RESEARCH ON LEARNING

The Relationship between Biology Classes and Biological Reasoning and Common Health Misconceptions

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Abstract

This study investigates the relationship among (1) college major, (2) knowledge used in reasoning about common health beliefs, and (3) judgment about the accuracy of those beliefs. Seventy-four college students, advanced biology and non–science majors, indicated their agreement or disagreement with commonly believed, but often inaccurate, statements about health and explained their reasoning. The results indicated that while the direct impact of college-level biology coursework on judgment accuracy was minimal, biology major was associated with increased reliance on advanced biological reasoning, which mediated judgment accuracy. However, the overall association of advanced biological reasoning with judgment accuracy was small. The discussion calls for strengthening the science–daily life connection in biology education for majors and nonmajors.

Key Words: *Biology education; health education; misconceptions; science in daily life.*

○ Introduction

Does teaching biology to students enhance their ability to deal with health information in daily life – to distinguish health myths from health facts, communicate with health professionals, and understand the nature of diseases, treatments, and prevention? Our goal as science educators is to engender knowledge and skills that are beneficial to all students, regardless of their future occupation. We hope that science knowledge will provide students with a useful basis for making daily decisions and contribute to their health and well-being. In introducing the *Next Generation Science Standards* (NGSS), Matt Krehbiel, a science-education program consultant from Kansas, expressed the conviction on the everyday applicability of science by stating that "The NGSS aim to prepare students to be better decision makers about scientific and technical issues and to apply science to their daily lives" (NGSS Lead States, 2013). When we think about areas of science that have practical applicability for lay people, the link between biology and health immediately comes to mind. This study is concerned with the association among formal education, biology knowledge, and thinking about health-related issues that are relevant to daily living.

We hope that science knowledge will provide students with a useful basis for making daily decisions and contribute to their health and well-being.

○ Theoretical Background

In thinking about the role of science education in daily life, we need to consider two questions. First, do we have evidence that science knowledge, however acquired, is useful in daily life? Second, does formal classroom instruction in science benefit daily living? The possibility of the affirmative answer to the second question is predicated on the affirmative answer to the first but does not automatically follow from it.

Indirect Evidence in Favor of Science Knowledge: The Effect of Health Literacy on Health

Surprisingly, the assumption of practical usefulness of scientific knowledge has not been broadly tested in educational research. In part, this could be because measuring the presence of science knowledge in daily life is much trickier than assessing students' performance in the classroom. The small number of studies that have been done have typically explored domains that are very different from biology and produced inconclusive results. For example, in a 1986 study, Kempton found that when lay people understand how heating works, this knowledge influences their thermostat control. By contrast, Layton et al. (1993) concluded that when lay people plan their heating budgets, they rarely think about scientific concepts.

Indirect evidence of the impact of biological knowledge on daily living comes from public health studies of health literacy, or "the degree to which individuals have the capacity to obtain, process, and understand basic information and services needed to make

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appropriate health decisions" (Ratzan & Parker, 2000). Although health literacy includes many skills, knowledge of health and disease is part of the capacity to process health information (Gazmararian et al., 2003). Ample evidence suggests that poor health literacy is correlated with undesirable health behaviors (e.g., not taking prescribed medications on time) and poor outcomes (higher viral loads in HIV patients, higher instances of retinopathy in diabetes patients) (Kalichman & Rompa, 2000; Schillinger et al., 2002). These studies give us reason to believe that biological knowledge does help people deal with practical health information that impacts their behaviors and outcomes.

Relationship between Depth of Biological Knowledge & Health Reasoning

Public health studies do not directly focus on biological knowledge and do not suggest possible mechanisms explaining how knowledge mediates health behavior. In our own work, conducted from the perspective of cognitive studies in science education, we hypothesized that biological knowledge may impact health-related decisions by providing the basis for good reasoning. This perspective is grounded in studies that define the ultimate, desirable scientific knowledge as "conceptual understanding," or a connected network of related facts that provide a causal explanation of a scientific phenomenon (Vosniadou & Ioannides, 1998). Our work is focused on the practical role of science knowledge in adolescent reasoning about HIV (Keselman et al., 2004), lay online information-seeking in response to a heart disease scenario (Keselman et al., 2008), and individuals' interaction with medical documents (Keselman & Smith, 2012). For example, Keselman et al. (2004) showed that the depth of adolescents' biological reasoning about HIV myths (e.g., demonstrated in discussing the nature of viruses and their ability to reproduce) was positively related to their ability to reject these myths as untrue. Other studies suggested that lack of biological knowledge may hurt individuals' ability to find relevant information on consumer health websites (Keselman et al., 2008) and to understand doctors' notes (Keselman & Smith, 2012). Jointly, these studies suggest that mere knowledge of health facts (e.g., "HIV is sexually transmitted and incurable") is often not sufficient for reasoning and dealing with new information. They also suggest there is practical utility to understanding basic properties of living organisms, recognizing that viruses have some properties of living organisms, and having some knowledge of bodily systems' organs and functions.

Relationship between Formal Education & the Application of Knowledge beyond School

Although the studies described in the previous section suggest that biological knowledge may have real-life application, they do not explicitly speak to the role of formal science education in producing such applicable knowledge. Are people with formal coursework in science better equipped to answer science-related questions outside the classroom?

In a striking film called *A Private Universe* (Schneps & Sadler, 1988), the filmmakers walk around Harvard's campus on the day of the commencement ceremony, asking graduating seniors what, in their opinion, causes the change of seasons. Graduate after graduate, one of whom reports having taken several physics courses, self-assuredly respond that seasons are caused by the elliptical shape of the Earth's orbit around the Sun: when the Earth moves closer to the Sun, it gets warmer. The film underscores the difficulty, well known to science education researchers, of replacing childhood theories of the world with formal, often counterintuitive, knowledge (e.g., McCloskey, 1983; Vosniadou & Brewer, 1992), as well as the notorious challenge of knowledge transfer (Perkins & Salomon, 1989).

Another piece of evidence for the dissociation between formal instruction and real life comes from studies that relate formal (classroom-acquired) knowledge and personal beliefs. One famous domain of the dissociation between knowledge and beliefs is evolution. For example, Cavallo and McCall (2008) demonstrated that while teaching students evolutionary biology increases their knowledge of relevant concepts, it does not necessarily affect their actual beliefs about evolution. Similarly, Johnson and Pigglucci (2004) demonstrated that while college science majors have better knowledge of science facts than business majors, the two groups do not differ with respect to their beliefs in pseudoscientific claims, such as the existence of UFOs or telepathy. The challenge of transferring formal classroom training to solving everyday problems is likely to affect the relationship between biology instruction and personal health beliefs.

○ Objectives

Our review of the literature suggests that the intersection of biology and health may be one area where science is highly applicable to daily life. At the same time, it warns us against making an unqualified assumption that formal biological training is easily transferable to everyday situations. The objective of the present study was to investigate the relationship among young adults' (1) exposure to advanced college-level biology coursework; (2) usage of in-depth biological knowledge in reasoning about commonly held, but often incorrect health beliefs; and (3) judgment accuracy about the health beliefs. We were also interested in the impact of nonbiological (e.g., experiential) knowledge on judgment accuracy. We hypothesized that exposure to advanced college-level biology would improve judgment accuracy and that the improvement would be mediated by using biological knowledge during reasoning.

Note on Terminology

In this work, we drew upon Smith and Siegel's (2004) definition of beliefs as true or false convictions that do not have to be grounded in evidence/explanations and knowledge as "justified true beliefs" (p. 555). Because one person's belief may constitute another person's knowledge, we use the term "beliefs" as shorthand, referring to correct and incorrect socially pervasive (in the United States) health-related assertions, and we use "knowledge" to refer to explanations that justify agreement or disagreement with such assertions.

○ Methods

Participants

Seventy-four students from a large, diverse, moderately selective public urban university in the United States participated in the study. Thirty-six were biology majors in the last 2 years of their 4-year program, recruited from an upper-division microbiology course. As part of their biology major requirements, they had also previously completed a year-long introductory biology sequence for biology majors

Table 1. Common Health Beliefs Questionnaire.

Statement	Correct Response
Not getting enough sleep makes you more likely to catch a cold.	True
Reading in low light may damage your eyesight.	False
You should drink at least eight glasses of water a day.	False
Antibiotics cannot treat a viral infection.	True
The shape and height of a pregnant woman's belly can indicate the baby's sex.	False
Eating a big meal before bedtime may keep you from falling asleep.[a]	**True**
Staying out in the cold and wind may give you a cold.	False
Don't kiss your baby if you have a cold.	False
Shaving makes hair grow back faster and coarser.	False
Take painkillers only for serious pain.	**False**
Humans use only 10% of their brain.	False
Vitamin C does not help you fight colds.	**True**
Hair and fingernails grow after death.	**False**
Colds and flu are most contagious before symptoms appear.	False
It is pretty much impossible to get an STD from a toilet seat.	**True**
Feeding kids sugar causes hyperactivity.	False
Teething causes fever in babies.	False

[a] Items in bold were eliminated from the analysis because of their low correlation with the remaining items.

and semester-long courses in genetics and cell and molecular biology. Virtually all had taken a course in introductory physiology, and most had taken, or were in the midst of taking, a range of upper-division biology electives. Thirty-eight were non–science majors in the last 2 years of their program, recruited from a survey science class for social sciences and liberal arts majors, who had never taken college-level courses for biology majors. In both groups, 39% of the participants were male. Both groups were racially and ethnically diverse. According to chi-square tests and one-way analysis of variance (ANOVA), the groups were statistically comparable on the demographic characteristics such as gender, race, ethnicity, age, and college years. However, self-reported GPA (grade point average score) was significantly higher for the biology majors group ($M = 3.33$, $SD = 0.37$), than for non–science majors ($M = 2.86$, $SD = 0.45$) ($F_{1, 68} = 22.11$, $P < 0.01$, $\eta^2 = 0.25$).

○ Instruments

All participants completed a demographic survey and a Common Health Beliefs Questionnaire (Table 1), developed by the authors specifically for this study. The questionnaire presented 17 commonly held health beliefs, some accurate, others false. Participants were asked to classify each statement as true or false and explain their opinion by writing a narrative answer to the printed "Please, explain" probe. The beliefs, along with normative correct responses, were obtained from articles on consumer health websites where the information is authored and/or vetted by health professionals or medical librarians, such as MedlinePlus (http://www.nlm.nih.gov/medlineplus/) and WebMD (http://www.webmd.com/). Examination of the internal consistency of the questionnaire revealed that several of the items were not strongly correlated with remaining items. Eliminating these items left us with a set of 12 beliefs with an acceptable internal consistency coefficient ($\alpha = 0.60$). The 12 beliefs were used in the analysis.

The content validity of the questionnaire is comprised of two components: the pervasiveness of the stated beliefs in the larger society where the student participants live (United States) and the validity of the "true" or "false" judgments in our answer key. The pervasiveness of the beliefs was ensured via our initial search strategy, when we entered terms such as "common" and "myth" into WebMD, one of the largest commercial consumer health information webites. We chose WebMD, because popular, attention-drawing, myth-debunking articles are common on this site (e.g., Moser, 2007). We used MedlinePlus, an authoritative noncommercial site produced by the National Library of Medicine, to verify the information.

Procedure

The procedure was approved by the Institutional Review Board of the City College of New York. After reviewing and signing informed consent forms, participants completed the instruments in a large-group proctored setting, using paper-and-pen questionnaires. Finally, they reviewed a debriefing statement. A research team member was available to answer questions. As a token of appreciation of their participation, students received bookstore gift cards.

Data Coding

Coding of the Common Health Beliefs Questionnaire involved assigning an accuracy score of 0 or 1 to each response and computing total accuracy score. Correct responses were determined on the basis of the articles used to generate the questions. In addition, narrative reasoning/justifications were coded according to the type of information that served as their basis. These codes, adapted from Keselman et al. (2004), were as follows: (1) *Basic Biological* (employing biological concepts at the most general level, such as "body," "disease," etc.), (2) *Advanced Biological* (employing explanatory mechanisms involving system-level and cellular-level concepts), (3) *Experiential* (based on own experience, as well as experiential information received from others in a social context), and (4) *Media/Culture* (received via print and electronic media, as well as references to "common knowledge" in a culture or a community). The coding manual specified the underlying basic concepts/facts and causal statements that were needed for the assignment of the *Advanced Biological* code. *Advanced* reasoning/justifications coding did not require highly specialized knowledge exclusively available to biology majors. For example, in order to be coded as *Advanced*, reasoning about the statement that "not getting enough sleep makes you more likely to catch a cold" had to (1) propose a physiological effect on a specific bodily system or organ (e.g., weakens the immune system) or state that there is none, or (2) explain that colds are caused by microorganisms. Although not highly specialized, this level of biological reasoning is in sharp contrast with the barely biological "Sleep causes tiredness," which would be classified as *Basic*. If an explanation drew on several sources, multiple codes were assigned. Two coders, blind to the participants' conditions, coded 15 randomly selected protocols. After they demonstrated a satisfactory level of chance-corrected intercoder agreement on reasoning/justifications coding (with Kappa value in the 0.61–0.80 "substantial agreement" range for one belief statement, 0.81–1.00 "almost perfect agreement" for nine belief statements, and perfect agreement for two belief statements) and resolved disagreements via discussion, one coded the rest of the data (Landis & Koch, 1977). The mean number of double-coded responses was M = 2.91 (SD = 2.81).

○ Results

Judgment Accuracy in Evaluating Common Health Beliefs

Students' total judgment accuracy ranged between 0 and 9 (out of 12) for biology majors (M = 5.08, SD = 2.21) and between 1 and 9 for non–science majors (M = 4.08, SD = 2.12). A one-factor ANOVA demonstrated that biology majors tended to have higher judgment accuracy scores than non–science majors ($F_{1, 72} = 3.98$, $P = 0.05$, $\eta^2 = 0.05$), although these differences were small in magnitude. To better understand this difference, we also examined participants' responses to individual questions by conducting chi-square analyses of the association between major and correct responses on individual items. Significant association between student major and response emerged in responses to 3 out of 12 questions: biology majors were more likely to correctly agree that antibiotics cannot treat a viral infection ($\chi^2 = 18.83$, df = 1, $P < 0.01$, n = 74), and to correctly disagree that teething causes fever ($\chi^2 = 6.52$, df = 1, $P = 0.01$, n = 74) and that kissing a baby can transmit a cold ($\chi^2 = 4.25$, df = 1, $P < 0.05$, n = 74). Note that the latter two differences do not withstand Bonferroni adjustments for multiple comparisons. Academic major was not a significant predictor for the remaining analyses (with $\chi^2 < 2.23$ and $P > 0.14$).

Types of Reasoning

A set of one-factor ANOVAs suggested that biology students were significantly less likely to rely on experiential and media- or culture-based knowledge in their reasoning (experiential: M = 0.53, SD = 0.77; media/culture: M = 0.64, SD = 1.21) than non–science majors (experiential M = 1.08, SD = 1.26; media/culture: M = 1.21, SD = 1.26) (experiential: $F_{1, 72} = 5.07$, $P < 0.05$, $\eta^2 = 0.07$; media/culture: $F_{1, 72} = 4.32$, $P < 0.05$, $\eta^2 = 0.06$). On the other hand, biology students were significantly more likely to rely on advanced biological reasoning (M = 4.83, SD = 2.82) than non–science majors (M = 2.58, SD = 1.97) ($F_{1, 72} = 16.02$, $P < 0.01$, $\eta^2 = 0.18$). There were no significant group differences in simple biological explanations (biology majors: M = 5.72, SD = 2.46; non–science majors: M = 6.40, SD = 2.24) ($F_{1, 72} = 1.52$, $P = 0.22$, $\eta^2 = 0.02$). Controlling these analyses for the participants' GPA did not affect the pattern of the observed group differences.

The Association between Types of Reasoning & the Number of Correct Responses

Next, we examined whether participants' reliance on advanced biological, experiential, and cultural explanations accounted for the group differences in the total number of correct responses. (Inclusion of GPA as a covariate in the multiple-mediator model did not affect the pattern of results.) We did not include basic biological explanations, because this variable did not differentiate the two groups and, hence, did not meet requirements for a potential mediator. To run this analysis, we employed a multiple-mediator model using a bootstrap multivariate procedure (Preacher & Hayes, 2008). This procedure allows one to examine the effects of each individual mediator, controlling for the effects of other mediators. One thousand random samples were taken from the data. Each data point was replaced as it was sampled. Indirect effects of students' major via the three mediators were examined. Indirect effects are significant if the boundaries of the 95% confidence intervals do not contain zero.

This analysis indicated that the effect of students' major on the total number of correct responses was jointly mediated by the positive effects of advanced biological reasoning (B = 0.27, SE = 0.11; $t_{69} = 2.48$, $P < 0.05$; 95% CI: 0.12 to 1.24) and negative effects of media/culture reasoning (B = 0.51, SE = 0.21; $t_{69} = 2.63$, $P = 0.01$; 95% CI: −0.83 to −0.06) on the total number of correct responses. The indirect effect of experiential explanations was not significant (B = −0.24, SE = 0.25; $t_{69} = -0.97$, $P = 0.33$; 95% CI: −0.06 to 0.47). The model accounted for a significant proportion of variance in the total number of correct responses ($R^2 = 0.20$). With the inclusion of these mediators in the model, the direct effect of major on the total number of correct responses was insignificant (B = 0.58, SE = 0.53; $t_{69} = 1.11$, $P = 0.27$).

Qualitative Illustrations of Biological Reasoning

Statistical analyses suggested that while all types of reasoning can be accompanied by correct and incorrect judgments, advanced biological reasoning is more likely to be associated with correct judgments. The following justification of (accurate) agreement that "Antibiotics cannot treat a viral infection" illustrates employment of advanced biological reasoning: "True; Antibiotics break down the cell walls of bacteria, but have no effect on viruses." In this case, the agreement is associated with accurate understanding of some characteristics of viruses and bacteria and an implied difference between the two. It stands in contrast to the following justification of the (incorrect) agreement that "Staying out in the cold and wind may give you a cold," which does not employ any specific biological concepts beyond the vague notions "True; Because it is stressful to your body, unless it is trained well to stay in the cold." The relationship between types of reasoning and accuracy, however, is less straightforward than what is evidenced by the above examples, especially in the case of statements that have an incorrect, but plausible, biological mechanism, as in "True [Reading in low light may damage your eyesight]; A strain is placed on the retina because of low light intensity." In addition, reasoning with specific biological concepts does necessarily mean accurate understanding and use of these concepts.

○ Discussion

The study found that the direct relationship between college-level biology coursework and judgment accuracy was statistically significant, but minimal for the participants: in evaluating 12 common health-belief statements, upper-division biology majors did unequivocally better than non–science majors on only one statement. Looking at the indirect association, however, creates a more complex story, as biology majors were more likely than non–science majors to rely on systems-level and cellular-level biological reasoning and less likely to rely on media- or culture-based reasoning. Higher levels of biological reasoning and lower levels of media/cultural reasoning were predictive of greater judgment accuracy. Although we cannot claim that enrolling in college biology courses per se leads students to more accurate judgments about common health beliefs, reasoning on the basis of systems-level and cellular-level biological knowledge rather than on the basis of media and cultural knowledge is associated with greater accuracy, though to a small degree. To put it differently, reasoning with "advanced" biological knowledge was advantageous, whereas reasoning with media/culture-based knowledge was disadvantageous.

Implications for Understanding the Impact of Biological Knowledge on Reasoning about Everyday Health

With respect to the applicability of biology to daily life, our findings can be interpreted as a glass either half empty or half full. On the one hand, consistent with Keselman et al. (2004), they provide evidence that employing systems- and cellular-level biological concepts can be useful in reasoning about everyday issues. Our results also provide a plausible mechanism (biological knowledge→reasoning→health beliefs→behavior) that partially accounts for the relationship between education, health literacy, and health outcomes (Kalichman & Rompa, 2000). On the other hand, the results suggest that the applicability of biological knowledge to daily life is less clear-cut than science educators sometimes assume.

Implications for Biology Education

The most interesting finding of the present study is the high number of misconceptions about health upheld by junior and senior biology majors. This may, in part, be explained by the biological plausibility of many commonly held misconceptions (this is precisely why they are common, after all) and the conceptual complexity of the underlying processes. However, not all erroneous beliefs can be attributed to plausible biological mechanisms. For example, across both groups of participants, the number of students who believed that it was possible to predict the gender of an unborn baby from the shape of the mother's belly was high.

Of course, the primary goal of specialized college biology courses is not, and should not be, imparting practical health knowledge. However, given that the biology classroom is the primary place for imparting biological knowledge, and because evidence suggests that biological knowledge can be useful in daily health reasoning, it is worth discussing how we can increase the practical impact of formal instruction. The subject of this discussion should not be limited to college courses for biology majors but, instead, should include middle and high school science courses, the setting that is prominently featured in the "science for all" discourse. Although exploring the daily life impact of various instructional strategies is beyond the scope of the study, our findings underscore the importance of building such strategies. Science education research suggest that the discussion of effective strategies should involve concepts of knowledge transfer, students' dispositions toward knowledge and controversies (Sinatra et al., 2003), and motivation to learn for understanding (Linnenbrink & Pintrich, 2002). In the future research, we would like to focus on the daily life impact of biology courses that make the connection to daily life explicit.

Limitations & Directions for Future Research

The limitations of the present study suggest the need for some caution in generalizing its results. Students were surveyed in a diverse urban public university; it is unclear how well such results would generalize to students who are part of a more homogeneous student body. As common in psychology research, the study drew upon a nonrandom convenience sample. The health statements that we asked students to evaluate differed in the complexity of their underlying biological mechanisms and in their plausibility, as well as in whether they were constructed as declaratives or imperatives. They also varied considerably in terms of their immediate relevance to health behavior. For example, a person who believes that colds are caused by cold weather may pay more attention to bundling up than to washing hands regularly during a flu season – a suboptimal behavior. The behavioral impact of believing that humans use only 10% of their brain, on the other hand, is less obvious. Finally, our study presented students with simple statements and required a binary agreement or disagreement. Follow-up interviews could yield greater precision by eliciting narrative or scale-based responses to common health beliefs.

Future research should expand the range of situations where the impact of formal education and biological knowledge is explored. It may employ diary-based and interview methodologies, prompting participants to record their real-life health decisions and to comment on their reasons and rationale. It should also investigate the effect of different instructional strategies on students' ability to apply biological knowledge, as well as the impact of other factors, such as health status, experience with health care, and general interest in health information. Another fruitful direction for future research is exploring argumentation skills, epistemic stance, and beliefs about the nature of science as possible mediators between formal education and thinking about practical health issues. Finally, although the primary focus of our study was on science education, it is worthwhile to explore potential links between science and health classrooms.

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