A Faculty Team Works to Develop a Concept Inventory that Measures Understanding of Microbiology Relevant to Host Pathogen Interactions.

Ann C. Smith, Gili Marbach-Ad, Volker Briken, **Najib El-Sayed,** Kennneth Frauwirth, Brenda Frederickson, Steven Hutcheson, Lian-Yong Gao, Sam Joseph, Vincent Lee, Kevin S. McIver, David Mosser, B. Booth Quimby, Patricia Shields, Wenxia Song, Robert T. Yuan and Daniel C. Stein

Department of Cell Biology and Molecular Genetics, University of Maryland

Abstract

Our goal was to establish bridges among seven Host Pathogen Interaction (HPI) undergraduate courses in the Department of Cell Biology and Molecular Genetics allowing students to develop depth in the area of host pathogen interactions. Our group of faculty and graduate teaching assistants met monthly to focus on reviewing the curriculum of each class, to identify learning goals, choose common microbial systems to highlight, and create a system of shared resources. We designed an assessment tool that includes 18 multiple-choice questions with open-ended explanations. This tool was distributed via WebCT to 200 students in General Microbiology (introductory class) and 60 students in Bacterial Genetics (one of our HPI advanced classes). The student responses were collated and reviewed by our HPI faculty as a group. We met for one day (9am – 4:30pm) to score student responses for alternate conceptions and then to develop a Concept Inventory which includes 18 multiple-choice questions that use commonly held alternate conceptions as distractors. Through Fall 2006 and Spring 2007 we distributed the Concept Inventory before and following six of our HPI courses (we collected total of 477 surveys). The surveys were analyzed once again in a full day group meeting. The findings allowed us to evaluate students' meaningful learning and specifically evaluate our courses to examine if we are covering all the concepts that we believe are required for understanding HPI at a level of sophistication appropriate for microbiology majors. Since we are implementing innovations in our courses, the concept inventory will allow us to monitor the effects of our curriculum reform.

Introduction

This study involved the development of a diagnostic assessment tool (concept inventory) to measure level of understanding relative to host pathogen interactions after completion of a set of microbiology courses. At the University of Maryland, as a group of faculty with expertise and research programs in the area of Host Pathogen Interactions (HPI), we are responsible for teaching the undergraduate courses with HPI content (presently seven courses). In fall 2004, we formed a teaching group to bridge learning between our courses (Marbach-Ad et al., 2007). Our group includes: five full professors, three associate professors, five assistant professors, three instructors, and an assistant professor from the College of Education with expertise in science education, as well as several graduate students with a strong interest in teaching who have joined us for various projects.

Our goal was to create bridges which would eliminate excessive overlap in our offerings and support a model where concepts and ideas introduced in one course would become the foundation for concept development in successive courses. We worked on curriculum and teaching approaches simultaneously with assessment. In this paper we describe the development of our concept inventory, applicable to other programs interested in assessing learning in biology and microbiology, we highlight common alternative conceptions identified through development of our assessment tool and document our findings that were gathered through the HPI Concept Inventory distribution before and following six of our HPI courses.

Alternative conceptions are ideas that differ from the corresponding scientific explanations. They are usually held by a significant proportion of students and are highly resistant to instruction. At the same time, these alternative ideas can serve as anchoring conceptions (Clement, Brown, & Zietman, 1999; Redish, 2003) from which to move to a scientific conception when suitable instructional strategies are developed. An assessment tool that identifies alternative conceptions of students is desirable for teachers who are striving to promote constructivist learning in their classrooms (Mintzes,Wandersee, & Novak, 2000).

Whereas experienced teachers and professors are usually aware of students' conceptual difficulties, novice teachers are not. In addition, many teachers recognize the need to assess their students' naive understandings but do not do so because they lack the appropriate tools. Perhaps the most effective way to identify alternative conceptions is to ask students to respond to open-ended questions. Obviously, this is logistically impossible in large classes. Therefore, the goal of our group was to produce an assessment tool that would elicit information about student conceptions that paralleled information obtained in open-ended questions, but could be used efficiently with large classes. Our approach (see design/procedure section) was similar but not identical to the two-tier method advocated by Treagust (1988), Anderson et al. (2002) and Odom & Barrow (1995). This test style is attractive because it separates factual knowledge (Tier 1=facts) from reasons for choosing a particular fact (Tier 2=mechanisms and beliefs).

In this paper, we describe a realistic and comprehensive tool for measuring undergraduate college students' understanding of HPI concepts. We describe the development and evaluation of our assessment tool (a concept inventory) and include an example question from the current 18-item version of our HPI Concept Inventory. [We are happy to share the HPI Concept Inventory upon request]

The design/procedure

The model system for learning and courses involved

This study is part of a longitudinal project that was started in Fall 2004. The project involved seven HPI undergraduate courses. General microbiology serves as a prerequisite for all other six courses: Pathogenic Microbiology, Microbial Pathogenesis, Bacterial Genetics, Immunology, Immunology Lab and Epidemiology (see Table 1). Our teaching group met monthly with average attendance of thirteen members. It was decided that to help students build bridges between content presented in the various courses and to help students anchor new material with previously learned material, we would focus discussion of host-pathogen interactions in all courses on two organisms *(E. coli* and *Streptococcus* sp.). Further it was decided that each course should include methods that would expose/engage students to the scientific research process. Simultaneously with these goals we developed the HPI Concept Inventory that was intended to evaluate our progress.

Table 1: The seven undergraduate courses in the project focusing on various aspects of host-pathogen interactions

Course	Lecture	Laboratory	Discussion session	Annual Enrollment
General Microbiology* (BSCI 223)	+	+	On-line discussion	800
Microbial Genetics (BSCI 412)	+	+		60
Immunology (BSCI 422)	+		+	100
Immunology Laboratory (BSCI 423)		+		60
Epidemiology (BSCI 425)	+		+	70
Pathogenic Microbiology (BSCI 424)	+	+		100
Microbial Pathogenesis (BSCI 417)	+		Discussion based class	25

* The General Microbiology course serves as a prerequisite for all of the other upper level classes.

Constructing the concept inventory

The HPI Concept Inventory development involved three phases: (a) defining the content boundaries of the test, (b) obtaining information about students' alternative conceptions, and (c) developing the instrument.

(a) ***Defining the content boundaries of the test.*** We considered as a group this question: "What do we want our students to truly understand and remember 5 years after they have completed the set of ours courses?" We asked our selves this question to determine the "**big ideas**" for our project. Accordingly, we developed a list of 13 HPI concepts (Figure 1). We aimed at concepts that we believe are required for understanding HPI at a level of sophistication appropriate for microbiology majors. Content validity of the concepts was established by our complete HPI group.

(b) ***Obtaining information about students' alternative conceptions***. Based on the HPI concept list, a 23-item multiple-choice test with free response answers was developed. With the free open-ended response, we aimed to assess students' alternative conceptions, which later would be used as distractors in the final multiple-choice test. Therefore, each question had two-tiers. The first tier consisted of questions with two to five choices (there could be more than one correct answer); the second tier consisted of a requests for explanation (explain your answer, or defend your response). Each question covered one or more concepts from the HPI concept list (See Figure 2, two-tiered questions).

Figure 1: The 13 HPI concepts: the "big ideas" for our project.

1. The structural characteristics of a microbe are important in the pathogenicity of that microbe.
2. Diverse microbes use common themes to interact with the environment (host).
3. Microbes respond to forces of natural selection. Important responses include changes in virulence and antibiotic resistance.
4. Microbes adapt/respond to environment by altering gene expression.
5. Microbes have various strategies to cause disease.
6. Pathogens and host have evolved in a mutual fashion.
7. The cell wall and the cell membrane affect the bacterial response to the environment.
8. There is a distinction between a pathogen and a nonpathogen.
9. The environment will affect the phenotype (pathogenicity) of a bacterium.
10. Microbes adapt/respond to the environment by altering their metabolism.
11. Immune response has evolved to distinguish between self and nonself.
12. Immune response recognizes general properties (common themes vs. specific attributes: innate vs. adaptive).
13. Immune response memory is specific.

Figure 2: Example for two-tiered questions

1A. Selection of an antibiotic resistant organism is based upon a change in the
a. Phenotype
b. Genotype
c. Both
d. Neither
e. either
1B. Defend your response
Question 1 covers the HPI concepts: 3, 4, and 10.

2A. What determines a Gram stain reaction?
a. Distinction relating to bacterial structure
b. Distinction relating to bacterial function
c. both
2B. Defend your response.
Question 2 covers the HPI concept 1.

(c) ***Developing the final instrument***. The 23 questions were piloted with a small focus group of two graduate students and two undergraduate students. Results from this focus group were analyzed by the HPI teaching team. Our 23 questions were amended to 18 two-tier questions. In the Spring of 2006 the 18 question assessment was distributed via WebCT (course management system supported at UM) to 200 students in General Microbiology (introductory class) and 60 students in Bacterial Genetics (one of our HPI advanced classes). In order to limit the time requirement for the students in this pilot, the delivery of the questions was limited to 5 questions per student. For each question we received around 60 responses from the General Microbiology course, and 20 responses from the advanced course. The student responses were collated and reviewed by our HPI faculty as a group. We met for one day (9:00am – 4:30pm) to score student responses for alternative conceptions and then to develop multiple-choice questions that use commonly held alternative conceptions as distractors. The product of this day was an 18 multiple-choice concept inventory. This concept inventory was distributed in Fall 2006 and Spring 2007 before and following six of our HPI courses.

The Two-Tiered questionnaire data analysis

The two-tiered questionnaire that we developed was used to obtain information about students' alternative conceptions, and to develop the concept inventory to assess the success in teaching HPI concepts. Table 2 shows an example for analyzing the two-tier questions. For each question, we first counted the number of students selecting each choice in the multiple-choice part of the question (first tier). Note, that depending upon how students chose to defend their response, there could be more than one correct option among the multiple choices. This test wasn't intended to grade students, we were interested in finding what alternative conceptions students held, and sometimes the answer to the first tier was correct and the explanation was incorrect, and vice versa.

Table 2: An example for analysis of one two-tier question and response's frequencies

Question	**Number of student that choose this choice**	
1. Selection of an antibiotic resistant organism is based upon a change in the	General Micro	Bacterial Genetics
Phenotype	1	7
Genotype	38	4
Both	25	13
Neither	0	1
Either	4	0
Defend your response (response categories)	General Micro	Bacterial Genetics
Excellent response	21	16
Basic response, more required to indicate higher understanding	9	0
Students didn't understand that *selection* is based on phenotypes.	28	1
Student responses indicated that they did NOT understand that a change in phenotype is due to a change in genotype	3	6
Misconception was with the understanding of the differences between genotype and phenotype	9	1
Either student did not answer question or student response was COMPLETELY off the mark ("at sea")	3	0

In order to define categories for the second tier ("defend your response") responses we decided to use the technique of Hodder, Ebert-May, & Batzli (2006). We formed three small groups of three instructors. Each group received 5-6 questions to analyze. For each question the group read all the answers and established categories (level of correctness and alternative conceptions). Then, each member went through each response and categorized the response. Finally, the three members of the group compared their ratings and discussed responses to reach a consensus for each student response. Figure 3 shows two examples for common alternative conceptions for the question 1.

Figure 3: Example for students' alternative conceptions

1. Selection of an antibiotic resistant organism is based upon a change in the
   (a) Phenotype (b) Genotype (c) Both (d) Neither (e) either.

   1. ***Students didn't understand that <u>selection</u> is based on phenotypes***.
      One student that chooses *(b) Genotype* wrote: When an organism becomes resistant to antibiotics (when it acquires an antibiotic-resistant gene that has been inserted as a marker), the organism's genotype has been changed.

   2. ***Misconception was with the understanding of the differences between genotype and phenotype***.
      Student wrote: This must be a change in the genotype because having antibiotic resistance will not necessarily change the look of an organism (phenotype). It will merely allow it to survive in situations where the antibiotic is present.

Following the analysis of all questions, each group built two multiple-choice questions for the final assessment tool (The HPI Concept Inventory). These questions usually include the opening sentence or sentences of the previous question and four or five choices of response: one is the correct answer and three or four distractors that reflect the students' alternative conceptions revealed in the analysis. For example, one question developed from the information that is presented in Table 2 was:

Selection of antibiotic resistant transformed bacteria is based upon a change in the:

A. phenotype of the bacteria.
B. genotype of the bacteria.
C. phenotype and genotype of the bacteria.
D. genotype and physiology of the bacteria.
E. genotype and morphology of the bacteria.

The concept inventory data analysis and findings

In Fall 2006 and Spring 2007 we administered the 18 questions concept inventory to six of our courses. Students were offered extra credit points for completing the survey. We collected pre-post surveys from 477 students with the following distribution:

- BSCI223 (General Microbiology), Fall 2006: 127 students.
- BSCI424 (Pathogenic Microbiology), Fall 2006: 96 students.
- BSCI223 (General Microbiology), Spring 2007, 109 students.
- BSCI412 (Bacterial Genetics), Spring 2007, 45 students.
- BSCI422 (Immunology), Spring 2007, 48 students.
- BSCI425 (Epidemiology), Spring 2007, 52 students.

Student performance on Concept Inventory

Table 3 shows average scores for each course pre-post surveys (each correct question weigh 1 point, since we removed 2 questions from the analysis, see below explanation, the maximum points on the test is 16 points). Inspection of these data shows that in both semesters of BSCI 223(General microbiology pre-requisite course), the pre-post grades are similar. This is an important finding, since in the spring and the fall semesters we had different instructors in the course. For future analysis we can treat these courses as comparable courses. Encouragingly, using T-test analysis, we found that in four of our courses (both BSCI223 courses, BSCI424 and BSCI422) there was significant improvement on the scores of the concept inventory from pre test to post test. And students taking pre-test in the advanced courses retained the level of understanding gained in the pre-requisite course (scores on BSCI 223 post are around 7.0 and scores on all pre tests in advanced courses are around 7 or greater).

Table 3: Courses' average scores on the pre-post surveys

Pre-Post	223/ 06 N=127	425 N=52	424 N=96	422 N=48	412 N=45	223/ 07 N=109
Pre	4.9	6.6	7.3	9.2	7.8	4.7
Post	7.0***	6.6	8.7***	9.9*	7.6	7.3***

note: Values were calculated without data from questions 8 and 13.
Questions 8 and 13 had very low discrimination values (under .30 for most classes).
* $P < 0.05$ *** $P < 0.001$

Table 4 shows percentages of correct answers for each question in the pre-post surveys. Since, different members of our group teach different courses, we decided to look over the percentages of the correct answers for each question in each course, and examine two major aspects: 1. the ability of students that receive good grades on the overall test to answer correctly to a specific question (discrimination factor); 2. the concept/s that each question covers, and which courses cover this concept/s.

Review of questions that make up the Concept Inventory

To examine the quality and appropriateness of each question, we calculated the percentages of correct answers dividing the students in each course into three groups in terms of grades on the complete inventory. We grouped percentages into high (25%), medium, low

(25%). Then we calculated for each question the discrimination value from 0 to 1. If a question has a value below .30 it means that students who did well on the test (high performance group) performed poorly on this question. We reviewed all questions administered in each class and found that in every class two questions (8 and 13) provided poor discrimination (no one did well, see Table 4).

Table 4: Students' percentages of correct answer on pre-post concept inventory

Question	Pre-Post	223/ 06 N=127	425 N=52	424 N=96	422 N=48	412 N=45	223/ 07 N=109
1	Pre	25	36	32	56	35	12
	Post	30	42	24	67	44	26
2	Pre	9	15	25	37	20	3
	Post	24	17	46	35	29	21
3	Pre	18	31	33	48	49	21
	Post	27	38	40	50	60	33
4	Pre	87	85	87	92	87	77
	Post	88	90	88	87	84	87
5	Pre	7	23	24	50	31	10
	Post	29	31	26	65	33	28
6	Pre	60	65	82	79	80	65
	Post	78	69	85	77	71	83
7	Pre	28	40	42	56	38	13
	Post	42	31	57	52	33	29
8	Pre	17	23	23	12	13	16
	Post	17	6	25	12	16	32
9	Pre	23	48	59	50	47	25
	Post	46	36	63	56	49	56
10	Pre	41	58	71	75	73	40
	Post	61	58	78	69	73	78
11	Pre	18	42	45	48	56	23
	Post	39	50	59	60	53	38
12	Pre	62	42	45	52	62	64
	Post	49	35	65	50	51	72
13	Pre	11	21	17	23	27	9
	Post	12	15	26	21	9	11
14	Pre	28	33	41	48	47	37
	Post	35	33	52	52	38	43
15	Pre	10	31	30	69	29	12
	Post	40	36	38	75	27	20
16	Pre	19	23	36	48	33	17
	Post	34	21	48	60	24	32
17	Pre	43	60	57	79	60	38
	Post	65	50	60	81	58	57
18	Pre	13	29	24	46	36	17
	Post	16	25	40	58	31	20

Questions 8 and 13 were designed to address issues regarding bacterial metabolism (Figure 1, concept 10). The group reviewed and discussed the importance of concept 10 and analyzed the clarity and specific student alternate understandings addressed in both question 8 and 13. As a result of this discussion, question 8 was re-worded. Question 13 was left as is. It was decided that the question wording was clear. We feel that in fact even our best students do not understand this concept. This was truly an excellent question as it revealed to us a gap in our curriculum.

2. Alignment of curriculum with HPI concepts

To examine the concept coverage in our courses we decided to use the Curricular Alignment Matrix (Assessing Academic Programs in Higher Education, URL). Curriculum mapping makes it possible to identify where within the curriculum learning objectives are addressed. In other words, it provides a means to determine whether our concepts are *aligned* with the curriculum. We decided to use three level of coverage 1-3. In which

1. Concept was introduced. Goal was to provide introduction. Expectation is that student is aware of the concept but has not mastered a deep understanding.
2. Concept was "covered" in a manner to engage students. Expectation is that students understand and can apply this concept to a straightforward circumstance.
3. Concept was fully "covered" in a manner were students understanding was assessed. Expectation is that students have a deep understanding.

Each instructor reflected upon their own course with respect to the HPI concepts. Table 5 shows the Matrix from this data.

Table 5: The Curricular Alignment Matrix (**1** = Introduced, **2** = covered, **3** = fully covered)

Concept \ Course (BSCI)	223	412	423	424	425	417	422
1. The structural characteristics of a microbe are important in the pathogenicity of that microbe.	1	2	-	1-3	-	3	2
2. Diverse microbes use common themes to interact with the environment (host).	1	1	-	1-2	-	3	0
3. Microbes respond to forces of natural selection. Important responses include changes in virulence and antibiotic resistance.	1	3	-	1-2	-	3	0
4. Microbes adapt/respond to environment by altering gene expression.	1	3	-	1-3	-	3	0
5. Microbes have various strategies to cause disease.	1	1	-	1-3	1	3	1
6. Pathogens and host have evolved in a mutual fashion.	1	1	1	1-2	1	3	1
7. The cell wall and the cell membrane affect the bacterial response to the environment.	1	2	-	1-3	-	3	0
8. There is a distinction between a pathogen and a nonpathogen.	1	1	3	1-3	-	3	2
9. The environment will affect the phenotype (pathogenicity) of a bacterium	1	1	-	1-3	-	3	0
10. Microbes adapt/respond to the environment by altering their metabolism.	1	1	-	-	-	1	0
11. Immune response has evolved to distinguish between self and nonself.	1	0	3	1	-	2	3
12. Immune response recognizes general properties (common themes vs. specific attributes: innate vs. adaptive).	1	0	3	1	-	3	3
13. Immune response memory is specific.	1	0	1	1	-	2	3

Discussion

The idea of a Concept Inventory as an assessment tool dates back to 1992, when the Force Concept Inventory (FCI) was developed to measure students' conceptual understanding of motion and force (Hestenes, Wells, & Swackhamer, 1992). The FCI has been used over the past decade by physicists at several institutions of higher learning to assess the effectiveness of different teaching methods. Similar multiple-choice exams have been developed in chemistry and biology (Anderson et al., 2002; Odom & Barrow, 1995). As a group of instructors who care about their teaching and have taken on the challenge to create a cohesive set of courses that result in meaningful learning of HPI concepts, we sought to assess the effectiveness of our teaching efforts. We believe that the process of constructing a concept inventory as a group has had great value not only in the production of the product, but in the conversation about teaching and learning within our group. Together we worked to articulate the most important concepts for undergraduates to grasp in order to develop meaningful learning of HPI (the "big ideas"). Together we reviewed students alternative conceptions revealed from the two tier test, and finally as a group we built a concept inventory. Through the first distribution of the concept inventory we already have some significant findings: Student scores indicate that overall understanding of concepts does increase within each course during a semester, and the level of understanding remains as student progress to more advanced courses. But even the highest scores are not what we would like of our graduates.

We believe that the concept inventory will work for us to monitor the progress that our students make as they complete each course (pre and post assessment) and as they move from course to course (comparison of post tests performances). The concept inventory from this year will serve as baseline data. We began work on the HPI inventory because our overall goal as a teaching group was to improve how we teach and ensure that our students learn the concepts that we considered essential for understanding of host pathogen interactions. As we began changing how we taught (changing curriculum and teaching methods) it was very clear we needed a tool to measure our progress. Although changes in courses has begun our most senior students in our most senior course achieved only an average score of 9/16 on the HPI inventory. Therefore we have a way to go! Work in progress includes adding to our courses active learning approaches, such as using clicker questions, case studies, team projects (Marbach-Ad et al., 2007). We consider the HPI inventory a tool that is essential in revealing success with each new teaching experiment.

What are our challenges?

- Relating information revealed from student responses to our curriculum and teaching methods.
- Detailed understanding of student performance: Is performance affected by gender, race, previous courses outside our 7 courses, overall GPA, major etc?

What help could we use from others?

- How do we encourage students to take the assessment seriously and perform at their best?

- How often can we use this same set of inventory questions? How would we determine if an alternate question is "equivalent"?
- How do we help students to understand the importance of assessment and counter "test fatigue"?
- Best delivery mechanism? We used WebCT, the campus has now moved to Blackboard. Are there delivery mechanisms that have statistic packages?
- What statistic diagnostics should we use?
- Does our survey cover "big ideas' of biology within the context of microbiology? Should we include some of the "big ideas" from biology surveys?

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