 26, 27], the conceptual-conflict collaborative group exercises, reflective-write-pair-share [28, 29], and the critique-writing exercises [21, 30]. The Reflective Writing Tool enhances students' understanding of concepts found in their textbooks by helping students to approach text in the manner of a hermeneutic circle:

> The hermeneutic approach starts by having students initiate a self-dialogue about each textual extract. Within the framework of such a dialogue, there exist two "horizons." There is the horizon that contains everything that a student believes from the particular vantage point of encountering the textual extract. The second horizon encompasses the potential in the textual extract; the sense in which the words, in the textual extract, are related within the language game understood by the author of the textbook. "To acquire a horizon means that one learns to look beyond what is close at hand –not in order to look away from it, but to see it better within a larger whole and in truer proportion" [24, p. 272]. The student approaches the textual extract with preconceptions (misconceptions) about the material within the textual extract. The key quintessential experience occurs when the student is pulled up short by the textual extract. "Either it does not yield any meaning or its meaning is not compatible with what we had expected" [24, p.

> 237]. At this point the dialogue begins. The student questions what is known within the entire horizon. The horizon may shift in the process. "A horizon is not a rigid frontier, but something that moves with one and invites one to advance further." [23, p. 163; 28]

The term reflective writing is used in this study to refer to the use of free writing to interact with material from a textbook before the material has been examined in the classroom in the manner of a hermeneutic circle [23, 28, 27, 31].

Two group exercises are used in class; reflective- write- pair share and conceptual conflict collaborative group activities. To engage all the students in the activities, in many instances students are involved in reflective-write–pair share. In this case, students are asked to freewrite for a short fixed time on the material presented on a single projected slide and then share their conclusions with their neighbours. The collaborative group exercises begin by the creation of groups and group members being assigned or taking on the roles of time keeper, critic, facilitator, and presenter. Groups are then asked to solve a problem. Each group writes down its solution and the instructor asks two or three group to present their solutions to the full class, and facilitates a wider discussion about the merits of the proposed solutions. The students vote on the various alternatives and the instructor presents experimental aids to help the students resolve conflicts.

The combined reflective write-pair-share and conceptual-conflict collaborative-group exercises deal with students' personal scientific concepts. "Students will cling to their personal concepts if problems with their personal scientific conceptions do not occur. This is because these beliefs make sense in explaining observations they have made about the physical world, and having taken the effort to construct their private understanding, students will not easily relinquish their original viewpoints" [26] (p. S48). This is indeed one of the reasons for the failure of traditional Conceptual Change Theory. To remedy this problem, this exercise was devised to help students develop their critical thinking skills

The critique activity was introduced to promote critical examination of the alternatives produced in the collaborative group exercise. It is, in essence, an argumentative essay in which students have to put forward as many possible arguments in favour of all the conceptual viewpoints raised in class and then point out which viewpoint is correct from an experimental point of view. Kalman and Aulls [14] reported moderate success in getting students "to change from a view that science is a matter of solving problems using an independent set of tools, classified according to problem type, to a view that a science subject consists of a web of interconnected concepts" (p. 762). In a study combining the conceptual-conflict group plus critique elements [30] there was a slight indication, but not highly convincing evidence, that students had rethought other concepts not directly addressed.

The stand-alone studies and the one paired study (1 to 7 in Table 1) demonstrated the promise of these individual activities, but did not address the potential value added of using the full set of activities. As Gadamer [24] noted, and as reflected by the notion of the hermeneutic circle, to most effectively assist students in building an understanding of scientific concepts in context, they need to repeatedly engage the topic from different approaches. Using the suite of activities might create such a condition for more effective and expert-like knowledge construction.

Figure 1 shows how the different activities are sequenced in the course. Each of these activities has been demonstrated to be effective, to varying degrees, for conceptual learning as stand-alone activities [32] using, for example, the *Force Concept Inventory* (FCI) [33]. As stand-alone activities we did not, however, study their impact on students' epistemic thinking or on direct learning within a college course, and the FCI does not enable such examination. In the current work, we have investigated the extent to which exposure to this full suite of activities changes the way students learn science, in addition to their performance. Table I shows how this new study (listed as Study 8) relates to the seven prior studies of the stand-alone learning activities. As evidence now we used the rubric ratings instructors gave to student responses to activities (quantitative data), the student responses to face-to-face semi-structured interviews (qualitative data), and the course final examinations (quantitative) and responses to the *Discipline-focused Epistemological Beliefs Questionnaire* [34] administered at the beginning and end of the semester (quantitative).

II. OBJECTIVES

The purpose of this study was to investigate if and how the combined implementation of reflective writing, reflective pair-share, conceptual conflict, and critique activities could change students' approach to learning physics over and above the impact of each approach undertaken alone, and also enhance their learning. In this paper we will not be trying to see if a single activity is more effective than lectures or more effective than another kind of activity. Rather we will examine if and how the combined implementation of a suite of experimentally tested activities 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 learning objective for the students was to recognize the importance of concepts in learning physics. The second objective for the students was to modify their learning approach so that they situated concepts within a coherent framework. The third goal was to enable the students to review all their concepts and ask how these concepts fit into the conceptual physics framework presented in the textbook and by their instructor.

III. METHOD

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. Measured outcome variables included student interviews and writing products. Because these course conditions are typical of each institution, we were vigilant for different patterns of results in case they needed to be addressed separately. However, at both institutions students were randomly assigned to two sections by the Registrar's office. These were courses normally taken by students intending to study further in physics and taken by students required to take physics for other program requirements. 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 the development of the rubrics and interview questions utilizing courses in the Fall 2010 semester. Data on students in the Fall 2010 semester are not incorporated in this paper. In Spring 2011 through Winter 2012, we collected data. 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 each semester and in Winter 2011 at institution A, one section (experimental groups) was exposed to all of the target activities: reflective writing, critique-writing activities, reflective-write pair-share, and collaborative conceptual-conflict group exercises. Both other sections (control groups) were asked to submit only summary writing of textual material before coming to class. Summary writing is a skill used by many students and for which some research is available showing positive effects of summary writing on recall and understanding [35]. Marks were given for reflective writing, critiques, and summary writing, based on the rubrics described below. The reflective-write pair-share and collaborative conceptual-conflict group exercises activities were done by all the experimental-group students during regular class hours, but did not count in the grades. The reflective writing and critiques were assigned as homework. Finally in Winter 2012 a further experiment took place in institution A involving 26 students in a single section. This section was taught by the same instructor as the two sections in Winter 2011. Roughly half of the students were involved in the reflective writing and critique-writing activities. The rest chose not to participate in these activities. All of the students participated in the reflective-write pair-share and collaborative conceptual-conflict group exercises activities. Overall, this study had potential access to data 346 students.

We carefully garnered feedback from scholars throughout this project. At the inception in July 2010 we presented the proposal for this research at a Physics Education Research [36] conference. As data became available we presented preliminary results at the March 2012 and March 2013 National Association for Research in Science Teaching conferences [37, 38], the June 2012 annual meeting of the Society for Teaching and Learning in Higher Education [39], the World Conference on Physics Education in July 2012 [40] and the June 2013 meetings of the Learning International Networks Consortium [41] to get feedback on the results. At the same time we conducted the analysis of the study using the rubrics and further analysis of the interviews. Analysis of the results was completed in January 2014.

This mixed-methods study combined quantitative test and rating results with qualitative analyses of semi-structured interviews about the same mechanics phenomena The rubric for reflective writing included eight categories reflecting increasing levels of competence, and the rubric for the critique included four categories also reflecting increasing levels of competence. These categories range from barriers and facilitators, to student learning, to changes in students' learning strategies. The rubrics for the interviews are complex. They do not fully cover all of the rich information found in the interviews and thus were followed by a further qualitative analysis to set out categories and to find all information related to these categories. The development of the rubrics is described below. The interviews elaborated on the rubric outcomes and verified the validity of the quantitative results. The interviews probed students' epistemic beliefs and their views about and the nature of science, whether their views have changed and, if so, the students were asked what brought about these changes. Interviews were audiotaped and videotaped then transcribed.

Several iterations of the reflective writing rubric were analyzed and applied to actual writing products over an extended period until a final version emerged with wide consensus in the team. One such application presented the reflective writing exercise and a prototype of its scoring rubric in experimental and control classes, and demonstrated that the rubric effectively discriminated between the two learning experiences [27, 42]. Rubrics for the critiques were subsequently developed following similar principles and procedures.

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 (a total of 55 products--only a subset of the potential population agreed to make their writing products available as research artifacts) was circulated to the authors so that each writing product was evaluated by two or three different evaluators using the rubrics.

IV. RESULTS

With Winter 2011 and Spring 2011 students we had thought that we would make comparisons between an experimental group and a control group to establish a benchmark for the study. We were able to test our rubrics and make comparisons with the control groups. For the students in Winter 2012 and Fall 2012, we were only interested in answering our main research question: Did the exposure to the entire suite of activities change *students' approach to learning physics over and above the impact of each approach undertaken alone, and also enhance their learning?*. We thus concentrated on the students exposed to the whole suite of activities except for the administration of the *Discipline-focused Epistemological Beliefs Questionnaire* [34] administered at the beginning and end of the semester.

The following illustrative excerpt is from a student's reflective-writing sample in institution B on Chapter 8 from a typical introductory physics textbook [43]:

> The theoretical content of this chapter is not all that different from chapter seven and fairly straightforward. It is more of a merging of the concepts of energy with more familiar problem solving strategies . . . . To me, a deceleration caused by kinetic friction of, say, 10 m/s^2 would produce an enormous amount of heat. I have never thought about where that energy goes till now. My first reaction was that the tire would not be able to handle that amount of energy transfer, which I now know must be false. . . . What I still do not understand is if the capacity of brake pads to absorb heat is higher than I expected, or rather if the rate at which deceleration translates to heat is much lower. (Student BC, Institution B)

The average ratings for "Student identifies key concepts from assigned reading and lecture in his or her own words" for the reflective writing and summary groups are shown in Table II (column 30. The reflective writing group mean score was 2.2 and the average score for the summary-writing group was 1.3 (*SD* of these two ratings = 2.02); a statistical test of significance would not be informative with this restricted sample, but the effect size was $d = .45$ and is considered medium in size [44] and, if replicable, would be meaningful. On every criterion by which the reflective writing was evaluated, the experimental group ratings were higher, and for four of the features applicable to reflective writing, the ratings for the summary writing were zero. This implies that there are desirable outcomes from the former that are not observable within the latter.

2. Critique-writing activities

Critique writing in conjunction with the conceptual-conflict collaborative-group activity has been shown to be effective previously [30] using the *Force Concept Inventory* (FCI) as a criterion (noted as Study 2 in Table I). In the present study, the outcomes were initially compared using the rubrics that were developed specifically to evaluate the critiques. Students were presented with two scenarios drawn from an earlier conceptual-conflict collaborative-group activity [32]. One scenario corresponded to an explanation that does not have experimental validity and the other to the Galileo-Newtonian framework. Figure 5 presents a critique from student #8 in Institution B and Figure 6 shows the critique written by student #6 in Institution A, from the total of 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 twenty five critiques were written by twenty five students at Institution B). Forty three more critiques from a further eleven students in institution A in Winter 2012 . As above, three raters evaluated each individual product on a scale of 0 to 3 points in each category.

3. Reflective write-pair-share and conceptual-conflict collaborative-group activities

This activity was previously evaluated as a stand-alone activity [25] (noted as Study 1 in Table I) using the *Force Concept Inventory* (FCI) and compared with peer instruction [21] (noted as Study 4 in Table I) using results on the final examinations as outcome criteria; the collaborative-group approach was more effective than peer instruction

B. Interviews as Criterion Outcomes

In Winter 2011 and Spring 2011, we conducted 13 interviews early in the course and 15 interviews around the end of the course. Six of the early interviews were with students in the experimental group and seven with students in the control group. Six of the 15 interviews around the end of the course were with students in the experimental group. Nine of the 15 interviews near the end of the course were with students in the control group. In Winter 2012 and Fall 2012 a further 13 interviews from the experimental groups at the beginning and 13 interviews at the end of the course were conducted. In this case the same students were interviewed at the beginning and end of the course. The information below portrays the most salient results from the Winter 2011 and Spring 2011 data.

Comments in the experimental group such as “making connections in your brain” and “life isn’t about just reading things in isolation; they are all connected” corroborated the evidence within their reflective-writing products that students in the reflective writing group focused on concepts and attempted to make connections between concepts. Another student, who did not think the activity was useful for him, nonetheless said that “it’s kind of happening a conversation with yourself, you’re basically interpreting the text for yourself” and a third student wrote that “it forces you to think about what you are learning.” This student also noted that “if you don’t understand them, maybe the lecturer will clarify them or you could at least ask questions.” Finally he noted that “you kind of build on things, building on concepts throughout the chapters.”

Just two students in the control group looked for concepts. One student mentioned that it would help the student find questions to ask in class about material that the student did not understand. Another student “look[ed] for some things I didn’t know” and he might use summary writing in other courses. Some students valued summary writing as not just a rote activity, but it did not as consistently focus their attention on concepts and the relations between concepts.

In the experimental group, most students reported a change in how they learned physics. Only one student claimed that no change had occurred. Replies especially noted applications to other domains, and that physics is more than plugging numbers into formulae. Another specifically addressed critique-writing with the observation that, “Without argument, how is one to know that the real view is the real view? . . . important to disprove certain ideas.”

Three students in the control group said that their ideas about learning physics had not changed. However, this question more than the first elicited responses from control-group students who mentioned the importance of concepts particularly in solving problems and that physics involved more than putting given numbers into equations. One student told the interviewer that “You have to understand the equations, not only memorize.” Another who noted that previously she had thought that physics was about plugging numbers into formulae, “but now I think . . . concepts are linked and you have to look at every single aspect of the problem to solve it.”

More students in the experimental group were aware that their understanding had changed.

Students in the experimental group, exposed to the full suite of activities, reported becoming more systematic and thorough in their approaches. A typical student reported that at the beginning of the course he was looking for direct examples of how to solve a particular problem, and already 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. They reported new ways of envisioning the problems, and thinking actively about the concepts. These reports supported the idea that students had actually changed their ways of learning.

Students who had done summary writing reported that that they were doing the same activities at the beginning, middle, and end of the course, typically reading the textbook and notes, summary writing, and attending the tutorials.

This direct questioning about what students actually did, not about their thinking or overall assessment of their experiences, revealed an important behavioral advantage for the suite of activities over summary writing.

C. Interviews in Fall 2011 and Winter 2012

It is noted that 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. (Unlike institution A these were not the same students – only three described the course this way on both pre- and post- interviews.

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). Four out of five students in institution A and at least three out of eight students in institution B responded positively to the direct question "Have you changed the way you learn as a result of taking this course?" The ways in which this occurred differed from student to student, but all of these students reported "less reliance on the textbook." When asked about "why do you think the professor has given you this activity RW?" four of five students in institution A responded "identifying important ideas" and four "Thinking about what you are learning". Three noted "Integrating ideas" and three "recognition that disagreements can be good". Five of eight in institution B reported "identifying important ideas" and three "Thinking about what you are learning".

D. Final Examination Performance as a Criterion

The interview results above are the primary data of this study. The instructors at both institutions, however, also gave us access to the final grades (or aggregated data) from their classes that were part of this study. Final examination results for the experimental and control groups were compared separately within each institution because of differences between them. Institution A was a university, and B was a community college. Within institutions students were assigned at random to the two sections, but class sizes were much larger at A (≈ 100) than at B (≈ 32). At Institution A, the class sizes were large enough that it was likely that the assignment of students to sections was random. However, doing the suite of exercises was optional at the request of the collaborating instructor.

The smaller class sizes at B entailed some risk that nonsystematic group differences might exist. As a precaution, at Institution B we were able to have the participants complete the enhanced version of the *Force Concept Inventory* (FCI) [33] and Lawson's *Classroom Test of Scientific Reasoning* (Lawson) [45] as pretests (covariates). The FCI is a probe of belief systems about mechanics and has been administered at a large number of universities internationally and has been validated similar populations. The Lawson consists of 22 multiple-choice questions addressing the identification of variables, controlling variables, probabilistic thinking, and hypthetico-deductive reasoning. The final examination from Institution B is presented in Appendix A to illustrate the kinds of questions students were asked. In addition, the suite of activities was required at Institution B.

At Institution A we found no significant difference on a one-way ANOVA between the final exam raw scores (maximum score 45) of students from the class that optionally did the suite of activities including reflective writing (*n* = 46, *M* = 25.83, *SD* = 11.29) and the class that only did summary writing (*n* = 66, *M* = 23.39, *SD* = 9.15), $F(1,111) = 1.58$, $p = .21$, $\eta^2 = .01$). The effect size was also effectively zero. The absolute difference of 2.44 final text points between the groups was masked by the high final-test variability within each group of students. This variability is unlikely to have been introduced by the experimental activities in which only 20-some students participated in its three elements, and more likely reflects the student population, their previous physics knowledge, and engagement in the course. Both group's mean scores are close to the middle possible score out of the maximum 45, consistent with assumptions of highly variable and not high overall student performance in the course, and with the possibility either that final test that was not optimally aligned with what the students actually learned or that their overall learning experiences were not well aligned with the goals represented in the final test (two sides of the same coin). Final examination results could be a useful criterion if the examination questions demand the knowledge and skills covered by the learning activities, that is, in this case actually draw upon students' changed manner of understanding and learning physics.

At Institution B, constraints on our access to (and therefore reporting statistics such as standard deviations) individual students' scores limited us to noting that 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. There was no significant difference and zero effect size between the experimental and comparison groups on the Lawson pretest, $F(1,48) = 0.02$, $p = 0.8783$ ($\eta^2 = 0$). It almost certainly addressed skills beyond the experience of both groups or the objectives of the gateway courses. It was left in the analysis as a predictor just to eliminate the small amount of variation it predicted.

A one-way between-subjects analysis of covariance was performed on the final examination scores from Institution B. The independent variable was the intervention type (reflective writing and other exercises versus summary writing only). The original sample of 56 students was reduced to 52 due to four missing values. 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 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 date. The final exam (appendix A) directly and broadly assessed students' ability to apply principles of mechanics and electricity for familiar categories of problems, and required thinking beyond just plugging in numbers; it was not necessary to have memorized formulae, but it was necessary to be able to select which applied to particular problems.

E Administration of the *Discipline-focused Epistemological Beliefs Questionnaire* [52]

Our objective was to see if *the combined implementation of reflective writing, reflective pair-share, conceptual conflict, and critique could change students' approach to learning physics over and above the impact of each approach undertaken alone, and also enhance their learning.* . Specifically, the purpose of this one-semester intervention study is to promote epistemic change in novice students through a physics gateway course by using three different learning activities. The research questions we asked in this study are (1) whether there is epistemic change in students in the experimental group and control group after taking the course for one semester, and (2) how experimental group and control group are different in terms of the patterns of the change or no change. Overall we are looking for evidence for common changes in students' epistemologies due to the instructional interventions.

We could only use 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; experimental group (N = 44) control group (N = 15). Students rated their agreement to each item using a 5-point Likert scale ranging from 1 (completely disagree) to 5 (completely agree). Lower scores on this scale represent more constructivist beliefs, with the exception of the justification dimension (higher scores indicate more constructivist beliefs).

In the DFEBQ the four epistemic belief dimensions includes: certainty/simplicity, justification of beliefs, source of knowledge, and attainability of truth [50]. The *certainty/simplicity* dimension represents individuals' beliefs about the nature of knowledge. The certainty component of this dimension reflects whether individuals view knowledge as being absolute and certain or as tentative and evolving, whereas the simplicity component reflects whether individuals believes knowledge is accumulated bits of facts or is interconnected and context specific. The *justification of beliefs* dimension reflects a belief that knowledge is justified by relying on experts versus individual opinion and firsthand experience. The *source of knowledge* dimension reflects beliefs that knowledge is handed down by an authority figure like a teacher or other expert or it can be personally constructed. Finally, the dimension *attainability of truth* reflects individuals' beliefs about whether ultimate truth is attainable. At the one end of the continuum of truth being obtainable, individuals believe that people can ultimately figure out the correct answer to any question. At the other end of the continuum wherein ultimate truth is not attainable, individuals believe that not every question has a correct answer.

Comparison

A 2 (group condition, i.e., reflective, summary) X 2 (time, i.e., pre, post) X 4 (epistemic beliefs, i.e., simplicity & 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: summary writing group and reflective writing group.

Multivariate Tests show that there was a significant main effect of GROUP, Wilks' Lambda = .75, F (4, 54) = 4.37, $p < .05$. The within subject test indicate that there is not a significant time effect, in other words, the groups do not change in their epistemic beliefs over time. The interaction between time and group was not significant. Univariate Tests results showed that there was significant change in the dimension Justification, $p < .05$.

From Figure 7, we can see that in the dimension Simplicity/Certainty the experimental group has developed their epistemic beliefs towards more advanced level, whereas the summary group showed the opposite trend. This confirms to what we expected, although the change was not significant. That means students from the experimental group with time believe that knowledge is complex and evolving instead of being simple and fixed. In the dimension of source of knowledge (Figure 8), both groups tend to believe that knowledge is handed down by authorities more and more, which means their beliefs didn't develop but went towards less advanced. The lines are parallel, showing that the interaction was not significant. In justification (Figure 9) both groups' epistemic beliefs become less advanced, with the summary group having a bigger setback than the reflective group and the difference of the changes between these two groups is significant. (Justification of Knowledge refers to the knower's evaluation or estimation of their knowledge in relation to the authority's knowledge). In attainability (Figure 10) both groups had growth in their beliefs, with the summary group having a bigger change than the reflective group, which means both groups see knowledge as more attainable. Although this change is not significant, it is towards the direction as we expected.

Discussion

The importance of personal epistemology in individuals' cognition, motivation and achievement has been increasingly recognized. As epistemological sophistication is considered as a desired educational outcome, efforts to promote its growth are necessary and worthwhile. This study aimed to affect actual epistemic change in novice science students by using a range of instructional activities. Results in the dimension of simplicity/certainty and showed that novice science learners become more expert-like and see knowledge as interconnected due to the effect of the intervention. The same trend of development was also found in the dimensions of attainability of truth, with the novice learners believing more and more that truth is attainable. The findings are limited since this is just an intervention of one semester, and that the sample size for each group is not balanced (Reflective = 44; Summary = 15). Although the improvements found in the experimental group in these two dimensions are not significant, better results can be expected when it is used to a larger sample for more extended intervention.

However, we did not expect that students' beliefs regarding source of knowledge and justification of knowledge become less advanced after the intervention. To explain this, Hofer and Pintrich [50] may be right in conceiving that "aspects of the nature of knowledge can act as constraints on the process of knowing" (p .118). Following this argument, it is possible that beliefs about certainty of knowledge and simplicity of knowledge would develop first, while changes in beliefs about source of knowledge and justification for knowing would be more dependent, constrained and difficult.

V. CONCLUSIONS

The main results of this study are the changes in students approach to learning physics. Final examination results were a bonus that added insight that complemented the main objectives of the study.

The qualitative results in 2011 demonstrated that students in experimental classes at both institutions changed their ways of thinking about physics and learning physics and students who did not experience the full suite of activities did not. The control sections had been asked to perform only a relatively neutral activity: summary writing of textual material before coming to class. The impact of the suite of activities was consistently stronger than the impact of each separately in previous studies.

The qualitative results in 2012 gave evidence of how students viewed learning and how they changed their ways of learning as a result of the suite of activities.

The quantitative results demonstrated that in Institution B, at which all students in the experimental group were required to engage in the full suite of learning activities (a) reflective writing, (b) critique-writing activities, and (c) reflective-write pair share combined with the collaborative conceptual-conflict group exercises, students' performance on the well-aligned final test also outperformed students from the control group, and did so having started with an initial disadvantage in terms of conceptual thinking assessed by the FCI. The quantitative results demonstrated the value-added of combining the elements of the suite of learning activities on actual performance in the course. The quantitative results are consistent with Austin and Shore's [14] results from concept mapping that also positively impacted final test scores, in their case on multi-step problems that required transformations of given information. In other words, helping students to think better as physicists not only improves their separately assessed thinking but also has the potential to enhance their examination performance. 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. This could explain their higher achievements on the end-of-course examination. Administration of the *Discipline-focused Epistemological Beliefs Questionnaire* showed that the novice science learners become more expert-like and see knowledge as interconnected due to the effect of the intervention.

Our first objective was "to help students to recognize the importance of concepts in learning physics." For the 2011 interventions, as one student in the experimental group had noted, "It is more of a merging of the concepts of energy with more familiar problem-solving strategies." In the interviews, students typically stated that they were "thinking about some of the concepts we are taught for problem solving." At the beginning of the course, students in the experimental group had reported that they searched the textbook for templates to solve problems. As the course progressed, they came to realize that solving problems requires an understanding of concepts. This was explicitly shown in the 2012 interventions as students stated that they viewed learn 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). When asked about "why do you think the professor has given you this activity Reflective Writing ?" four of five students in institution A responded "identifying important ideas" and four "Thinking about what you are learning". three noted "Integrating ideas" and three "recognition that disagreements can be good". Five of eight in institution B reported "identifying important ideas" and three "Thinking about what you are learning". The twenty eight students for every given viewpoint or scenario identified a key assumption or concept.

Our second objective was "to bring students to recognize that mechanics can be viewed as a coherent framework." As students learned, they related new material to that which they believed they already understood and, in the process, assimilated the new material within the framework. Faced with scenarios taken from two different frameworks, all but one of the twenty eight 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 student 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.

Our third objective was "to enable students to review all their concepts and ask how they fit into the framework presented in the textbook and by their instructor." The rubrics showed that students 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, or data presented in the textbook are in conflict with the students' own ideas and then also to discuss the conflict. Students in the control group did not do this.

The overall goal of the study was "to investigate if and how a set of specially developed activities can help students change their approach to learning physics." The "how" was addressed in the three specific objectives. The "if" was also supported. Both the interviews the student-writing products and the *Discipline-focused Epistemological Beliefs Questionnaire* indicated that students had undergone a shift in their thinking about physics and physics learning. Students changed their way of thinking about science and the nature of science. The way they approached studying physics indicated that the students changed their manner of learning due to their exposure to these activities. Furthermore, as a consequence of meeting these objectives, in Institution B, the experimental group achieved significantly higher scores, with a relatively large effect size) on the final examination than the control group (nonsignificant differences in the same direction were found in Institution A where participation was optional).

Students in the experimental section had thought about concepts and related the concepts in a chapter to previous chapters and their life experiences. In his book about helping science and engineering professors enhance their teaching, Kalman [40] presented a letter from a student, who ended up getting a perfect score on her final examination:

> In the first couple of assignments, I spent hours trying to figure out how to do the problems and never seemed to get the right answers. I didn't understand why. During the classes, I followed along and seemed to grasp all of the concepts, and then when I got home, I couldn't do the problems. . . . After the midterm, I started to realize that the concepts were extremely important. . . . If there was a problem I couldn't get . . . I went through the concepts in order to try and

> understand what the problem was asking. And for the most part, even if I couldn't get the right answer, I had the concepts and knew at least the gist of the problem. (pp. 135-136)

Numerous studies [46] have shown that many students, just like the student quoted above, have difficulty abstracting a principle from examples, encoding information into flexible memory representations, and accessing the appropriate principle in new problem contexts. For a novice problem solver, each problem on an exam is expected to correspond to a template. The student anticipates needing only change the information on the template to make it correspond to the examination problem. Such students lack the ability to apply principles garnered from one problem to an apparently different problem [47,48]. Students need to approach problems in the manner used by experts, which is what the most able students do [15, 16, 20]. Experts use paradigms--procedures to apply principles abstracted from many sample problems. To meet this challenge, students must make the shift in their learning from template solving to solution by paradigms. Salomon and Perkins called these learning approaches "Low-Road and High-Road Transfer" respectively [49].

A. Implications for Physics Teaching

Implementing the pedagogical strategies discussed in this paper has a 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.

The three specific exercises--reflective writing, critique-writing activities, and reflective-write pair share combined with the collaborative conceptual-conflict group exercises--are well described in accessible literature, they are easy to implement, and the do not consume an inordinate amount of class time. They can even increase student engagement and interest, and can be easily built into a wide range of instructional situations from traditional lectures, tutorials, and labs, to inquiry-driven and project-based courses.

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 required. The activities should be built into the evaluation system.

It is also important to ensure that content quizzes and examinations draw on the skills and require paradigm-level thinking and transfer of thinking approaches across problem types. Toward this end, also ensure that TAs and laboratory assistants who may not have experienced such activities themselves are helped to understand that each problem category is not a world unto itself and that they in their support of teaching and learning demonstrate these parallels in tutorials and in their feedback. For example, they can relate how certain paradigms in an earlier problem are used again in new situations as the course progresses, and not just tutor the problem of the day.

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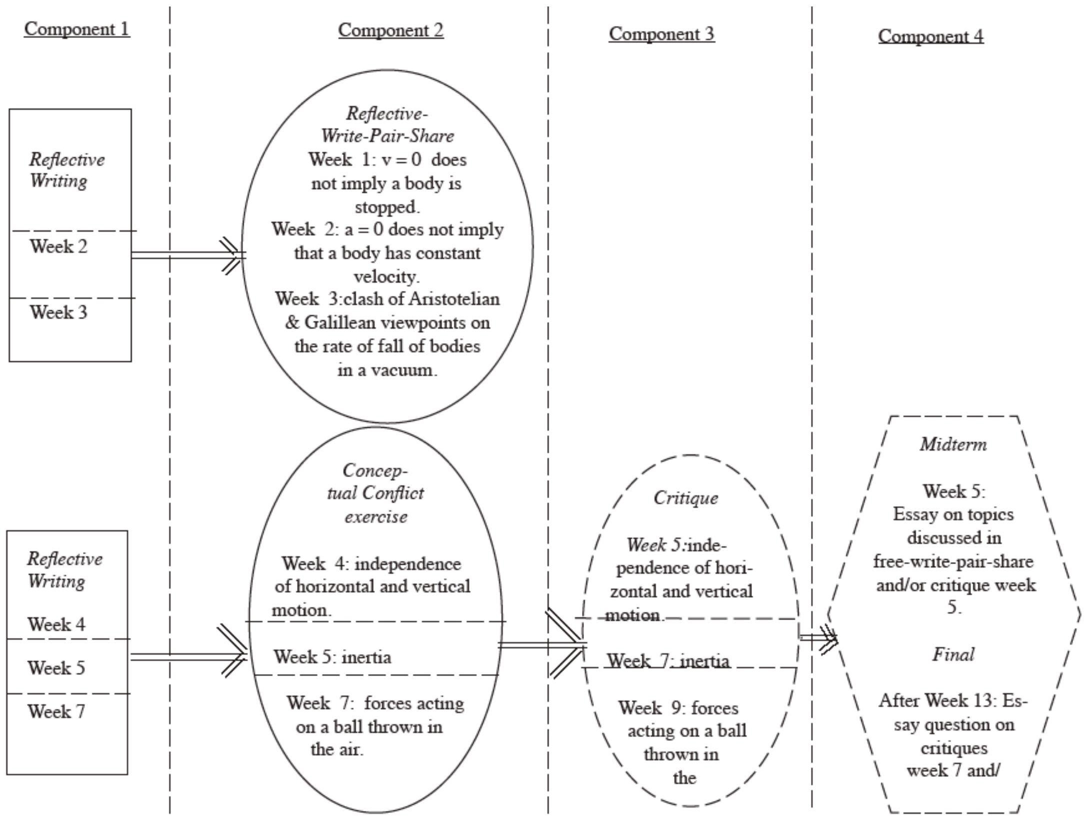

FIGURE 1. The Set of Different Activities including Four Components Utilized in the Experimental Groups.

Reflective Writing Ch.10

Right off from the start this chapter had me confused. It states clearly that an extended object such as a wheel which obviously rotates about its own axis..which I assume is kind like a bowl spinning on top of a pole? Kind of like if I stood straight and had a hoopla hoop spin around me. Anyways, it goes on to state that this motion cannot be analyzed by modeling the object as a particle because it at any given time, has different arts going and different speeds or accelerating at different levels.

Again there it is not quite clear to me why we could not still model it as a particle in uniform circular motion? It may be, that in the example I was talking about, the wheel spins really fast on a car while you're driving, but while the wheel is in rotation, the axle (or whatever that piece is called) is not rotating, or doing so at a much slower pace. If so than we would then need to measure the two separately or together but with a completely different reference frame. It seems to me it's almost like having to separate particles in uniform circular motion, at the same time, but with reference to each other.

Another extremely confusing concept that I found in this chapter is that of Torque. In the book, it is described or defined as, the tendency of a force to rotate an object about some axis. Torque is essentially a quantity by which this force is measured. To me that is not at all very clearly explained. What I was talking about earlier though is clearly somehow related to it. Using the wheel example, the wheel is said to be rotated about its axis, as in the case of a car in motion the wheel is rotating around the axle.

This of course is done in a certain direction, which is based on a force. So there is a force that is moving the wheel in the direction, for example that your driving. Now to qualify and determine what exactly this force is, we use torque. Essential from what I can infer from this, is that Torque measures how hard/fast or the force needed in order to move the wheel or some circular object about its own axis.

FIGURE 2. Improved Reflective Writing Example (Student KL, Institution A, Experimental Group, transcribed verbatim).

Reflective Writing Assignment 4 Chapter 7

Chapter 7 introduces mainly work and energy. This chapter explains how work is done with a constant force and how various forces can apply work. Also, the energy it takes to do the work while converting energy from kinetic to potential. Also, power is introduced and the scalar product of two vectors is shown in this chapter.

The first section introduces work. Work is done when a force is applied to an object at a certain point and the displacement of that point from the start to the finish is known by the amount of work done. Therefore, lets say that the displacement is zero, if this is the case, then there has been no work done. If the displacement is zero then the work is zero. For example, the magnitude of the force has to be considered but also the direction. If the object is on top of the ground and force being applied is perpendicular to the floor, then the mount of work is zero. The force has not moved the object and therefore no displacement has been made. So since the force has to also have an angle, then the work is done. Given the same scenario, if the force applied was at an angle positive in the first quadrant in a Cartesian coordinate system, then the only component taken into consideration would be the x component. Work would equal the force multiplied by the distance by cosine theta. Work is also an transfer of energy. If there is work done from the system, work is positive. If there is work done to the system, then work is negative. In this case, if there is work done from the surroundings then work is negative and if the work is done from the surrounding to the system, the work is positive. The amount of work done is also calculated like the moment. The force multiplied by the displacement. Work is always measured in Newton meters therefore giving one joule.

Since the forces are calculated in vector format, we need to learn how to use scalar multiplication. The scalar multiplication is the multiplication of the magnitude of the two vectors added together and multiplied by the cosine of that angle. Since scalara is a product of two vectors, then we can assume that if vector a is multiplied by vector b, then that would equal vector b multiplied by vector a. This is know as the commutative propertied. Also, there is a distributive law stating that if the product of the addition of vector a and b by c are equal to the addition of the product of vectors a and c and b and c. The final interpretation that is important is the vector components and how they are calculated. When doings scalar multiplication the components of i, j, and k are added with the second components of the same i, j, and k.

Work can also be done by the application of various forces. In nature, there is rarely ever just one force applying to an object, but multiple forces. Therefore we need to know how to sum up all these forces and stick it in an equation. The change of work is done by the x component of the force multiplied by the change in displacement. In this case, if there are multiple forces then we just take the summation of this equation for calculating every individual force and sum up the values form the final displacement to the initial displacement. If this is true, then work is the integral from x final minus x initial of the x component force in respect to the displacement. You may also apply the summation to this equation also. The fore done by a spring is a little different. Since the force is constant and minute, we use Hook's law where the force resolved from the x component is equal to the negative displacement multiplied by k, where k is the force constant positively. To find work, when the integral is taken from x final to x initial, we know that the k hoes outside the integral while calculated and therefore the displacement becomes squared and multiplied by a half. Note that this is the area under the curve of the line of motion that we are calculating and then multiplying it by the force which in this case is a constant. Note that if the spring was in a horizontal angle then the mass at the end of the object would have to consider gravity giving it the equation of k as mass multiplied by gravity over d, where d is the displacement of the spring from where it was originally in equilibrium to the point where the force applied it.

FIGURE 3. First Reflective Writing Example (Student SB, Institution A, Experimental Group, transcribed verbatim).

<u>Initial velocity of Sandbag is 0.</u>
The first reason as to why people would conclude that the sandbag has a velocity of 0 m/s is that the sandbag is physically not moving. It is the hot air balloon that is moving and the sandbag is in it. Therefore most people would conclude that the hot air balloon has a velocity of 8 m/s but the sandbag has 0 m/s.

The second reason as to why people would conclude that the sandbag has a velocity of 0 m/s is because when we draw the free body diagram we are only focusing on one object thus in this case we would think that the sandbag has an initial velocity of 0 m/s.

The third reason that would make a person to conclude that the sandbag is a 0 m/s would be the idea of gravity pull. Therefore when the bag is all up you would think is that the sandbag has only gravitational force acting on it thus the final velocity would be at 9.8 m/s making the initial velocity at 0 m/s.

<u>Initial velocity of the sandbag is the same velocity as the velocity of the hot air balloon,8 m/s</u>.
The definition of velocity states that velocity is the measurement of the rate and direction of change in the position of an object. Due to this reasons we can say that the sandbag has a velocity of 8 m/s as there is a change in position. Both the hot air balloon and the sandbag leaves at the same time thus they are travelling together allowing us to know that they both have the same speed to get to the distance that they are in.

One experiment that was done to explain this would be when Robin had a ball in his hand and he jumped. When Robin released the ball we were able to see that the ball had gone up slightly before it came down thus we can conclude that the initial velocity would be start at 8 m/s.

Another reason that got me to conclude that the initial velocity of the sandbag is at 8 m/s would be that the initial velocity is the velocity of an object when an outside force is applied to it. In this case the outside force would the transfer or energy from the hot air balloon to the sandbag. In Marina's key experiment, if a person is walking at a speed of 8 m/s and we say that the key has an initial velocity of 0 m/s then we are saying that the key is left behind and it would not be in her hands. Since the key is in her hand and it not left behind then we can conclude that the key is moving the same speed as Marina.

Objects are linked together in the physical world thus of one object is contained within a moving object then it is also moving. Another example would be if a car is moving and it crashes to another object and let's just say you are not using a seatbelt in most cases your body would fly out of the car this is only because you are travelling at the same speed as the car.

My final conclusion after all the experiments and explanations is that the initial velocity of the sandbag has to be at 8m/s.

FIGURE 4. Sample Critique, Experimental Group, Institution B, transcribed verbatim.

CRITIQUE # 1.

A bullet that is fired from a gun horizontally actually takes a path that is curved downward. the downward curve is caused by gravity acceleration causing the bullet to accelerate downwards.
Although we may think that a bullet flys in a perfectly straight line, several different forces act on a bullet as it goes through the air. Over a very short distances, the bullet does follow more or less straight line, but over a long distance shot, the bullet follows a downward curve because gravity tugs the bullet toward the ground as it goes along.
As stated above, the trajectory taken by a bullet is affected by several forces, mainly by two forces, force of velocity and force of gravity.
looking at the picture in the center we can see that the bullet follows a straight horizontal line then follows a downward curve. this mix trajectories of straight line and a curve occurred probably because of the combination of the two forces. the force of gravity given by the ~~bullet~~ the gun. the velocity force tends to make the bullet move in a straight line out of the mouth of the gun and parallel to the ground as depicted in the picture in the center. the force of gravity in it is turn, allows the bullet to travel away from the gun, it is pulled downward by earth's gravitational field. So instead of travelling in a straight line it travels in a curve path toward the earth's surface.
On the other hand, the picture to the right is more likely showing that the bullet is taking a downward curve as soon as it leaves the gun. that downward curve trajectory can be explain by the fact that a bullet flied in an arc shape because when the sights are aimed at the target, the gun is not parallel to the ground. it is pointed up at a slight angle.
Moving either the front or rear sight up or down will change the angle of the barrel. Also in the picture to the right, they must have taken consideration by the fact that the force of gravity pulls the bullet down as it is traveling forward as soon as the bullet was shot, this results in a quick downward curved trajectory. Contraraly to the picture in the center where they assume gravity being introduced after the bullet had traveled a certain horizontal distance.

FIGURE 5. Sample Critique, Experimental Group, Institution A, transcribed verbatim (this Critique received full marks for the physics).

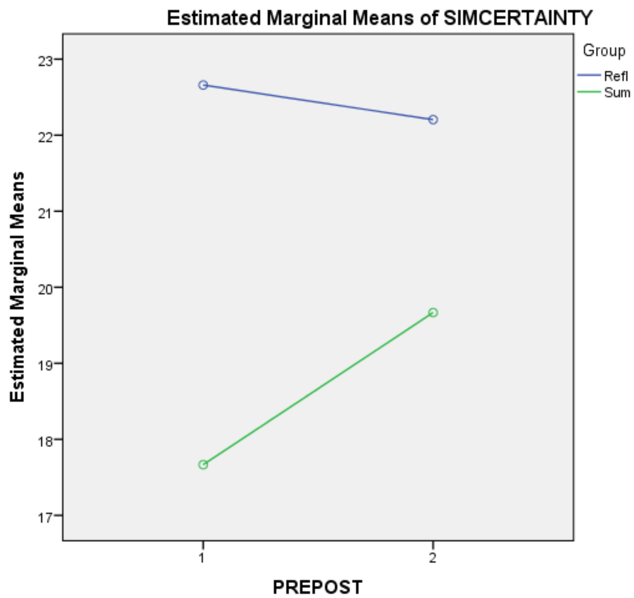

FIGURE 7. Dimension of *Simplicity/Certainty.*

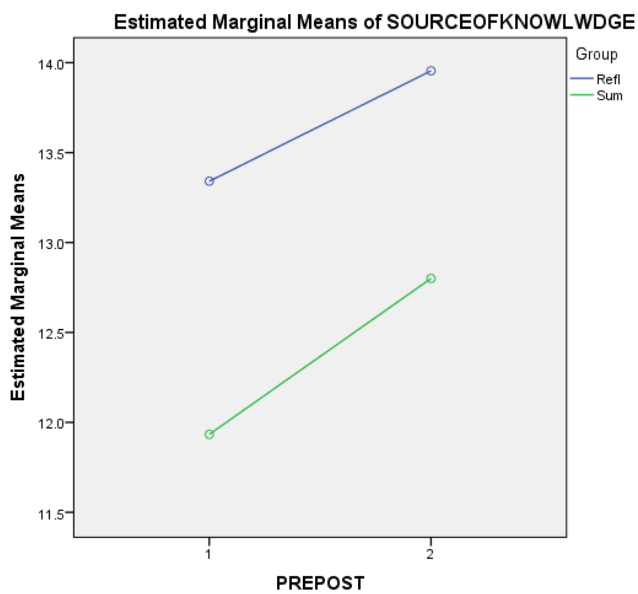

FIGURE 8. Dimension of *Source of knowledge.*

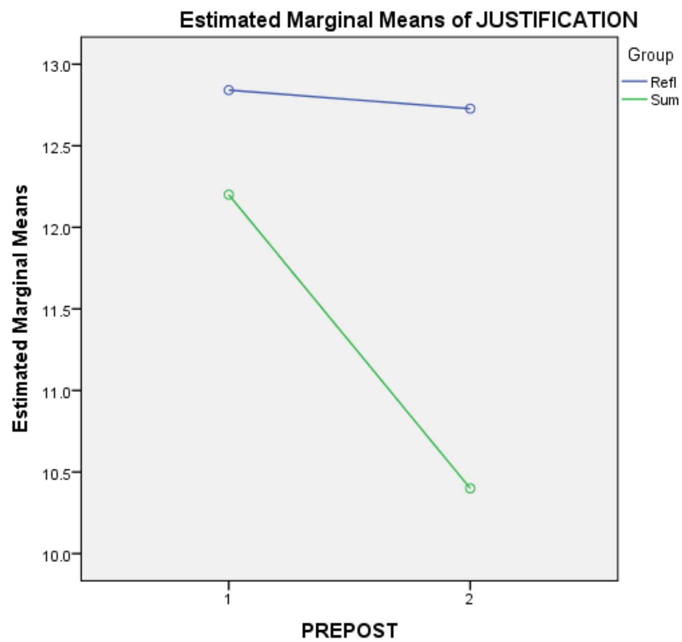

FIGURE 9. Dimension of *Justification.*

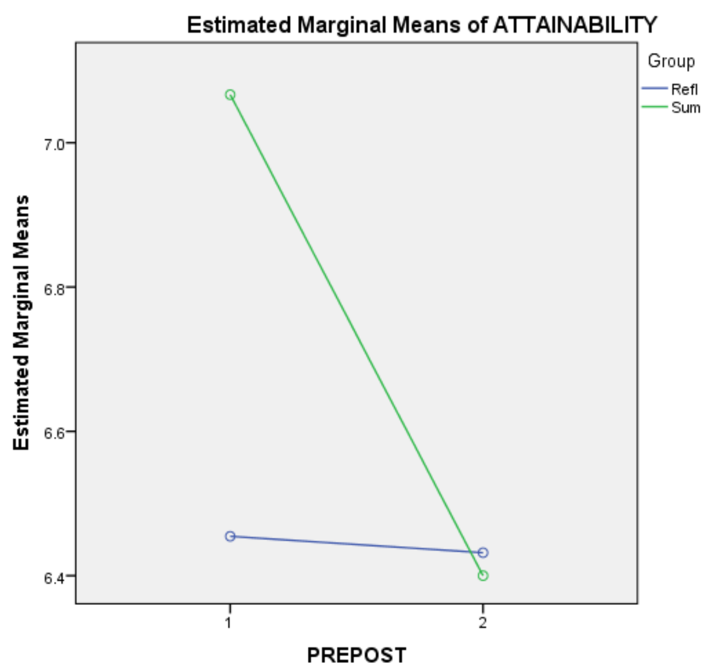

FIGURE 10. Dimension of *Attainability.*

Table I. *Overview of Studies Comprising the Present Program of Research*.

Study	Setting, Population	Method	Purpose
Study 1 (1999) Kalman, Morris, Cottin, & Gordon [4]	University, 2 groups of students in two successive years	-Quantitative	Analyze the collaborative-group exercise as a stand-alone activity
Study 2 (2004) Kalman, Rohar, & Wells [36]	University, 2 more 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	Analysis of the Conceptual conflict model (using collaborative group exercises) enhanced by the introduction of the writing-to-learn exercise ("critique")
Study 3 (2008) Kalman, Aulls, Rohar, & Godley [4]	University sample of students from Study 2, year 2	-Qualitative	Analyze reflective writing as a stand-alone activity
Study 4 (2010) Milner-Bolotin, Antimirova, & Kalman [31]	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 [40]	University, 2 Colleges. - 3 groups of students in a single semester	-Qualitative	Comparison of students from University and one College performing the reflective-writing activity, collaborative-group exercise and critique exercise. Comparison with the second College was for the reflective-writing activity only.
Study 6 (2012) Huang & Kalman [27]	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 hermeneutical circle
Study 7 (2011) Lee, Ha, & Kalman [38]	University	- Analyzing group discussions and written student responses	Analysis of a lesson from a hermeneutical 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

Table II. *Comparison of Average Ratings of Reflective and Summary Writing Products (Maximum Possible = 3, Minimum 0).*

	Fluent, students' own words	Identifies concepts, own words	Relates concepts to previously studied concepts	Relates concepts to life experiences	Identifies conflicts with own ideas	Discusses conflict	Formulates questions	Addresses questions
Reflective Writing	2.8	2.2	1.8	2	1.2	0.8	1.3	1.1
Summary Writing	1.3	1.3	0.5	0.7	0	0	0	0