BEYOND CONTENT AND SKILLS: MISALIGNED EPISTEMOLOGICAL BELIEFS FOR SCIENCE AND BIOLOGY LEARNING

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This study explores college biology students' epistemological beliefs about science and biology learning using a previously developed tool; the MBEX (Maryland Biology Expectations) survey. The survey was administered in an introductory biology course, at the beginning (pre-) and end of the semester (post-) and differences in students' epistemological beliefs were calculated between post-pre. None of the changes was found to be significant, with a majority of students (61% of n=161) holding the same mismatch of epistemologies throughout the academic semester. Although students' science epistemologies are favourable, they are not aligned with their epistemologies about learning biology when it comes to an introductory biology course. Students seem to bear a group of unfavourable epistemological beliefs relevant to their classroom learning. Development of instructional approaches that could foster the development of student science epistemologies and align them with those about biology learning is necessary in order to advance college biology education.

INTRODUCTION

Although college biology students usually excel in knowing facts about different biological principles, it has been well-documented that they lack critical thinking, experimental hypothesis development, and data interpretation abilities (Barnett & Francis, 2012; Butler et al., 2012; Flores, Matkin, Burbach, Quinn, & Harding, 2012). In addition, the learning goals and assessment items of introductory biology courses have been found to focus more on memorization of facts rather than higher-order cognitive skills (Momsen, Long, Wyse, & Eber-May, 2010).

Several publications have discussed the need to create learning environments where students are supported towards the development of higher-order cognitive skills (American Association for the Advancement of Science, 2011) [AAAS]. Content and procedural knowledge is important for the development of students' scientific skills, however epistemological beliefs may play as important of a role as well (National Research Council, 2012) [NRC].

Epistemological beliefs are an individual's beliefs about the nature of knowledge and nature of knowing (Hofer, 2004; Schommer-Aikins, 2004; Hofer & Pintrich, 1997). Epistemological resources are "smaller in size" than beliefs, providing a finer unit of analysis for research studies on students' epistemologies. An epistemological resource is an individuals' perception of the source of their own knowledge, in other words, the understanding of “how do I know what I know,” which is necessary to develop their personal epistemology (Hammer & Elby, 2002; Hofer, 2006). Building on diSessa’s knowledge in pieces (diSessa, 1993), epistemological resources can be seen as units of thought, which are context-dependent. This means that when a student’s epistemological resources are activated in the right context, they can be productive reasoning tools that students use to understand a phenomenon (Hammer, 2000). In other words, epistemological resources can shape a student’s beliefs for scientific knowledge and biology learning. As such, the MBEX (Maryland Biology Expectations Survey) was designed to help educators unravel biology students’ epistemologies about science and biology learning and it has been used in large-enrollment introductory courses (Hall, 2013).

There is evidence that the development of epistemology is affected by the characteristics of the learning environment where a learner is situated (Hofer, 2001). However, literature reporting biology students’ epistemological beliefs for science and biology learning is scarce. The aim of this study was to investigate the question “What are the introductory biology students’ epistemological beliefs at the beginning and end of the semester?” The study was completed in a fast-paced introductory biology class, without any particular class implementation focusing on epistemology. The aim of this study was to measure biology students’ beliefs about science and biology learning in class, in order to invite conversations regarding the epistemic climate of large-enrollment introductory biology courses.

METHODS

Participants and course information

Participants of this study were students enrolled in an introductory biology course at a large public R1 institution during the spring semester of 2017. A total of 83% of the student population (n=392) were freshmen and the course is required for biology majors. Some non-majors were also enrolled because they needed to fulfil a requirement for an introductory biology course. The course has three main parts: 3 lectures of 50min. per week, 1 weekly discussion of 75min., and 3h long weekly laboratory sessions.

Maryland Biology Expectations (MBEX) survey

To examine the changes in student’s expectations about scientific knowledge and biology learning, the MBEX survey (Hall, 2013) was administered to students at the beginning (pre-) and end (post-) of the semester. The MBEX survey is composed of a total of 32 questions: 24 five-point Likert scale from strongly disagree (1) to strongly agree (5), 3 open-ended questions, and 4 multiple-choice questions. MBEX questions measure student beliefs along four different dimensions/clusters: I) Facts vs. Principles, II) Independence vs. Authority, III) Interdisciplinary Perspectives vs. Silo Maintenance, and IV) Connected vs. Isolated. Clusters I and II included 5 overlapping questions, according to the original survey’s structure. Only multiple-choice questions were used in this study.

Data Analysis

Only responses of students who had consented (during the pre-survey) to participate in this study were used for data analysis. Any students with incomplete survey profiles (with >50% missing responses) were removed from the dataset as those who did not complete the post-survey. The final paired dataset was composed of 161 students who had completed both pre- and post-surveys. The number of favourable, neutral, and unfavorable responses were counted for each question and each survey. Favourable responses can be seen either as experts' beliefs or, alternatively, beliefs that the instructors would like their students to have. When a favorable response is associated with the first two Likert choices, then the last two will be associated with the unfavorable response and vice versa. Shifts in student beliefs were calculated by subtracting the pre-scores (favourable, neutral, unfavourable) from the post-scores (favourable, neutral, unfavourable) for each question and for each student. In previous research, it has been found that a shift of 5% in a particular cluster is considered statistically significant (Hall, 2013).

RESULTS

Overall, beliefs of students tended to favourable ones in all four clusters of MBEX survey during an academic semester (Table 1). On average, a majority (pre%, post%) of students believed that scientific knowledge should be independently built (Cluster II, 73%, 70%), interdisciplinary (Cluster III – 58%, 56%), based on principles (Cluster I – 72%, 72%), and connected (Cluster IV – 62%, 58%). However, when a further break down of each MBEX cluster's statements were made, it was seen that these beliefs are opposite from those students have about learning biology, where facts seem to matter more than concepts, knowledge coming from the instructor seems most important, and connections with the real-world or other disciplines can not be easily made. A brief description is given for each MBEX cluster:

Beliefs about Facts vs. Concepts - Cluster I (pre%, post%)

Almost half 53%, 53% (pre%, post%) of the total student population disagreed that "Learning biology is mainly a matter of memorizing the various facts presented", however only 25%, 37% of the students agreed with the statement "I am more interested in general biological principles than the specific facts that demonstrate those principles." Similar results for this question were found by Hall (2013), where the majority of students disagreed with this statement in all the various courses studied. On the other hand, 89%, 88% of students agreed with the belief that learning biology concepts for a test and organizing information should not be done verbatim, but in a self-constructed way, and 71%, 71% of them agreed that their exam performance in biology courses should reflect how well they "apply course material to situations not discussed in class."

Beliefs about Independence vs. Authority – Cluster II (pre%, post%)

73%, 70% of students seemed to prefer independent learning instead of relying on knowledge coming from an authority. However, 40%, 41% of the students agreed that exams should be made of "A large collection of short-answer or multiple-choice questions, each of which covers one specific fact or concept," in contrast to the favourable response "A small number of longer questions and problems, each of which covers several facts and concepts." Regarding organization of biology textbooks, 89%, 88% of students agreed that "A good biology textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each chapter as separate because they're not really separate." In addition, 52%, 39% of students disagreed with the statement "If biology professors gave really clear lectures, then most good students could learn the material without having to spend a lot of time thinking outside of class." This belief shows that learning is associated with studying outside class and that students expect to spend time independently (without an instructor) to complement their classroom experiences.

	Pre-survey (%)			Post-survey (%)			Differences (%)			
Q #	Fav.	Neut.	Unfav.	Fav.	Neut.	Unfav.	Fav.	Neut.	Unfav.	
1	*53	26	21	53	20	27	0	-6	+6	Cluster I
3	86	12	2	84	12	4	-2	0	+2	
6	**25**	**30**	**44**	37	33	30	+12	+3	-14	
16	86	7	6	83	13	4	-3	+6	-2	
20	71	n/a	29	71	n/a	29	0	n/a	0	
21	92	n/a	8	92	n/a	8	0	n/a	0	
22	89	n/a	11	88	n/a	12	-1	n/a	+1	
23	60	n/a	40	59	n/a	41	-1	n/a	+1	
24	89	n/a	11	84	n/a	16	-5	n/a	+5	
Av.	**72**	**19**	**19**	**72**	**19**	**19**	**0**	**0**	**0**	
1	**53**	26	21	53	20	27	0	-6	+6	Cluster II
4	65	26	9	63	16	21	-2	-10	+12	
5	**52**	**27**	21	39	27	34	-13	0	+13	
17	92	6	2	80	9	11	-12	+3	+9	
20	71	n/a	29	71	n/a	29	0	n/a	0	
21	92	n/a	8	92	n/a	8	0	n/a	0	
22	89	n/a	11	88	n/a	12	-1	n/a	+1	
23	60	n/a	**40**	59	n/a	41	-1	n/a	+1	
Av.	**73**	**21**	**19**	**70**	**18**	**23**	**-3**	**-3**	**+4**	
2	46	37	17	42	34	24	-4	-3	+7	Cluster III
8	45	29	26	40	34	27	-5	+5	+1	
12	40	34	**27**	38	38	24	-2	+4	-3	
14	**35**	**40**	25	42	30	28	+7	-10	+3	
18	65	31	4	60	31	9	-5	0	+5	
19	96	4	1	91	6	2	-5	+2	+1	
Av.	**58**	**30**	**15**	**56**	**30**	**17**	**-2**	**0**	**+2**	
7	89	4	6	80	12	9	+9	+8	+3	Cluster IV
10	84	15	1	72	19	9	-12	+4	+8	
11	67	25	8	66	20	14	-1	-5	+6	
13	**22**	**29**	**49**	23	25	52	+1	-4	+3	
15	84	15	1	80	13	7	-4	-2	+6	
Av.	**62**	**20**	**17**	**58**	**19**	**22**	**-4**	**-1**	**+5**	

Table 1: Differences in the percentages of favorable, neutral and unfavorable responses per each question of each cluster of the MBEX survey.

*No decimal places are shown, numbers are rounded up.
Highlighting shows the lowest and highest percentages in each cluster in the pre-survey

Beliefs about Interdisciplinary perspectives vs. Silo maintenance Cluster III (pre%, post%).
Freshmen in this university seemed to recognize the value of learning chemistry along with biology (96-91% agreed for chemistry), but not so for physics (35-42% agreed) and mathematics (46-42% agreed). A high number of neutral responses (ranging between 29%-40%) were seen in this cluster, which may indicate indecisiveness of students over agreeing or disagreeing with a statement about interdisciplinary knowledge coming from a lack of personal interest or expectations. These results are probably not surprising for the introductory biology course population of this study, since there was no overlap between the course's syllabus and physics or mathematics courses. Hall's results on high unfavourable scores (33%) (and 27% neutral), even in reformed interdisciplinary biology courses, may show that a particular learning environment may not be enough to shift student beliefs (Hall, 2013).

Beliefs about Connected vs. Isolated Knowledge – Cluster IV (pre%, post%)
A majority of students (62%, 58%) agreed that knowledge learned in this class can be applied to other situations. Similar findings have been reported on the real-world connection part of the CLASS-Bio survey (Colorado Learning Attitudes about Science Survey), where 65% of majors and 53% of non-majors expressed similar beliefs in the pre-survey (Mollohan, 2015). However, about half of the students (49%, 52%) agreed with the statement "Biology classes should be designed to help students master the factual material for doing well on the MCATs, GREs, and other professional exams." This expectation probably results from the ambition of many introductory biology students to follow professional careers and their high interest in these required performance tests. Along with the agreement with the statement "Biology class should just present all the different facts. Trying to present the unifying theories doesn't really help us understand anything" (86%, 84% - from Cluster I), it is interesting to note that these statements imply fact-based learning having taken place in an introductory biology course.

DISCUSSION

On a per student analysis, this study found that out of total 161 students (paired data), 82 students shifted negatively, 16 did not change their beliefs, and (65) shifted positively (ranging from 1 to 10 out of 24 total responses), using the MBEX survey. Considering each cluster's averages of favourable and unfavourable responses (Table 1), no significant (>5%) shifts were found, however students shifted their beliefs either favourably or unfavourably for specific items of each cluster. It was also noticed that the variety of favourable-unfavourable scores per student was greater in the post-survey, indicating that their beliefs shifted throughout a semester of introductory biology. Hall has previously reported shifts ranging from 0% to 2% for Organismal Biology course, which is similar to the introductory biology course described in this study (Hall, 2013). On the other hand, comparing these findings with the conceptual connections/memorization part of CLASS survey, it was found that the epistemic beliefs of introductory biology students who were majors had largely shifted towards novice-like beliefs (-39.7), however positive shifts (+1.8) were seen for the non-majors. The authors are unsure about the reasons for these shifts (Mollohan, 2015).

What students are invested in learning is affected by what they believe about science. In this study, when students were asked whether "Knowledge in biology consists of many unrelated facts," (#3, Table 1) 86%, 84% (pre%, post %) of them disagreed with this statement, however only 53% disagreed with the statement "Learning biology is mainly a matter of memorizing the various facts presented" (#1, Table 1). The difference between these two questions is that the first one asks about the nature of (scientific) knowledge in general, whereas the second one asks about the environment of learning biology, which students probably relate to their classroom experiences. Memorization of facts may appear more practical or applicable in a fast-pace introductory biology course, even though students recognize that the science of biology is perceived as a coherent network of biological principles. When we informally asked students about how they studied for the final exams, one statement was: "I found I didn't have enough time to make all the connections I wanted to be able to do well in this course but I definitely think it helps."

In pre- and post- surveys respectively, 40% and 41% of students agreed that "a large collection of short-answer or multiple-choice questions, each of which covers one specific fact or concept" (#23, Table 1) is the best way to measure how well students understand the material, positioning them against conceptual understanding. Students seem to understand their role in the classroom as heavily dependent on the instructor and the information that is delivered by them. Some students also described this by saying: "So for the first exam I definitely looked at the discussion quizzes, because I think the professor wrote those, I am not entirely sure [short pause] but the in-lecture activities looked them too, because they were written by him I think." Sandoval has argued that students' practices in class are different from their personal beliefs about science, even in an inquiry-based course. Practical epistemologies are beliefs students have about their own scientific knowledge building in the classroom, whereas formal epistemologies are epistemological beliefs about science that professional scientists have (Sandoval, 2005). Findings from this study are in agreement with Sandoval's work, supporting the statement that learning in classroom may enact a category of epistemologies for science, which we name "classroom epistemologies" and they differ, to various extent, from the formal epistemologies about science, or simply called science epistemologies.

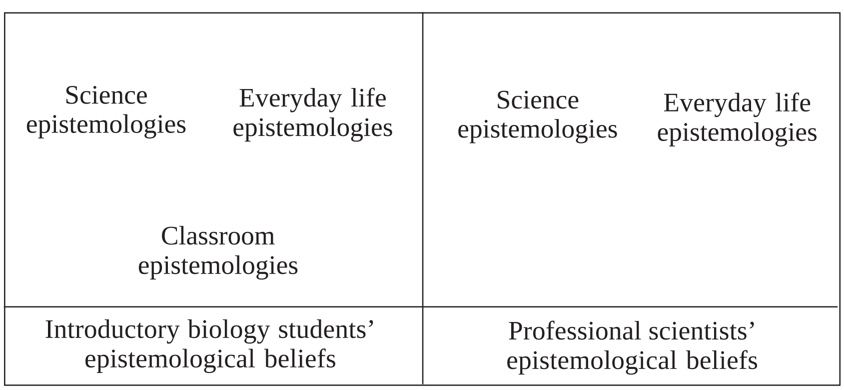

Figure 1. Comparative analogy of probable epistemological beliefs held by introductory biology students versus professional scientists

In this study, an obvious distinction between beliefs about biology learning and beliefs about scientific knowledge was seen in both the pre- and post- surveys. Specifically, we argue there are three main categories of epistemologies that college students might possess (Figure 1). First, they have science epistemologies –

or beliefs about "what real scientists do to produce evidence for a phenomenon." Second, they have everyday life epistemologies, personal beliefs about knowledge and learning in informal environments, at home, or places outside the classroom. Third, there are classroom epistemologies, beliefs students have about "what do I need to do to succeed in this course." These findings suggest that beliefs about success in class and beliefs about (biology) science are differentiated in students' minds and their educators may not be aware of this mismatch.

The instructors of the introductory biology course of this study were heavily interested in students' conceptual understanding. For this reason, the course exams were very concept-related and much less fact-related. Regardless of the instructors' efforts in the course exams, and the amount of in-class activities incorporated within lecture time, a lecture-based learning environment may not be appropriate for the development of student science epistemology. Regarding final exam studying methods, students who responded to the follow-up questions recognized that memorization of facts wouldn't have helped them succeed in this course and a lot of studying time was needed to understand the material. The students talked about drawing on whiteboards, or explaining biological processes/phenomena to their friends, or that they "tried to connect stuff from lecture to lecture." In particular, one student mentioned: "I combined all the stuff from the circulatory system and the different systems and tried to connect them, so I can make connections in my mind and then I explained it in my own words." These attitudes are all supporting the belief of connectedness in biological knowledge, however, achieving this in an introductory biology course may not always seem practical in the students' minds.

Introductory Biology courses should provide students with the epistemological resources necessary to build their favourable beliefs for science and align those to the ones for biology learning. Biology instructors need to be able to measure their students' epistemic beliefs and adjust their course syllabus according to the results. Unfortunately, this is a rather undeveloped area of research in biology education. We have made a lot of progress in teaching scientific content and lab skills, however, these cannot suffice for scientific skills development, without proper (favourable) epistemological beliefs for science.

CONCLUSION & LIMITATIONS

The findings of this study showed that first-year college students have various beliefs about biology knowledge and biology learning, with the latter heavily related to their classroom experiences. Those expectations, however, do not seem to align with those of their instructors (favourable ones) and they do not seem to shift to more favourable ones by simply introducing active learning in lecture. Because of the misalignment between epistemological beliefs about science and learning biology, students may prioritize their work on meeting the classroom expectations, which negatively impacts their authentic learning early in the beginning of their college education. Given the importance of these epistemologies on student learning, we must consider the question of how educators should introduce content along with professional science epistemology, with the goal of shifting and eliminating students' classroom epistemologies (Figure 1).

This study was conducted during a single semester with students from one biology course, thus the findings may not be representative of all US college biology students. Although measurements were taken to eliminate unintentional responses, there is always a chance that a percentage of responses may not reflect the true beliefs of students. To the best of our knowledge, no statistical validation of MBEX survey is available, which may be needed before using it in different learning environments than the original one.

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