What did I learn and why do I believe in it?

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Abstract: The paper describes a study of students' reflections on their learning in the Investigative Science Learning Environment (ISLE). ISLE was implemented in two freshmen introductory physics courses for engineering students at risk. Weekly Reports - structured journals - were a part of their homework assignments. We found that a thorough reflection on their reasoning based on experimental evidence had a positive effect on student performance. However a surprising finding was that learning from authority was beneficial as well. This result is in contradiction to a similar study conducted by May and Etkina in 2001 [1] in a freshmen course for honors engineering students. The current study therefore suggests that instructors should encourage different ways of knowledge construction when dealing with different student populations.

Introduction:

Being able to reflect on the construction of knowledge and to ask yourself questions such as: "How do I know this?" or "Why do I believe in it?" is a part of a regular practice of science. In addition, focusing the attention of the students on these questions was shown to develop high-order thinking skills – metacognition and epistemic cognition [2]. Arnold Arons suggested that physics instructors consider these questions while developing curriculum materials [3].

It is very difficult for a student to answer the question: "Why do you believe in Coulomb's law?" if the law was learned as a ready formula in lecture. Investigative Science Learning Environment [4] is a learning system in which students learn physics using a path similar to that used by physicists. First students conduct observations and collect data without making any predictions. Then they look for patterns in the data and possible explanations for the observed results. Then they use their proposed explanations to predict the outcomes of the new experiments designed to test their explanations. The rejection of an explanation means that a new one is needed. The same cycle works on a quantitative level. Thus, in ISLE, students' knowledge comes primarily from experimental evidence and reasoning, and is based on the coherence of different ideas.

However, teaching a course in this manner does not guarantee that students will focus on the knowledge construction process as opposed to the facts and formulas. To help students reflect on the process, ISLE courses use Weekly Reports (WR), reflective structured journals submitted by the students on-line or on paper [5]. In WRs students answer the same questions every week: 1) What did I learn this week? 2) How did I learn it? 3) What remained unclear? 4) If I were the professor, what questions would I ask to find out whether my students understood the material? WRs are a part of homework, they are read by instructors or special graders. The graders answer students' questions and provide feedback on their writing.

Previous study:

In 2002 May and Etkina [1] reported on the study of Weekly Reports written by freshmen honors engineering students (680 average on mathematics part of the SAT) in an ISLE-type course. They devised and validated a coding scheme for WRs that allowed them to relate the quantity and quality of the 12 students' responses to the first two WR questions to their learning gains in mechanics and E&M as measured by the FCI, MBT and CSEM tests. The following is a summary of their findings:

1. The quality of the writing was related to the gain.
2. While reflecting on what they learned, both high and low gainers reported learning concepts equally often, low gainers reported learning formulas more often.
3. While reflecting on how they learned, low gainers described the experiments that they observed but not the reasoning process, and

CP720, *2003 Physics Education Research Conference*, edited by J. Marx, S. Franklin, and K. Cummings

relied on authority. High gainers described reasoning from evidence or mathematical derivations, focused on the coherence of the ideas, and did not mention often learning from authority.

Research questions of the new study:

Were the findings of the previous study specific to the student population, or could they be generalized? How will students with low math preparation (480 average on the mathematics part of the SAT) and low reading skills report on their learning? Does reflection help them learn?

Sample: To answer these questions we set up an electronic WR submission system in a freshmen engineering two–semester course sequence for at-risk students at Rutgers University [6], taught using the ISLE system. During the first year of the project (2001/2002), students responses to the second question were very different from those of the honors students. For example, they would say: "I learned because I went to lecture." Students were not focusing on the process of learning. After some interviews, we decided to change the second question to: "Why do you believe in it?" The new format of the WR was used in the two consecutive semesters of the introductory course in 2002/2003.

There were about 140 students enrolled each semester. Every week, a special grader read all of their reports and provided feedback. Later all of the reports were coded. A sample for the study consisted of the students who enrolled in both semesters, had pre-FCI scores and two final exam scores (for both semesters), and wrote at least 13 reports out of possible 14 in the second semester. Thus we ended up with a sample of 35 students.

Procedure:

I. To note students' progress in the course, we used a complicated measure as we did not feel that traditional FCI Hake-gain could describe student learning adequately. Concepts addressed by the FCI occupied about 10% of course time. We chose to use two final exams as post-test measures not only because they assessed all the topics covered in the course, but also because they evaluated quantitative understanding, problem-solving ability and some of the science process skills [7]. The final formula for the "gain" in the course was constructed from 3 measures:

a) measure ***a***: pre-test FCI/max FCI score

$$a = \frac{\text{preFCI}}{\max \text{FCI}} = \frac{\text{preFCI}}{29}$$

b) measure ***b***:

$$b = [\frac{\text{1st FE}}{\text{max 1st FE}} + \frac{\text{2nd FE}}{\text{max 2nd FE}}]/2$$

Where 1st FE is the final exam score in the 1^{st} semester, 2nd FE is the final exam score in the 2nd semester, max 1st FE and max 2nd FE are max final exam scores in the first and second semesters

Using measures ***a*** and ***b*** the normalized gain was defined as follows:

$$GAIN = \frac{b-a}{1-a}$$

II. Students' reflections on WR questions 1 and 2 were coded using a slight modification of the coding scheme used by May & Etkina [1]. Code indications with examples of student statements are shown below:

Question 1: What did you learn this week?

1. Formula – "We learned Newton's second law F_{net}=ma".
2. We learned about – "We learned about vectors".
3. Concept – "This week I learned that fluid moves because of a pressure differential in the fluid".
4. Skill – "We learned how to do free body diagrams (isolate different types of forces acting on an object and represent them through vector diagrams)".

Question 2: Why do you believe in it?

1. Observed an experiment – "I saw a gas pipe with flames coming out at different distances".
2. Observed a concept – "When the flag on the turntable turned around, it showed that the centripetal force is provided by the friction force".
3. Reasoned to the concept from observations or other concepts in lecture – "For the second law (an object accelerates when a force acts on it), I believe this because of the reactions I observe in lecture. The cart was pulled by a

spring. The more the spring pulled the faster it moved. We marked its position during a certain time and then graphed the data. It was a straight line – acceleration was directly proportional to the force".

4. Derived from observations or reasoned in a workshop – "I believe in what we learned because we have observed the properties of constant acceleration and found out that the results are repetitive. This evidence is backed up from the fan and cart experiment with the motion detector. The cart's displacement, velocity, and acceleration were calculated from this one computer tool. It showed that the displacement was a parabolic function, velocity was a linear function, and the acceleration was a horizontal function".

5. Learned by doing – "I believe this because in the recitation we experimented with a motion detector and an object that moved away from it with constant acceleration. The computer showed the line as being very similar to a parabola".

6. Authority – "There is something called the head to tail method of adding vectors and I think it's right just because it's sort of like a proof if it's called a method".

7. Predicted and tested – "We predicted the wavelength and then did the experiment".

8. Predicted, tested and elaborated – "The main reason that I believe what we learned is because in workshop we predicted what we thought the graph of the cart driven by the fan would be. Once we ran the experiment, the graphs almost matched perfectly. So, I realized that the theories in the book really matches what happens in reality".

9. Applicability – "I also believe it because situations on earth follow this theory. One example is a boat, how does a boat float on the sea, and that is mainly because of the density of the boat is less than that of the seawater and if the density of the boat ever becomes more than the sea it will sink".

10. Coherence – "That is why I believe it, because it incorporates a lot of geometry that I am already familiar with, and so it makes sense".

III. To note the effect, ***e***, of a particular code indication on the gain, we developed the following formula:

e = [$\Sigma(G_{student}$ x # of times this student used the code) – average G x # of times this code was used by all students] / # of times this code was used by all students

According to this definition $-1 < e < 1$. When $-1 < e < 0$, this particular code reflection has a negative effect on learning gain; when $0 < e < 1$, the effect is positive.

Results: For the selected 35 students during the second semester (14 weeks) we obtained the following results:

Total number of code indications	2753 (100%)
Question 1	1805 (66%)
Question 2	948 (34%)

Distribution of code indications for question 1 "What did you learn this week?':

1.	Formula	439
2.	Learned about	71
3.	Concept	1187
4.	Skill	108
5.		

Distribution of code indications for question 2 "Why do you believe in it?":

1.	Observed an experiment	84
2.	Observed a concept	113
3.	Reasoned from observations or derived in lecture	188
4.	Same in workshop	157
5.	Learned by doing	142
6.	From authority	91
7.	Predicted and tested	2
8.	Predicted , tested and elaborated	23
9.	Applicability	75
10.	Coherence	73

Relationship between different code indications for question 2 and normalized gain

In the table below we present combinations of code indications that we consider favorable or unfavorable. We encouraged students to construct knowledge through reasoning from evidence, to test knowledge against new evidence, and to connect physics ideas to everyday life and to each other. Thus, codes 3, 4, 8, 9, and 10 are considered favorable and 1, 2, 5, 6, and 7 are considered unfavorable.

Q 2 code	Description	# of indications	Effect ***e***
3+4	favorable	345	0.05
1+2	unfavorable	197	-0.03
3+4+8+9 +10	favorable	515	0.03
1+2+5+6	unfavorable	430	-0.013
6	authority	91	0.05
All codes	amount of writing	2753	0.02

Discussion

As we conclude from the results of the previous section, some of the patterns in the written reflections of at-risk students and of honors students in the same learning environment are similar: both groups mention concepts, not equations, as the most important part of their learning. In both groups students learn better when they focus on the construction of concepts from experiments through reasoning and from relations to other concepts. However, there are some important differences between the two groups.

1. In the at-risk group, high gainers mention learning formulas more often than low gainers (opposite to honors students). This may mean that focusing on mathematics in addition to concepts helps at-risk students, while honors students do not benefit from focusing on formulas.
2. At risk students write more about what they learned then how they learned or why they believe in what they learned, thus showing a lack of metacognitive skills. Perhaps that is why they are in the group of "students at risk".
3. At-risk students also might benefit from learning from authority, unlike honors students who are better off focusing on their own reasoning processes. This result deserves some special attention. 'Authority' code was used when students talked about reading the book or learning from a TA. It is not surprising that those students who actually read the book and visit TAs do better. In the second course for at-risk students the office hours were moved to a room with lab equipment as more as more students started asking for experimental evidence when TAs answered their questions. Thus some of the authority code indications actually might hide reasoning from evidence.

Implications for instruction

Reflective writing is a useful exercise for all students. However, while honors students benefit only from epistemologically favorable reflection, at-risk students benefit from the writing process itself. Thus, we should look for ways to encourage our physics students to reflect on the construction of knowledge regularly. At-risk students should seek knowledge from different sources; primarily from their own observations of physics experiments and reasoning but they should also be encouraged to reflect on reading the textbook and visiting office hours.

Much work is needed to confirm preliminary results reported here.

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