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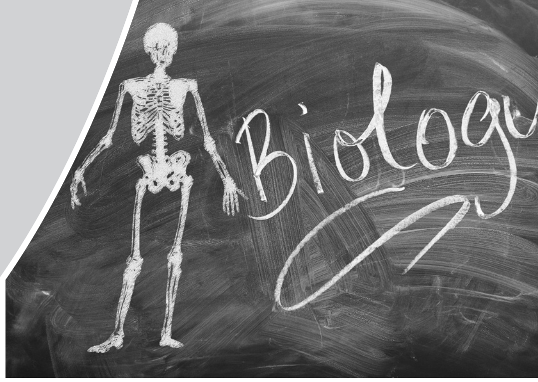
RESEARCH ON LEARNING

Defining Understanding: Perspectives from Biology Instructors & Biology Education Researchers



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Abstract

Promoting student understanding of biological concepts is a key part of biology education, and the ability to "understand" a concept forms one of the six categories of the oft-used Bloom's Taxonomy. Despite this, there remains no consensus as to what it means to understand a concept. While several formal definitions have been offered, we investigated how biology instructors and biology education researchers define the term and how they perceived the skill sets needed for a student to understand a concept in the context of assessments. We found that there was no agreement on the definition of understanding, and that responses differed in the cognitive level required to reach "understanding" of a concept. We discuss these findings in the context of Bloom's Taxonomy and variation theory and provide directions for future inquiries. We conclude by discussing implications for biology instructors and the importance of explicitly conveying expectations to better align student and instructor expectations.

Key Words: *assessment; Bloom's Taxonomy; higher education; understanding*

○ Introduction

Much of biology education is centered on promoting student understanding of core concepts. Indeed, "understanding" forms one of the six categories of the revised version of Bloom's Taxonomy, a scheme that classifies different learning objectives by their cognitive process (Bloom et al., 1956; Anderson et al., 2001). Despite the prevalence of Bloom's Taxonomy, there remains no consensus as to what "understanding" means. The original Bloom's Taxonomy defined the second category of "skills and abilities" as "comprehension," or a "type of understanding or apprehension such that the individual knows what is being communicated and can make use of the material or idea being communicated without necessarily relating it to other material or seeing its fullest implications" (Bloom et al., 1956). Under the revised version of Bloom's Taxonomy, this second category was reclassified to "understanding," and associated with the ability to interpret, exemplify, classify, summarize, infer, compare, and explain a concept (Anderson et al., 2001), a definition similar to that of Wiggins and McTighe (2005). Others have taken different approaches. Zagzebski (2001) defines understanding around the basis of connection, whereby a student who understands a concept is able to see how the concept relates to other concepts and principles in a larger framework. Other works have centered their definitions of understanding on the ability to provide meaning to a concept (Dewey, 1933; Killen, 2007), while Watson (2002) argues for a more complex, nuanced definition of understanding that, depending on the context, can include both a "sense of underlying meaning" and making connections to prior concepts. There also remains a difference in how the word is applied in various contexts in biology education research (BER). For example, many papers differentiate between a deep conceptual understanding of a topic that is required for higher-order cognitive skills as opposed to a lower-level cognitive process more commonly associated with understanding used in the context of Bloom's Taxonomy (Crowe et al., 2008; Jensen et al., 2014).

These differences in how "understanding" is used and the variety of different meanings ascribed to the word become important when considering learning in the context of variation theory, which holds that the act of learning is dependent on both the instructor and student spheres (Bussey et al., 2013). An instructor begins with an *intended* object of learning; however, the *enacted* object of learning – what actually occurs to promote learning – is influenced not only by the pedagogical choices and instructional materials the instructor uses but also by the interactions between and relationship among instructor and students. This enacted object of learning may be different than the intended object of learning and represents the overlap between the instructor and student spheres. Finally, there is a *lived* object of learning that falls solely within the student realm and encapsulates what the students actually learned and perceived during the lesson. This model of learning shows that if an instructor holds a different meaning of the term "understanding" than students or even other instructors, there can be a disconnect between the intended object of learning and the lived object of learning. Similarly, instructors who teach the same concept but who define understanding differently may design course activities and assess student understanding in disparate manners, leading to different enacted objects of learning, and confusion among students.

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These points are further magnified when considering that exams in biology courses may not be accurately assessing student conceptual understanding (Sato et al., 2019), with many students taking non-biological, nonconceptual strategies in their approach to problems on exams (Sung et al., 2020).

These differences demonstrate that it is critical to investigate how biology educators define "understanding," particularly in the context of student assessment, since their perceptions of this term may influence pedagogical decisions, assessments, and both their intended and enacted spheres of learning. Hence, our research question: How do biologists define the word "understanding" in the context of student assessment, and is there a consensus in how this term is viewed by biologists, biology instructors, and biology education researchers?

○ Methods

Study Sample

To determine whether there is a consensus as to what is meant by "understanding" when assessing our students, we surveyed biology instructors and members of the BER community. We felt that this population was the most relevant for this inquiry, because instructors are primarily responsible for presenting undergraduate biology students with exams meant to measure their "understanding" of a particular topic, while BER investigators examine teaching and learning in the context of the biology classroom. Data collection took place at the Society for the Advancement of Biology Education Research (SABER) conference in summer 2016 during the opening plenary session. The SABER conference includes a range of attendees, including biology education researchers, instructors, postdoctoral scholars, graduate students, and undergraduate students from different institutions. We collected demographic information about participant institution type, role, field, number of SABER meetings attended, and years of most recent degree; this protocol was approved from the Institutional Review Board at University of California Irvine (HS no. 2016-2669).

Attendees were asked to provide a written response to the prompt "In the context of assessing student understanding, how would you define 'understanding'? Please be as specific as possible" (50.7% of attendees responded to this question; $n = 144/284$). Not all attendees opted to complete the survey, which included questions for a different study as well. Among the attendees who completed the survey, many did not finish and respond to this question, which was the last one on the page, due to time constraints. Responses ($n = 144$) were from STEM faculty at two-year (2.8%) and four-year (46.1%) institutions, as well as STEM undergraduate students (7.9%), graduate students (18.5%), and postdoctoral scholars (15.2%). Respondents were also asked what field their most recent degree was in; of those who answered the question, the vast majority of respondents (91.5%) reported biology or a subfield of biology, while 8.5% of respondents reported that their most recent degree was from another discipline, such as education or psychology.

Data Analysis

Survey responses were coded by two researchers (BS and SL). The team used an iterative, inductive approach to generate codes using content analysis (Mayring, 2000). They began by first reading 10% of the responses to generate codes independently, with the resulting discussion producing six distinct codes Following this, each researcher independently coded 35% of the survey responses. With this fraction of the responses, the percent agreement between the two reviewers was 98% (Cohen's kappa = 0.92). Based on the high levels of agreement, one individual (BS) coded the remaining 65% of the survey responses. To check if there were differences in responses correlated with respondent demographics, we used contingency analysis to explore the distribution of one categorical variable (codes for understanding) across another categorical variable (different demographics parameters) and used chi-square statistics to test their independence (Cochran, 1952) in JMP Pro version 15.0.

○ Results

Survey respondents produced a broad array of responses (Table 1). There was no clear consensus on how instructors and biology education researchers define understanding, though the coding showed several themes emerging. The plurality (41.0%) of respondents defined understanding as being able to apply knowledge to a different scenario than the one originally presented, while <30% of participants included the ability for students to describe the concept in their own words (27.8%), place the concept in a larger framework (26.4%), and demonstrate mastery of material relating to the concept (24.3%). Far fewer respondents (11.8%) stated that understanding was the ability to apply knowledge to the process of science, while ~3% of the respondents stated that they could not define understanding. Given the open-ended nature of the question, responses could fall within more than one category, and thus the sum of the percentages provided is >100%.

To determine whether responses to the survey question varied by respondent demographic group, we performed a correlation analysis. There was no correlation between any of our sample's reported demographics (type of institution, respondent role, number of past SABER conferences attended, and number of years teaching) and frequency of reported "understanding" definition, except when comparing responses of those who earned their most recent degree in biology to responses of those who earned their most recent degree from a non-biology discipline like education or psychology (chi-square, $p < 0.05$). These differences are shown in Table 2. From this table, we can see that while certain understanding codes were reported with similar frequencies between the two groups, those whose most recent degree was in biology were much more likely to define understanding as "describe in one's own words" (22.8% of biology respondents vs. 0% of non-biology respondents) while being much less likely to define it as "demonstrate mastery of material" (14.4% of biology respondents vs. 42.9% of non-biology respondents).

○ Discussion

The responses demonstrated that there was no consensus about what it means to understand a concept in the context of assessing students, with definitions that differed drastically from each other. A few respondents even stated they were unable to provide a definition of the word. Each of the six categories that emerged from the responses provides discrete and different definitions that do not necessarily align with each other. For instance, it is conceivable that students could describe a concept in their own words but not be

Table 1. Respondent definitions of the term "understanding" by category of response to the question "In the context of assessing student understanding, how would you define 'understanding'?" Respondents were biology instructors and biology education researchers attending a biology education research meeting. Responses were coded by a team of two researchers (see text).

Category	Percent of All Respondents [a]	Percent of All Codes [b]	Example Quote
Apply knowledge to a different scenario than presented	41.0	30.6	"…requires an individual to be able to apply a concept in a novel circumstance."
Describe in one's own words	27.8	20.7	"Able to effectively communication to someone else what they know."
Place concept in a larger framework	26.4	19.7	"…the ability to see connections between concepts, rather than as discrete, separate ideas."
Demonstrate mastery of material	24.3	18.1	"To know, with an ability to demonstrate knowledge…"
Apply knowledge to the process of science	11.8	8.8	"Knowing something well enough to use it to learn new things, solve novel problems, and ask questions."
Can't define	2.8	2.1	"Honestly I have no idea. I think it's a red herring."

[a] Percentage of responses that were ascribed to this category, summing to >100% because some respondents provided definitions that fell within two or more categories.
[b] Percentage of all codes included in the analysis, accounting for total number of codes applied.

Table 2. Comparison of definitions of "understanding" between respondents who identified biology versus other disciplines as the field of their most recent degree, by category of response to the question "In the context of assessing student understanding, how would you define 'understanding'?" Respondents were asked to identify their field of study for their most recent degree and were binned into those whose most recent degree was in biology ("biology") versus those whose most recent degree was not in biology ("non-biology"; e.g., education or psychology).

Category	Percent of All Codes within Responses	
	"Biology" Respondents (n = 172)	"Non-biology" Respondents (n = 16)
Apply knowledge to a different scenario than presented	31.1	33.3
Describe in one's own words	22.8	0
Place concept in a larger framework	21.0	9.5
Demonstrate mastery of material	14.4	42.9
Apply knowledge to the process of science	8.4	14.3
Can't define	2.4	0

able to apply that concept to a novel scenario if they do not have a deep conceptual mastery of the concept. Likewise, students may be able to place the concept in a broader framework and connect it to previously learned concepts while not being able to use the concept and apply the process of science.

Most of the categories of responses define understanding as the ability to perform a concrete, measurable skill, with the exception of the category of responses that defined understanding as demonstrating mastery of the material. Given that students can demonstrate mastery of a concept in many different ways, we further examined these responses to gain more insight. We found that 19 of the 35 respondents (54.3%) who defined understanding as demonstrating mastery of material also provided a second definition in their response, with the majority of these responses (n = 11) also stating that understanding can be defined as applying knowledge to a new scenario, with fewer respondents also stating that understanding can be defined as describing a concept in a student's own words (n = 4), placing a concept in a larger framework (n = 3), or applying knowledge to the process of science (n = 1). It is plausible, then, that the majority of respondents who defined understanding as demonstrating mastery of material view this mastery as the ability to apply knowledge to a different scenario.

Responses also ranged in what cognitive level they perceived understanding to be. For instance, the ability to define a concept is likely a lower-level cognitive skill, while the ability to apply knowledge to new scenarios or to apply the concept to the scientific method likely requires higher cognitive processes. Interestingly, these two definitions of understanding, along with responses that defined understanding as demonstrating mastery, may align with the "apply" level of Bloom's Taxonomy, which is one level above the "understand" category, while the ability to define a concept may be categorized in the "recall" level of Bloom's Taxonomy, which is one level below that of understanding (Anderson, 2001). Thus, instructors are perceiving different definitions of understanding and may be ascribing different cognitive levels to this term in the context of assessments. In turn, these differences in definition and perception of understanding may drive different intended objects of learning, which would influence the enacted objects of learning, the instructional materials used to support the learning, and the lived object of learning.

It is also noteworthy that those who self-reported that the field of their most recent degree was not in biology defined "understanding" differently than those whose most recent degree was in biology. Although the sample size of those who earned degrees in other fields was small, none of the responses from those who earned degrees in other fields defined understanding as being able to describe a concept in one's own words; likewise, fewer of that group's responses identified understanding as the ability to place a concept in a larger framework, compared to those whose degrees were in biology. Conversely, a far greater proportion of those who earned degrees outside of biology defined understanding as the ability to demonstrate mastery of the material, again compared to those who earned biology degrees. These differences may reflect differences between biology and fields like education and psychology. The largest difference between biology and non-biology respondents was in the percentage of those who defined understanding as the ability to define a concept in one's own words, a definition that closely aligns with the "understand" level of Bloom's Taxonomy. Bloom's Taxonomy has been emphasized heavily in biology education in recent years (e.g., Lord & Baviskar, 2007; Crowe et al., 2008; Arneson & Offerdahl, 2018), while there have been considerable critiques of this taxonomy in education fields (e.g., Pring, 1971; Sockett, 1971; Furst, 1981; Hyder & Bhamani, 2016), mirroring the results we observed for this particular definition of understanding. Similarly, a far higher number of respondents with degrees outside of biology who defined understanding as demonstrating mastery of material, compared to respondents with degrees in biology, may reflect differences in mindset regarding classroom assessment. Those with education degrees may be more likely to adopt a mastery-oriented mindset when assessing student learning that focuses on "achievement based on intrapersonal standards of learning" (Svinicki, 2010), as compared to the more norm-referenced grading (i.e., curved grading) traditionally observed in higher-education biology classrooms (Schinske & Tanner, 2014). While there have been some limited work investigating biology instructors' mindsets (e.g., Richardson et al., 2020), particularly in the context of assessment, future work is needed to investigate how this difference in background may be contributing to disparate definitions of understanding.

Future Directions

This study is one of the first to examine instructors' and biology education researchers' perceptions of "understanding." Variation theory posits that learning is influenced by both the instructor and student spheres (Bussey et al., 2013); while our work focuses solely on the instructor sphere, exploring factors that influence the intended object of learning is critical for establishing a framework for investigating the enacted and lived objects of learning. Future work can build upon this framework by examining the student sphere of learning. In particular, it is unclear how effectively, if at all, instructors convey their definition of understanding and their expectations on assessments to students, and how students in those studies perceived what understanding meant. Many instructors provide course learning outcomes as well as content-specific learning objectives, but given the discrepancies in how instructors define understanding, future studies could investigate how students interpret the learning objectives provided by the instructor and whether these match the instructor's intended object of learning. Given that previous studies have already identified mismatches in student perceptions of their own level of understanding of biological terms (Zukswert et al., 2019), along with the lack of consensus among biologists about defining understanding shown here, it would be reasonable to expect that different students may be interpreting course learning objectives differently from each other and from what the instructor intended. It would be intriguing for future work to examine these areas more and determine how such differences influence student learning.

In addition, further work is needed to more completely understand the implications of these differences in instructor definitions of understanding and how they influence the interaction between the instructor and student spheres. For instance, Sato et al. (2019) demonstrate that exams in biology courses may not be accurately assessing student understanding, which they define as arriving at a correct answer by "using particular pieces of information to support how they arrived at the answer." Sung et al. (2020) explored student response processes more and found that many students use nonconceptual approaches to answer exam questions and may arrive at the correct answer even without a deep conceptual understanding of the concept. Future work could investigate the instructors' definitions of understanding in these contexts to see how their definitions influenced their enacted objects of learning, as well as the impact on students' lived objects of learning.

Implications for Teaching

In addition to prompting a range of potential avenues for future biology education research, our results also provide insight for biology educators. It is important for instructors to be aware that they may perceive understanding differently than their students and may be ascribing different cognitive loads to this term. This supports recommendations that instructors spend time in class explicitly setting expectations for learning objectives and assessments (Allen & Tanner, 2006; Osueke et al., 2018), and not assume that everyone will interpret a learning objective in the same manner. For example, instructors may wish to regularly review learning objectives in class and how they are intended to be interpreted, provide examples of assessment questions that are aligned with such learning objectives, and discuss strategies for how to use learning objectives to guide one's studying, consistent with past work finding that students in general need to be prompted to engage in metacognition (i.e., think reflectively on their own studying; Stanton et al., 2015).

This work also aligns with the advice of several centers for teaching and learning to avoid the use of the term "understand" when writing learning objectives (e.g., https://courses.dcs.wisc.edu/design-teaching/PlanDesign_Fall2016/2-Online-Course-Design/2_Learning-Objectives-Alignment/5_objectives_strategies.html), given that the word is not measurable, and to instead rely on more specific action verbs that convey clear, concrete, actionable skills or objectives that students should be able to do by the end of the module. In alignment with our work, the concern is that a learning objective written with the word "understand" will likely be interpreted differently by the instructor and students.

Finally, we urge each instructor to consider instructional techniques to better support student development of the concept of "understanding" based on their expectations. For instance, if an instructor perceives that it is most important for a student to understand a concept by placing it in a larger framework, the instructor can design activities that require students to practice connecting that concept to other ideas presented during the course, extending students' mental model of the broader themes of the class. Alternatively, if an instructor defines "understanding" as the ability to apply the concept to new scenarios, then the course should be scaffolded in a way that promotes this student ability with instructional tools and formative assessments shaped around this skill set.

No matter how instructors define understanding, we urge instructors to make their definitions and expectations clear, to design instructional tools that support student understanding of a concept as driven by the instructor's definition of understanding, and to better align intended objects of learning with the lived objects of learning.

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