



# Using a Concept Inventory to Reveal Student Thinking Associated with Common Misconceptions about Antibiotic Resistance

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Misconceptions, also known as alternate conceptions, about key concepts often hinder the ability of students to learn new knowledge. Concept inventories (CIs) are designed to assess students' understanding of key concepts, especially those prone to misconceptions. Two-tiered CIs include prompts that ask students to explain the logic behind their answer choice. Such two-tiered CIs afford an opportunity for faculty to explore the student thinking behind the common misconceptions represented by their choice of a distractor. In this study, we specifically sought to probe the misconceptions that students hold prior to beginning an introductory microbiology course (i.e., preconceptions). Faculty-learning communities at two research-intensive universities used the validated Host-Pathogen Interaction Concept Inventory (HPI-CI) to reveal student preconceptions. Our method of deep analysis involved communal review and discussion of students' explanations for their CI answer choice. This approach provided insight valuable for curriculum development. Here the process is illustrated using one question from the HPI-CI related to the important topic of antibiotic resistance. The frequencies with which students chose particular multiple-choice responses for this question were highly correlated between institutions, implying common underlying misconceptions. Examination of student explanations using our analysis approach, coupled with group discussions within and between institutions, revealed patterns in student thinking to the participating faculty. Similar application of a two-tiered concept inventory by general microbiology instructors, either individually or in groups, at other institutions will allow them to better understand student thinking related to key concepts in their curriculum.

## INTRODUCTION

### Misconceptions about antibiotic resistance impact learning

Understanding the concept of antibiotic resistance is important for all microbiology students (1) as well as for the general public, including nonscience majors. Combating the increase in antibiotic-resistant microbes is a national priority (2) and public education campaigns, such as Get Smart: Know When Antibiotics Work (<https://www.fda.gov/Drugs/ResourcesForYou/Consumers/BuyingUsingMedicine-Safely/AntibioticsandAntibioticResistance/default.htm>), are being used to curb antibiotic misuse. Unfortunately, many

scientific misconceptions about antibiotic resistance persist in the public. For example, interviews with over 100 clinical patients revealed that many of them believe that "The body gets used to them [antibiotics]" and this is what contributes to antibiotic resistance rather than the resistance being a property of bacteria (3). Research shows that people construct new ideas by connecting them to what they already know (4, 5). Therefore, instruction that does not take into account individuals' prior knowledge from classroom education and everyday experiences will hinder their acquisition of new information (5–7).

Since students build upon prior knowledge while learning, it is essential for faculty to have insight into students' thinking while developing their courses. This is consistent with the learning theory known as constructivism (e.g., 7–9). Students may harbor ideas about course concepts that are alternative to those commonly accepted by experts in the field (10, 11). Misconceptions are often shared by a significant number of individuals; cut across age, ability, gender, and cultural boundaries; and generate consistent error patterns (4, 10, 12). These misconceptions may be deeply

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ingrained into students' thinking and will impede learning if left unaddressed (13–15). Assessment tools such as concept inventories are built on common student misconceptions and are designed to assess conceptual understanding in a discipline. Below, we will describe how a concept inventory was used to provide insights about student preconceptions (i.e., misconceptions that students bring with them prior to formally learning about a new topic) with regard to the topic of antibiotic resistance. Uncovering student thinking about antibiotic resistance (and other critically important concepts) can lead to the design of specific and targeted educational programs and approaches.

### Utilizing the host-pathogen interaction concept inventory assessment tool

The first concept inventory, the Force Concept Inventory (16) for physics, influenced the development of additional concept inventories, including several that have been developed to assess student misconceptions on an array of important biology concepts. (The Society for the Advancement of Biology Education Research (SABER) has compiled a list of such inventories here: <https://saber-biologyeducationresearch.wikispaces.com/DBER-Concept+Inventories>.) Recently there has been a concerted effort, supported by the American Society for Microbiology (ASM), to create two new inventories of microbiology concepts for general microbiology and allied health sciences. Prior to this initiative, in 2009, a faculty-learning community (FLC) at the University of Maryland (UMD) developed and validated the first concept inventory for microbiology (17). The Host-Pathogen Interactions Concept Inventory (HPI-CI) is designed to assess student understanding of concepts related to host-pathogen interactions (including concepts related to antibiotic resistance). The UMD FLC used the HPI-CI to gather information about several things, including student learning in a course, the impact of curricular innovations, student retention of concept knowledge, progress of learning specific concepts within a curriculum, and the possible impact of background variables such as gender, ethnicity, GPA, age and previous education on student learning outcomes, as well as for professional/community development (6).

The HPI-CI consists of 19 two-tiered questions; it is based on 13 key learning concepts that align with Vision and Change guidelines (18) and ASM curriculum guidelines (1). The first tier consists of multiple-choice questions where incorrect response choices (distractors) are derived from commonly held misconceptions using the students' own words, similar to the approach of other inventories (19–23). The second tier is a space for students to provide an open-ended explanation for the response choice in the first tier (17, 24). Traditionally, many science educators use the first-tier multiple-choice questions as pre- and post-measures to gauge student-learning gains across a specific course (25), or even across a curriculum (17). The second-tier open-ended explanation is critical in the development of the distractors for the concept inventory,

providing both the content and response process validity (26). To complete the response process validity, the UMD FLC looked for correlation between students' open-ended explanations and their multiple-choice responses, to ensure that the student thinking aligned with the meaning of the distractor. During this process the team became aware of the value of reading student explanations to uncover information about student thinking. After completing the validation process, they continued to use this method of analysis of student explanations. The UMD team was interested in working with another set of faculty to see if they would find benefit in using the inventory in a similar manner to analyze student thinking. Therefore, they began a collaborative project focused on student conceptions related to antibiotic resistance with a peer group of microbiology faculty at another research-intensive university, Virginia Tech (VT).

### Assessing student preconceptions about antibiotic resistance

To ascertain student thinking about concepts related to antibiotic resistance prior to instruction in microbiology, students at UMD and VT were asked to complete the HPI-CI as a pre-assessment. The HPI-CI was offered to students as an online pre-survey either for homework or extra credit points, as determined by the instructor, within the first two weeks of a general microbiology course. At both UMD and VT, general microbiology is a large-enrollment, second-year course with a prerequisite of introductory biology. Working in collaboration, FLCs at both universities analyzed student responses to the HPI-CI and carefully examined the student explanations for one question related to the topic of antibiotic resistance (Table 1) to probe student thinking.

The dataset included 1,125 total student responses to the HPI-CI pre-survey gathered at both institutions over three semesters. This quantitative data was first pooled and tabulated (Table 1). While the absolute numbers of students selecting each multiple-choice response varied between institutions, the relative frequencies with which the students ( $N = 1,125$ ) chose each response was highly correlated (Pearson product-moment correlation coefficient  $R = 0.891$ ,  $N = 5$ ). Approximately half of the students ( $N = 509$ ) in the sample provided an explanation in the second tier for their response choice (Table 1). Looking at total responses from students providing an open-ended response, the most common response at both institutions was "I don't know" (~40% overall; UMD 47.4%; VT 32.6%) About 18% (UMD 19.7%; VT 16.8%) selected the correct response, whereas the remaining students (~40%) selected distractors that portray erroneous preconceptions. It can be concluded that many students entering general microbiology were not confident in their understanding of antibiotic resistance.

The student-written explanations were sorted by response choice and analyzed for common content/themes. Then the common themes were grouped into categories. The findings of each FLC were shared in a virtual meeting

TABLE 1.  
Student response rates on one HPI-CI multiple-choice question given prior to instruction in general microbiology.

	Virginia Tech		University of Maryland	
	Responses (N = 375)	Responses with 2nd tier open-ended explanations (N = 184)	Responses (N = 750)	Responses with 2nd tier open-ended explanations (N = 325)
Can both Gram-positive and Gram-negative bacteria use the same mechanism of resistance to an antibiotic that affects protein synthesis?				
(A) Yes, because they both have similar mechanisms of protein synthesis CORRECT	47 (12.5%)	31 (16.8%)	78 (10.4%)	64 (19.7%)
(B) Yes, because they both have similar cell wall structures	6 (1.6%)	2 (1.1%)	9 (1.2%)	1 (0.3%)
(C) No, because most antibiotics are bacterial species specific	53 (14.1%)	30 (16.3%)	56 (7.5%)	36 (11.1%)
(D) No, because Gram-positive bacteria are intrinsically more resistant to antibiotics than Gram-negative bacteria	106 (28.3%)	61 (33.2%)	102 (13.6%)	70 (21.5%)
(E) I do not know the answer to the question	163 (43.5%)	60 (32.6%)	505 (67.3%)	154 (47.4%)

where it was determined that there was a strong agreement between the patterns of student thinking at UMD and VT. Both FLCs found that students' explanations for their responses most often corroborated the distractor statement, but many statements also illuminated the logic that led to the students' answers. These efforts collectively revealed three broad categories of student thinking associated with the explanations for their response choice: antibiotic function and targets, Gram-positive/Gram-negative differences, and terminology (Table 2).

With regard to the first category, function and targets of antibiotics, students failed to realize that antibiotics might be broad spectrum, targeting more than one microbe, or that different antibiotics might target different bacterial structures. This type of thinking was primarily associated with selection of distractor response C ("No, because most antibiotics are bacterial species specific"). One way to help overcome these student preconceptions may be to introduce information during instruction about more than one antibiotic and more than one mode of action (e.g., penicillin versus tetracycline and cell wall versus ribosome, respectively).

Incorrect thinking about the differences between Gram-positive and Gram-negative bacteria was a second major category of student thinking associated with student explanations for incorrect responses. The vast majority of students understood that Gram-negative and Gram-positive bacteria are different and do not have similar cell wall structures, as indicated by the low percentage of students selecting distractor response B ("Yes, because they both have similar cell wall structures"). However, as revealed in their explanations, some of them thought the bacterial mechanisms of protein synthesis or overall physiology were also different. Others lacked detailed understanding of cell structure, especially the cell wall. In some cases where students talked about

cell wall structure, their thinking could be attributed, at least in part, to the misuse of words that have different meanings in different contexts (see discussion about terminology below). For example, a "wall" in everyday life is a thick barrier that is not penetrable. Some students apparently extrapolated a scientific meaning from the everyday meaning—they assumed that a cell "wall" is an impenetrable barrier and therefore provides "resistance" or makes the cell "immune" to attack. One student wrote, "Gram-positive have thicker cell walls than Gram-negative bacteria, making them more resistant" for a response associated with the most common distractor, choice D ("No, because Gram-positive bacteria are intrinsically more resistant to antibiotics than Gram-negative bacteria"). This insight suggests that activities that ask students to compare and contrast bacterial structures, especially in the context of the targets of different antibiotics (e.g., a cytoplasm target requiring the antibiotic to transverse the cell wall) will help students to correctly conceptualize the relationship between differences in bacterial physiology/structure and antibiotic resistance. At UMD, an active-learning activity case study focused on antibiotic resistance mechanisms in relation to bacterial cellular structure was shown to help students overcome some of the most significant misconceptions they harbor on the topic (27, 28).

Finally, various explanations across distractors suggested student thinking stemmed from erroneous interpretation of terminology (Table 2). These could be attributed to students not knowing or not using the scientific meaning of a word, as mentioned above, or to inappropriate attempts by students to apply knowledge from previously learned microbiology concepts (29, 30). It was clear that many students did not understand the distinctions between the terms "wall," "membrane," "capsule," and "envelope." One student wrote, "No they don't have the same resistance

TABLE 2.  
Categories of student thinking associated with common misconceptions about antibiotic resistance.

Category	Examples of Types of Student Explanations (themes of content determined by VT or UMD, as indicated, with most common explanation listed first)
<b>Antibiotic function and targets</b>	<ul style="list-style-type: none"> <li>• All antibiotics are species-specific (VT)</li> <li>• Antibiotics target a specific type of bacteria not a common process (target) (UMD)</li> <li>• Bacteria respond to the antibiotics that are suited to them (UMD)</li> <li>• Antibiotics only work on disease (causing) bacteria (UMD)</li> <li>• Peptidoglycan is the target for all antibiotics (UMD)</li> <li>• Don't know how antibiotics enter cell; antibiotics need to enter the cell (UMD)</li> </ul>
<b>Gram-positive/ Gram-negative differences</b>	
Related to protein synthesis:	<ul style="list-style-type: none"> <li>• Protein synthesis mechanism is different in G<sup>+</sup> and G<sup>-</sup> (VT)</li> <li>• Protein synthesis is not the same in Gram-positive and Gram-negative sp.; bacterial structure (Gram stain morphology) is related to protein synthesis (UMD)</li> </ul>
Related to overall physiology:	<ul style="list-style-type: none"> <li>• Gram-negative are more resistant than Gram-positive (UMD)</li> <li>• Physiology is different in G<sup>+</sup> and G<sup>-</sup> (VT)</li> <li>• Gram-positive and Gram-negative have different compositions therefore protein synthesis in the two types of bacteria are different therefore they must have different susceptibility to all antibiotics; Gram-positive and Gram-negative have different compositions therefore protein synthesis in the two types of bacteria are different (UMD)</li> <li>• Phylogenetic differences between Gram-positive and Gram-negative (UMD)</li> </ul>
Related to cell structure:	<ul style="list-style-type: none"> <li>• Wall thickness or structure affects entry of antibiotic (VT)</li> <li>• Gram positive cell wall is thicker therefore the microbe is more resistant to all antibiotics (UMD)</li> <li>• Antibiotics must penetrate cell wall differences in order to impact protein synthesis (UMD)</li> <li>• G<sup>+</sup> have PG and G<sup>-</sup> do not (VT)</li> <li>• Membrane, capsule, envelope differences in G<sup>+</sup> and G<sup>-</sup> are the relevant issue in this question (VT)</li> </ul>
<b>Terminology (word association with everyday life or other scientific concepts, and over-generalization)</b>	<ul style="list-style-type: none"> <li>• Cell wall is the only difference between Gram-positive and Gram-negative; no other difference among these sets of bacteria (UMD)</li> <li>• Membrane is the (only) distinction between Gram-positive and Gram-negative (and thus antibiotics affecting protein synthesis are equally effective) (UMD)</li> <li>• Membrane difference between Gram-negative and Gram-positive dictates all antibiotic resistance (UMD)</li> <li>• Membrane = cell wall (UMD)</li> <li>• Terminology of cell wall vs. cell envelope created confusion (VT)</li> <li>• Resistance is a coat (skin) protecting the bacterium (UMD)</li> <li>• Protein synthesis is the same in all bacteria but because of the cell wall the antibiotic can't get in (UMD)</li> <li>• Knowledge from previous class (incorrectly applied) (VT)</li> </ul>

because they have different membrane compositions” as an explanation for distractor B. It is thus important for instructors to emphasize the distinction between the terms used to name cell structures and to use these terms appropriately in the classroom. Other students understood that the cell wall in Gram-positive and Gram-negative bacteria is different, but believed that was the only difference between the two microbes. Conversely, some students appeared to overgeneralize and infer too much from their limited recall of facts. For example, students selecting response C gave explanations such as “Because the two types of bacteria have different structures and work in different ways, they cannot be treated with similar antibiotics and do not have the same antibiotic resistance regarding protein synthesis.” Overcom-

ing these ways of thinking requires a deeper development of understanding, building on the students' correct knowledge (Gram-positive and Gram-negative bacteria have different cell walls), but guiding them through the nuances in bacterial structures and the antibiotics that target those structures.

These findings represent the knowledge that UMD and VT students have as they enter our courses and will be used to further inform our teaching. Given that students at two different peer institutions had similar patterns of distractor selection (Table 1) and displayed similar associated thinking about misconceptions (Table 2), we suggest that these findings about student thinking may be widely shared amongst college students elsewhere and will provide useful information for anyone teaching a microbiology course.



## Concept inventories inform development of instructional practices by faculty

Reading the second-tier student responses to questions in a concept inventory provided significant benefit to the members of the UMD and VT FLCs. It provided insight into student thinking about antibiotic resistance that helped to bridge the novice-to-expert gap that exists between students and instructors (31). This approach assists individual instructors seeking to identify what they should emphasize in their classroom, and what is important for their particular student body. It helps anchor the instructor to the individuals in the course and allows them to “recalibrate” or “recalculate” their approach to instruction and thereby keep it relevant to ever-changing student populations. Deep analysis of student performance on a CI that includes reading student explanations introduces instructors to the current scientific views of their students, some of which may be preconceptions that are barriers to instruction.

The data gathered from a concept inventory can be used to promote intellectual discussion about teaching and learning amongst faculty. The UMD FLC team found great value in the work of creating the HPI-CI (32), and the reading of student explanations to explore student thinking was a common intellectual endeavor that bonded the group (6, 17). During this educational research project about misconceptions associated with antibiotic resistance, the HPI-CI developed by the UMD group was used to catalyze the development of another FLC at VT (24). “Meaning making” of student explanations served as the catalyst for FLC development (33).

## CONCLUSION

Pre-course concept inventory data can and should be used by faculty to reveal details of student thinking that can then inform faculty thinking about student learning. Concept inventories that ask students to explain their rationale provide nuanced insight into student conceptions that can inspire specific curriculum redesign. Additional awareness about topics prone to erroneous preconceptions (such as antibiotic resistance), which students encounter in everyday life situations (e.g., medical visits), is necessary as these misconceptions are most often resistant to instruction. The HPI-CI, as well as new two-tiered concept inventories (the Microbiology Concept Inventory (MCI) for general microbiology and the Microbiology for Health Sciences Concept Inventory (MHSCI) for allied health), will serve as valuable assessment tools for improving the teaching of microbiology. We encourage instructors to employ these tools, take the time to understand student thinking about key microbiology concepts and, whenever possible, share their findings with others. This will inform instructional practices and thereby improve the ability of students to learn difficult microbiology topics prone to misconceptions.

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