Conceptions of Germs:

Expert to Novice Understandings of Microorganisms

by

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Introduction

The media is increasingly filled with reports about outbreaks of SARS, AIDS, ebola, hanta virus, anthrax, polio, and mad cow disease. The rapid spread of these diseases and the concerns that arise from the media attention raise questions about how to best educate the public to be able to make informed decisions about their health, travel and family safety. The purpose of this study is to document what students of different ages and their teachers know about viruses and bacteria and to examine how this knowledge compares to that of experts.

Research in the area of students' conceptual understandings of biological science phenomena has become increasingly prevalent over the past two decades emphasizing the shift away from rote learning in science. Studies have investigated the ideas and reasoning students have about the cell (Flores, Tovar & Gallegos, 2003), the human circulatory system (Arnaudin & Mintzes, 1985), mammals, (Markham, Mintzes & Jones, 1994), and biotechnology (Dawson & Schibeci 2003; Dori, Tal, & Tsaushu, 2003). These studies and others have found that students and adults can have drastically different ideas about science concepts compared to the models held by the scientific community. Disparity between students, adults and experts within a specific field of inquiry are often associated with the development of preconceptions (also called naïve conceptions, misconceptions, alternative conceptions or personal theories) by the learner during interactions with physical, social, and cultural environments. Students begin developing these early concepts about natural phenomenon prior to formal instruction (Driver, 1987) and enter school with individual explanations and understandings about the science concepts they are taught. The personal theories held by children emerge as they try to understand and explain the experiences they confront in their environment. These working theories may, or may not, be consistent with current scientific explanations but are nevertheless resistant to change. Research has shown that students may hold original intuitive concepts simultaneously with new formal science concepts (Hewson & Hewson, 1992; Scott, 1992; Strike & Posner, 1985).

As individuals move from novice knowledge to expert knowledge they move from holding disconnected information to a system of connected knowledge bound by larger principles (Chi et al., 1981). Ericsson and Charness (1994) maintain that expert knowledge is more than an accumulation of facts but instead is structured to facilitate problem solving. For science educators, the challenge arises when students learn factual knowledge without developing the connections that move them along the continuum to principle-guided knowledge like that held by experts. When scientific knowledge conflicts with intuitive naïve knowledge the challenge is even greater.

Although research on children's development of science concepts has greatly expanded in recent years, most studies have focused on concepts related to the physical sciences and there are only a limited number of studies of biological systems. According to Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993), there has been little research on germs and one of the few studies by Nagy (1953) examining elementary school children's ideas about germs is "an admittedly dated study [which is] still cited by many authors" (American Association for the Advancement of Science, 1993, p. 345). There is a distinct lack of research in the area of the human body in general, and more specifically the effect of microorganisms on human health as well as the role of microorganisms in the environment.

Children's Conceptions of Germs

Research into children's conceptions of germs and illness has focused primarily on interview and test data. Few studies regarded children's physical representations of germs as insightful. However, Nagy's (1953) research on how children represent germs showed clear distinctions between age groups, consistent with Piaget's developmental stages. When children were asked to draw pictures of germs, more than half of the children between the ages of 5 and 7 were unable to draw a germ. The remaining children drew abstract figures such as dots to represent germs. Children ages 8 to 11 represented germs in one of three forms: germs, animals such as insects or scenes such as a garbage dump. When the elements of the drawings were analyzed three distinguishing categories emerged: animals, abstract figures, or a combination of both. The use of abstract figures seemed to decrease with age as animal representations increased.

Adults' Conceptions of Germs

As research in the area of causative agents associated with illness has increased, the focus on adult conceptions and personal theories continues to be minimal. The studies in the area of biology which primarily focus on the young seem to make the assumption that children will eventually reach a point of scientific understanding in adulthood. However, very few studies have explored what adults actually know about the effects of microorganisms on the body; therefore the similarities and differences between adults' and children's conceptions are not clear. In studies on children's understandings of biology it is believed that young children are able to access naïve theories on the subject "which are constrained in ways quite similar to adult versions" (Rosser, 1994).

This study adds to the conceptual development literature through an examination of elementary, middle and high school students' knowledge of germs. In response to the lack of research on adult and expert conceptions, teachers and science professionals have been included in this research. In this study the concepts of children, adolescents, and adults are examined in order to provide a broad spectrum of ages that allows for the examination of how knowledge of microorganisms differs by age and experience.

This study seeks to answer the following research question: *How does knowledge in the domain of germs*[1] *held by students, teachers, and science professionals differ?*

Methodology and Procedures

Participants

Three participant groups were investigated in this study: students, teachers, and medical professionals. The three school sites selected for this study were from the same community in order to reduce the effect of differences in student populations. Once the

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[1] The domain of germs includes: microorganism (broadly defined) function, characteristics, size, structure, and shape. The term "germ" was utilized to allow elementary students to participate in the study.

sites were selected, one class from each targeted grade was randomly chosen for data collection. Student participants in each class were invited to volunteer to participate in the study. One of the goals of this study is to document concepts held from novice to expert levels. For the purposes of this study elementary, middle and high school students and elementary and middle school teachers are categorized as novices due to the limited opportunities they have had to study microbiology. High school biology teachers and medical professionals were categorized as expert for the analyses.

Students. The student participants were selected from suburban public schools in the central region of North Carolina. A cluster sampling approach was used to select one elementary and middle school class, and two high school classes in the same suburban area. Each student in the selected classes was invited to participate in the study. Data were collected on approximately twenty students at each grade level (5, 8, and 11) for a total of 63 student participants. In order to ensure that all student participants had little or no instruction related to germs or illness during the semester of the study, each grade level was selected after consulting the North Carolina Competency-Based Curriculum for Science K-12 (1994). There were no specific guidelines or competencies for students in grades 5, 8, or 11 related to teaching about germs, viruses, or bacteria.

A description of the participating schools' demographics is provided in the following section. Table 1 shows the demographics of the student participants.

Table 1

Demographic Information of the Participating Schools' Population

Grade	Race (%)			Free/Reduced Lunch Participation (%)
	African American	European American	Other	Grade level Total
5	.34	.40	.26	.48
8	.44	.51	.05	.54
11	.43	.53	.04	.37

Note. The other included Asian, Hispanic, and Native American students.

The participants included: 23 fifth grade students (57% females and 43% males); 20, 8th-grade students (45% females and 55% males), 20 high school students (85% females and 15%males). The high school students were from an Anatomy course and a Biology course. Two classes were selected in order to achieve an adequate sample size of 11th-grade students.

Teachers. All teachers of 5th-grade students at the elementary school site were invited to participate in the study. Three classroom teachers and the science resource teacher at the school volunteered for the study. The two female and two male elementary teachers were all of European American ethnicity with a mean of 15.2 years teaching experience.

Three middle school science teachers (1 male, 2 females) and four high school science teachers (2 males, 2 females) volunteered to participate in the study. The middle school teacher participants were of European American ethnicity with a mean of 6 years teaching experience. The high school science teachers were all of European American ethnicity and had a mean of 11 years of teaching experience. All the teachers in the study were fully certified and had completed at least a bachelor's degree.

Medical Professionals. In order to gain a broad view of the understanding and organization of knowledge of microorganisms held by experts, individuals working in the area of medical research were invited to participate in this study. Three females of European American ethnicity volunteered and completed all of the data. One of the volunteers was a virologist who works with Human Immunodeficiency Virus (HIV). Another participant was a toxicologist at the State Medical Examiner's Office with a background in clinical chemistry and pharmacology. The third participant was in the process of completing her final year of medical school. She completed and passed all her board examinations and was beginning a residency program in pediatrics.

Research Design

Data Sources

The term "germ" was used in the study to allow for data collection and analysis across children, adolescents, and adults. As noted in the *National Science Education Standards*, "(m)ost children use the word 'germs' for all microbes" (p. 139, National Research Council, 1996). Because of concern that 5th grade students may not be familiar with the term microorganism we used the term germ to elicit information about viruses and bacteria. During interviews participants were encouraged to consider the broader use of the term germ.

Graphical Representations. Each participant was asked to draw two different types of germs. Several studies have shown that children in particular are more able to express their beliefs about topics in science through the use of drawings (Hayes, Symington, & Martin, 1994).

The graphical representations of the germs were analyzed by noting common traits and developing categories from the emerging commonalities. For example, each drawing was examined for shape (dots, circles, or irregular), and features (nucleus, cell wall). During the second round of analysis, the drawings were coded based on the number of structures present in each germ depiction. Twenty percent of the drawings were scored by the researcher and an independent coder. The coders agreed on 92% of the category placements at the end of a first round of review and increased their level of agreement to 95% by a second round of coding. As part of the coding process, each structure was counted and a total was calculated for each drawing.

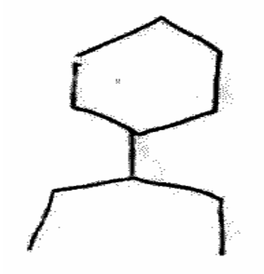
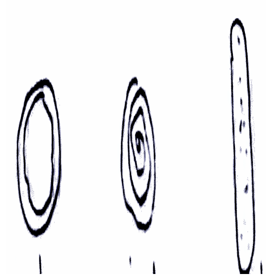
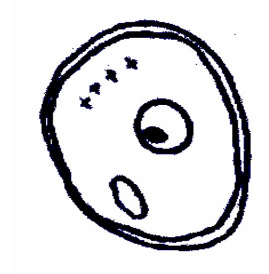
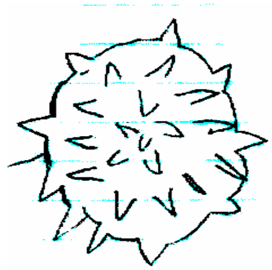
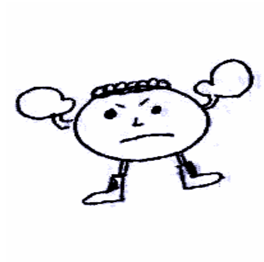
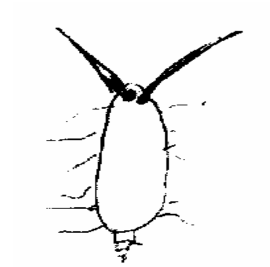
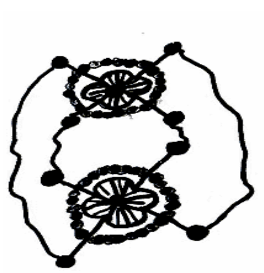
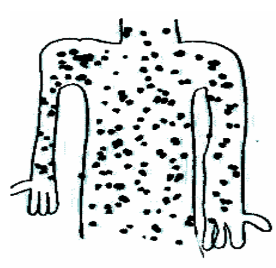
An additional round of coding compared the drawings to images of viruses, bacteria and animal cells common in textbooks and other sources of media. A list of common features for each organism was used to categorize the drawings (Table 2). Drawings were classified during this phase of coding as “viral-like,” “bacteria-like,” “cell-like” or “other.” The category labeled “other” included drawings of protists, drawings of body parts with disease, or caricatures of a germ. Caricatures were defined as pictures intended to represent a germ but included human characteristics with facial features such as eyes, mouth, teeth or other human body parts such as arms, legs or clothing. Table 3 provides examples of participants’ images representing each coding category.

Table 2
List of Common Organism and Cell Characteristics

Organism / Cell	Characteristics
Virus	Helical or symmetric protein capsid Nucleic acid DNA or RNA
Bacterium	Shapes: rod, cocci, spiral Prokaryote Nucleoid Plasma membrane Flagella Pili Lacks membrane bound organelles
Animal Cell	Cell membrane Cytoplasm Nuclear envelope Nucleus Chromosomes DNA Organelles: Endoplasmic reticulum, Golgi Bodies, vacuoles, centrioles, mitochondria, ribosomes
Protist	Unicellular Eukaryote Plasma membrane Cytoplasm Nuclear membrane Nucleus DNA Flagella, cilia, pseudopodia Oral groove Organelles: Golgi apparatus, food vacuole, anal pore

Table 3

<u>Examples of Drawings of Germs for Each Coding Category</u>

Virus- Type 1	Bacteria	Cell
		
Virus- Type 2	Other- Caricature	Other- Insect
		
Other- Unclassified	Other- Disease	Other- Protist
		

Interviews. Semi-structured interviews were conducted with each of the participants. Participants were encouraged through the use of probing to offer deeper meaning and more descriptions of microorganisms and their functions. Interviews were audio-taped and transcribed. They were read and re-read for common categories and were coded according to the characteristics of microorganisms present and locations where germs were thought to be prevalent. Descriptions related to the similarities and differences between viruses and bacteria were coded. This category was subdivided into size, replication, and structure.

Interview data were examined across and within categories as described by Erickson (1986). Additionally, twenty percent of the transcripts were read and re-read by the researcher and an independent party to ensure agreement on categories and as a measure of inter-rater reliability. The scorers agreed on 85% of the categories that were coded.

Results

Personal Definitions of Germs

The word "germ" was used throughout this study as a basis for beginning discussions with participants to probe their understanding of microorganisms, specifically bacteria and viruses. Although this term is commonly used by the public to indicate unseen microorganisms that may or may not cause illness, a wide range of personal definitions emerged throughout the interviews. When asked to define the word "germ" each of the medical professionals had very different explanations for the term. Debbie the virologist, briefly stated that a germ was "any microscopic pathogen that causes disease." Rose, the toxicologist, said, "to me when I hear that term I'm thinking virus. I'm thinking cold, virus, rhinovirus.” Melanie, the medical resident had yet another understanding of the term: “you break them down into bacterial and viral and you break down the bacterial into gram positive and gram negative and neither.”

Like the medical professionals, the individual teachers also varied in their personal understanding of “germ.” No clear distinctions between the teacher groups were evident. Most of the responses mentioned a germ as a cause of sickness related to bacteria and viruses. Paige, a high school teacher, described:

> A germ is something that can cause an illness in a general term. That’s a catch-all term. And when most people think of germs they think of viruses and bacteria, so germ is what we normally think of as something that can make you sick. It’s a catch-all term rather than what I would call an official [term]. We use the term ourselves like in germ warfare. Well it makes you sick, but it is chemically-based most of the time, or microbial-based, so it’s a catch-all phrase for the genetic cause of the impediment.

Like the teachers, the word germ had various meanings to the students. Students in middle and high school tended to mention bacteria and viruses more frequently when defining the term than elementary students. When asked to describe what came to mind when the word germ is used Sonya, a high school student, said:

> I think of anything that makes you get sick. . . I would say that bacteria are germs. I’m not sure if viruses would be germs or not, probably. When I think of germs I think anything that makes you sick, like a pathogen. Isn’t it a broad term for all those things that make you sick? That’s what I think a germ would be.

Another student, Kimberly described it as “like microscopic bacteria that eats away at your cells or something, or puts diseases in your cells and you get sick.”

Even though elementary students were not as likely to use the terms bacteria or virus when defining what a germ was, a few students such as Ellen did cite bacteria in their descriptions; “they are really tiny. . .and the most major one that I can think of is bacteria.” None of the elementary students used the term virus when defining “germ.”

Students at all grade levels viewed germs as a general cause of sickness and even death. One high school student, Kayla described germs as “prey.” When asked to explain what she meant, she continued to explain how it causes harm. “I think it preys on people, makes them sick. Like a robber to me. It robs away all of your energy and brings you down.” Another theme that emerged from the definition of germs given by all levels of participants, was the idea that there were both good and bad germs. This dichotomy was less often referred to by the medical professionals than the other study participants.

Defining Germs in a Cultural Context: Good or Evil?

For both adults and students, the process of defining “germ” led to a spontaneous classification of germs into three groups, those that were harmful, those that didn’t cause sickness but were in no way beneficial and those that were of benefit to the body. Initially, the majority of adults and children stated that they thought “germ” conveyed a negative meaning. When asked if the word germ conveyed a negative, positive or neutral feeling, one teacher stated: “Negative normally, it elicits a negative response” (Jason, 11th-grade teacher). Upon further probing, the adults clearly understood that there were microorganisms that were used by the body for normal functioning or normal biological processes such as decomposition. Melanie described how she and other medical school students classified germs: “I break them down in to bacterial and viral; you can [also] have good germs. You have normal body flora that help prevent the colonization by the bad germs.”

One elementary teacher also explained the benefits of bacteria as he understood them: “I know there are bacteria involved in decomposing organic matter so I don’t think of them as causing diseases or sickness they seem like they are beneficial” (Richard, Elementary Teacher).

All student groups tended to categorize germs as “good,” “neutral” or “bad.” When asked specifically if there were “good” germs students at all grade levels conceded that there probably were microorganisms that were “good” but many could not think of any or how they were beneficial. Some students clearly understood the benefits of some bacteria, such as Katy, a high school student; “You have bacteria and things in your body systems and they were meant to be there. If you didn’t have them you’d be sick.” Some elementary students said that good germs were blood cells or antibacterial because they helped your body. The younger students tended to provide more examples or explanations of their conceptions even when they were unsure of their understanding, unlike the older students who would end the questioning by stating that they didn’t know.

In summary, when asked to define what a germ was, both adults and students primarily thought of bacteria. Viruses were also mentioned by the older students and adults however they were mentioned at a lower frequency than bacteria. Adults and students believed there were beneficial microorganisms.

Where Are Germs Found?

During interviews, participants were asked to describe where they would find germs in their surrounding environment. Most of the participants across all groups expressed that germs would be everywhere. When probed for additional information the participants noted germs were typically found in areas with high levels of human contact such as door handles, desks and other surfaces, bathrooms, kitchens, floors, books, and computers. Students also suggested germs were found in places that were dark and moist or where there were dirt particles. Parts of the body were also noted by students. High school and middle school students said germs would be found in the mouth or on the hands while half of the elementary students said that the body would have germs specifically in areas such as the saliva and on the skin.

As a follow-up to the question about the location of germs, each person was asked to describe or name a place where few or no germs would exist. This question elicited a wide range of replies within and between participant groups. The most frequent reply remained that germs would be found everywhere. This answer was more prevalent among students than adults. Adults tended to think of conditions where microorganisms would find it difficult or impossible to survive. Although the medical professionals were reluctant to say there was a place where microorganisms were non-existent, Debbie, the virologist, described locations where it may be possible to greatly reduce the numbers of microorganisms present.

> Some places are more intensively covered than others. If I was looking for a place with a low coverage of germs it would be somewhere like a BSL 3 facility or a BSL 4 facility which have been sterilized.

Teachers of upper and lower grade levels, as well as middle school students, also mentioned the controlled and sterile environment of a lab as a possible location absent of germs. Teachers and students alike described places that were "clean" such as a soap dish, nurses office, lunch room, hospital and filtered water. Perry, an 11th-grade teacher, described two possible locations where no germs existed as follows:

> Maybe in a vacuum-sealed artificially created [chamber] by scientists who study them so there's no cross contamination. . . .. Well probably in the core of the earth there are no germs because the temperature and pressure factors would negate that but I don't know of anybody getting down there to test it.

Unlike most adults, students at all grade levels thought that places with extreme temperatures like erupting volcanoes and the frozen landscape of Antarctica would not be suitable environments for microorganisms to live. Other locations that students described as having few or no germs were places with little or no human contact like the moon, the desert and the mountains. Students at all grade levels tended to link germs with humans. Although a few students mentioned that animals and other living things could carry and pass germs, students viewed germs to be primarily associated with humans.

Differences Between Bacteria and Viruses

The use of the terms virus and bacteria were used frequently by people in all age groups and yet the use of the terms were not always based on current scientific beliefs. All of the participants in the study had previously heard of the terms prior to being interviewed but there were differences in understandings of bacteria and viruses.

Structural Differences. Each medical professional described approximately the same structural differences of viruses and bacteria. According to the medical professionals, bacteria were independent living cells that contained DNA. Viruses were not considered living cells, and were made up of a protein coat that contained RNA or viral DNA but did not have a nucleus. The medical professionals did not mention the overall shape of bacteria or viruses that were commonly described by the high school and middle school teachers. The high school teachers and middle school teachers described bacteria as cells that appear in three different shapes: cocci, rod, and spirilla. They also reported that viruses were not living, contained no organelles, were made of a protein coat and came in many shapes and forms. The elementary teachers did not have a clear picture of the structural differences. One teacher summarized her understanding by saying "viruses are nothing but a strand of their own DNA." No student groups mentioned any structural differences between bacteria and viruses.

Replication Differences. The medical professionals and high school teachers had a very detailed understanding of the different processes used by bacteria and viruses to reproduce. One of the medical professionals described the differences in reproduction as she understood them:

> Bacteria will reproduce by themselves just like any other macroorganism. Viruses use the host cellular system to produce more viruses. The virus will attack a cell and inject its DNA into the host cell. This DNA then depending on the virus, finds a way to convince the host cell that it should read this DNA. DNA is basically instructions for what the cell is supposed to be doing. The cell starts reading the viral DNA and the viral DNA says

> make this protein and copy this DNA and then put them together and depending on the virus they will either be transported to the cell surface or they will flood off which is just a way of leaving the cell or the cell will just keep making more and more until it is so full of virus particles that it explodes. Then they infect new cells.

Although the middle school teachers were confident in their understanding of the structural differences they did not provide any explanation of how microorganisms reproduced. The elementary teachers had some understanding although it was not as complete as the medical professionals and the high school teachers. Jessica, a 5th-grade teacher, related her conceptions about the production of new viruses and bacteria as follows:

> A virus takes over the DNA of a single cell and uses that to produce more of itself and it just sort of multiples geometrically where it doubles and doubles and doubles until you are sick. I’m not sure if bacteria work the same way. I think they do. I think they take over one cell at a time. (Jessica, 5th-grade teacher)

Only two students, out of all of the student participants, noted that a virus took over a cell and reprogrammed it.

Size Differences. The general consensus among adult participants was that although both bacteria and viruses were very small, bacteria were definitely larger than viruses. Of the students who responded to the question regarding the size difference between bacteria and viruses, all but one middle and high school student noted that viruses were bigger than bacteria. Important differences become apparent when examining the students' explanations for why they thought viruses were larger. Students attributed the size of a virus to the length of time it took to rid the body of the illness and the degree of illness experienced by the type of microbial infection. For example, Renee stated that "a virus might be bigger because it stays in the body longer and [with] bacteria people can take something to fight off the bacteria and make it go away." In general, students reasoned that *a virus was more virulent* compared to bacteria and therefore *it was larger in size*.

Student Conceptions on the Differences Between Bacteria and Viruses

One idea common to all student age groups that emerged from the transcripts was the belief that bacteria caused viruses. One high school student tried to explain the difference between the two microorganisms: "I don't really think there is a difference …I think bacteria is what usually causes a virus." Another high school student confidently ended her explanation by saying "bacteria is something you could get sick from and recover. Then a bacteria can turn into a virus you know." Even the youngest students had the same idea. A 5th-grade student explained "probably a virus is like you're sick all over, like you have a stomach virus and bacteria are things like germs that are making the virus." This belief that viruses are created from bacteria supports another idea that students from all grade level groups mentioned; that virus was the illness that was the result of infection by microorganisms.

Students had different ideas about the severity of infection caused by bacteria and viruses. Based on the belief that viruses originated from bacteria, many students hypothesized that viruses were worse than bacteria. A middle school student stated;

“bacteria can build up in something . . . . It comes from old foods, old or gone bad. Then a virus gets inside you and makes you sick, but bacteria doesn’t.”

Other students thought that the difference between bacteria and viruses were based on the illness they caused. An elementary student summarized his thoughts by saying that bacteria and viruses were “a different kind of category of what kind of sickness it is. Like bacteria cause one thing and viruses cause another kind of thing.” Many of the elementary students reported that bacteria caused plaque or other problems with the teeth.

Few students mentioned any differences in treatment for bacterial or viral infections. While a few students stated that antibiotics were taken to kill bacteria, most students were only able to explain that there were medicines of some type that killed bacteria. There were also students who reported that viruses could be killed by medicines. No elementary student discussed treatments of any kind for infections caused by bacteria or viruses.

In summary, medical professionals, teachers and students held a wide range of conceptions about bacteria and viruses. While there was not a linear progression from novice to expert across all areas of questioning, the medical professionals and high school teachers tended to hold formal and more scientific types of knowledge. Lower grade teachers and students often combined spontaneous and formal knowledge while expressing their understandings of microorganisms.

Images of Germs

Germ Morphology. Students tended to draw irregular shaped images whereas none of the adults drew irregular shaped microorganisms. In general, all groups except elementary students and high school teachers tended to draw a circle most often. Rod shaped images appeared in every participant group ranging from 8-29%. Images that were not classified as a specific shape such as a body with dots covering it or a rendition of a bacteriophage were classified as "other." This category of shapes appeared in all groups but was most frequently used by high school and elementary teachers.

Table 4
Proportion of Germ Shapes by Participant Group

	Medical	Teachers			Students		
		Grade					
Drawing Shapes		11	8	5	11	8	5
Circle	0.43	0.13	0.25	0.38	0.39	0.33	0.18
Rod	0.29	0.12	0.25	0.12	0.12	0.08	0.16
Spiral	--	0.13	0.25	--	0.03	--	--
Oval	--	0.24	0.13	0.12	0.03	0.10	--
Bean	--	--	--	--	0.03	--	--
Irregular	--	--	--	--	0.28	0.31	0.41
Other	0.29	0.37	0.13	0.38	0.12	0.18	0.25

Note. The participants within each group drew two pictures

Types of Microorganisms Drawn. Teacher participants and medical professionals drew images containing bacteria-like features more frequently than any other type of image (Table 5). Middle school teachers had the highest percentage of their drawings categorized as bacteria-like (83%), followed by elementary school teachers with 62%, and high school and medical professionals each drawing half of their germs as bacteria. Although students at all grade levels also drew images of bacteria, the frequency was much lower, with less than a quarter of the images resembling bacteria for each grade level.

Adults in general also drew images of germs that were classified as viruses at a higher rate than students. The elementary school teachers were the only teacher group that drew virus-like images at similar frequencies as students. High school teachers drew half of their drawings as viruses compared to the medical professionals who drew one-third of their images similar to viruses. In the student groups, the high school participants had the highest number of drawings classified as virus-like (15%) followed by elementary students with 4% and middle school students at 3%. The cell-like classification was most often drawn by older students and elementary teachers.

Middle and elementary students ranked the highest in the category “other” with 74% and 71% of their total number of drawings being classified as something other than bacterial, viral or cellular in nature.

Table 5
Proportion of Germ Categories by Participant Group

Drawing Categories	Medical	Teachers Grade 11	Teachers Grade 8	Teachers Grade 5	Students Grade 11	Students Grade 8	Students Grade 5
Bacterium	0.50	0.50	0.83	0.62	0.23	0.20	0.24
Virus	0.33	0.50	0.17	0.13	0.15	0.03	0.04
Animal cell	--	--	--	0.13	0.29	0.03	--
Other:	0.17	--	--	0.13	0.33	0.74	0.71
Disease	--	--	--	--	--	0.10	0.22
Caricature	--	--	--	0.13	0.03	0.03	0.02
Insect	--	--	--	--	0.05	0.03	0.02
Protozoa	--	--	--	--	0.08	0.08	0.11
Unclassified	0.17	--	--	--	0.17	0.50	0.34

Note. The participants within each group drew two pictures.

Figures 1-7 provide examples of the organism most frequently drawn by each participant group. The examples in this section were selected because they represent the typical representation of the organism most frequently drawn by each participant group.

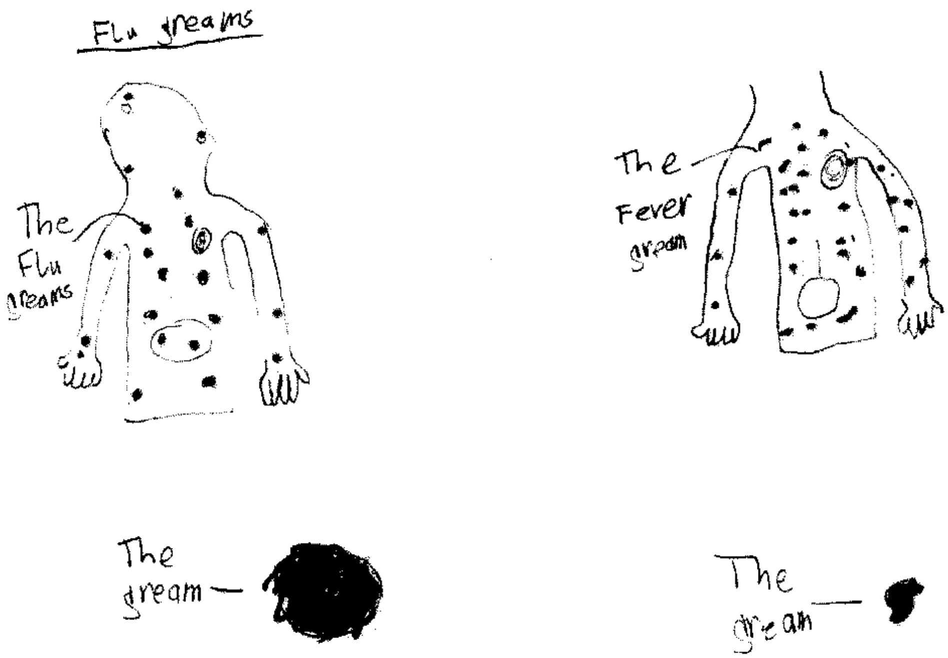


Figure 1. A 5th-grade student's drawing of germs as a disease.

Figure 2. An 8th-grade student's drawing of a germ as an unclassified organism.

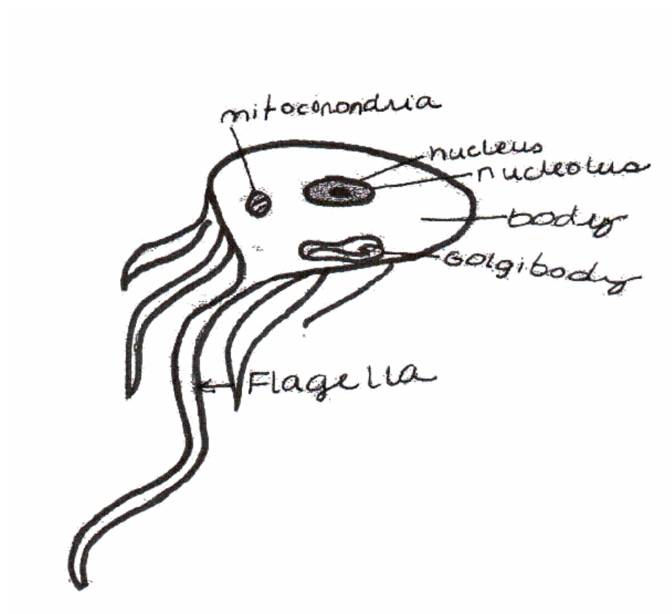
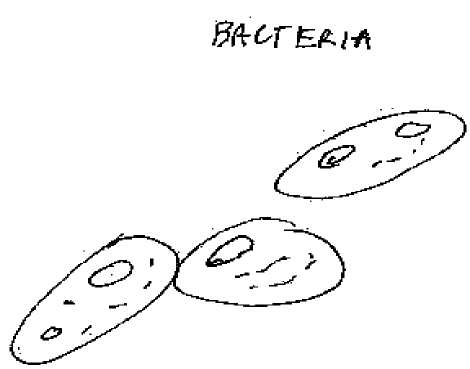
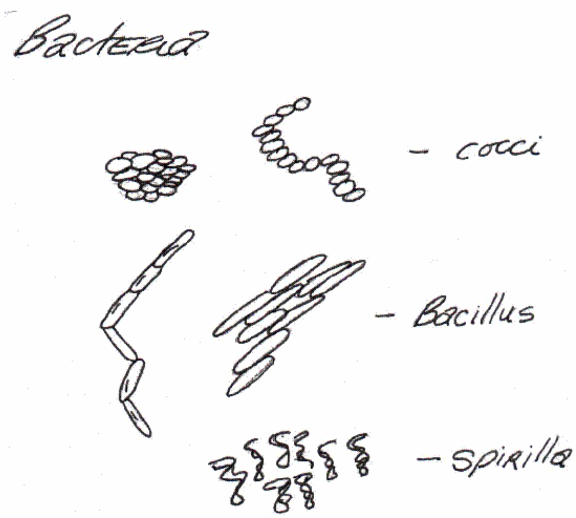


Figure 3. An 11th-grade student’s drawing of a germ as a protist.



<u>Figure 4</u> A 5th-grade teacher’s drawing of germs as bacteria.



<u>Figure 5.</u> An 8th-grade teacher's drawing of germs as bacteria.

<u>Figure 6.</u> An 11th-grade teacher's drawing of a germ as a virus.

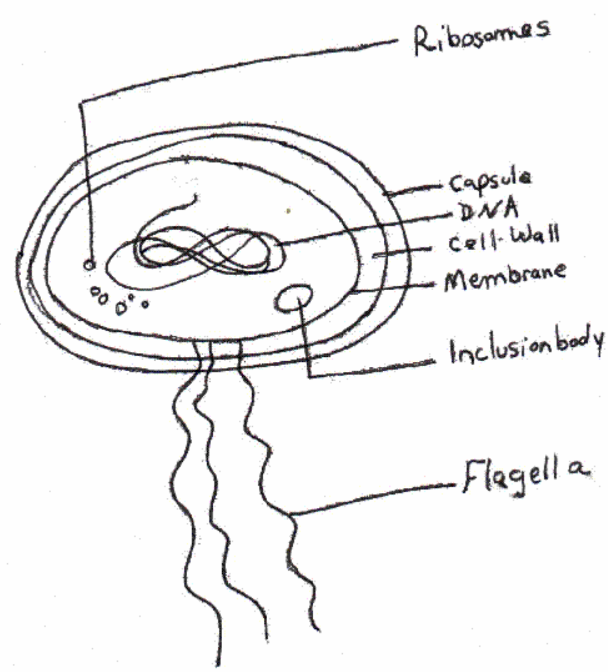


Figure 7. A medical professional's drawing of a germ as a bacterium.

Discussion

When young students talked about germs, they thought of them as a strictly human problem, rather than seeing microorganisms as one of many organisms in the ecosystem or as pathogens for other organisms. For example, when asked to describe a location that was germ free, the students referred to places that had little or no human contact such as other planets and places with extreme weather conditions. One explanation is that students hold an incomplete picture of the interrelationships between the macro and microorganisms that inhabit the planet and this further limited their ability to understand the impact that bacteria and viruses have on organisms other than humans.

The older students and the teachers had many formal and informal experiences to draw upon when conceptualizing bacteria and viruses. These participants not only drew from their own experience of being sick but also from prior courses in biology or microbiology. By drawing upon these experiences, the teachers provided scientifically accurate explanations during the interviews. These explanations, however, varied in explicitness based on the grade level they taught.

The medical professionals had extensive formal training that they utilized daily. In their role as a specialist, each medical professional focused on formal knowledge specific to their area of expertise. For example, the medical resident revealed her conceptions about bacteria and viruses from a physician's perspective related to diagnosis and treatment of illness. The virologist and toxicologist discussed their understandings from a laboratory-oriented research view. The medical professionals also tended to structure their knowledge in discrete categories.

Graphical Representations: A Closer Look

The drawings provided a visual perspective that focused on a concept of a germ rather than the entire conceptual domain. In both the student and teacher groups, an increase in realistic images of bacteria and viruses was aligned with an increase in grade level. This seems to indicate a connection between formal educational experiences and the visual images held. This is evidenced in the close resemblance between the drawings created by participants of bacteria, viruses, protists and cells and the illustrations and photographs found in textbooks. For example, the image frequently used by the participants when drawing a virus was a bacteriophage. Although this illustration is not necessarily representative of a large portion of viruses, this image is commonly represented in textbooks. When drawing bacteria, the images noted by many people were of the three classic textbook shapes: rod, spiral and spherical.

Media's Influence: Culturally Derived Images of Germs

According to Brandes (1996), "children's images of science are influenced by societal images of science portrayed in books, movies, advertisements, and other media" (p. 39). With the explosion of media influences from television, print publications, computer software and the internet, it is not surprising that students and adults referred to these predominate images when describing what they knew about bacteria and viruses. When asked to draw a germ many students reflected on images seen in the media and made comments such as, "I think all germs have dots and stuff because I saw a TV show and it showed these germs that have a lot of dots" (5^{th} grade student) or "that's the germ on the Listerine commercial" (8^{th} grade student). Other students such as Todd, an 8th-grade student, referred to movies and magazines as a source of information about diseases. After mentioning the Ebola virus he explained, "I read about it in the paper and I read a book on it and then I watched a movie on it." When asked what movie he had seen, he stated "Outbreak. It was about the Ebola disease." He also said that he learned about AIDS and sexually transmitted diseases (STD's) from "magazines, <u>People Magazine</u>, they kind of talk about that stuff." Although some of the information gained through media was based on accurate science information, it often did not fit with the student's existing knowledge base. For example, when Simmeon, a 5th-grade student, was asked if there was more than one kind of germ, she said, "yeah, I guess like antibacterial." When asked to explain what antibacterial meant, she stated, "I don't know I just hear it on TV." On further probing she stated, "they [media] normally say it's like from animal blood."

Many times the images and information from the media are the first encounters that students have with science topics. In the area of bacteria and viruses, most of the young students did not have prior experiences or images such as microscopic photographs or even illustrations of microorganisms to access when asked to draw a picture of germs. The only images in their pre-existing schema were those they had seen in the media. By referring to images and information gained through the media, children try to link what they see and hear on TV and in advertisements to their personal and school based learning. Many times this link does not lead to correct or complete understandings.

Gaps in Students' and Adults' Knowledge about Bacteria and Viruses

Students, teachers and medical professionals held different concepts of microorganisms. These differences did not always follow a predictable, linear developmental path from novice to expert. Gaps in knowledge were found in areas such as: where germs are found and differences between bacteria and viruses. What may be problematic is the lack of knowledge that elementary and in some cases middle school teachers hold related to microorganisms. The data showed that elementary teachers hold knowledge that is only slightly greater than that of their students. If science educators are to foster a more complete conceptual framework of microorganisms it may be beneficial to begin with more extensive teacher preparation in science.

The Ubiquitous Nature of Germs

The conceptions held by students and adults about where germs were found are strongly associated with proximity to humans. Although students and teachers reported that germs were everywhere, when pressed for more information, both groups reported places that had higher than normal contact with humans. Conversely, areas that had little or no human contact were places where germs would not be located. For example, objects touched by humans such as computer keyboards, door handles and desktops were the most frequently mentioned locations to find germs. When probed, students indicated a belief that bacteria and viruses were in some way intentionally targeting humans in order to cause sickness. Students tended to think of humans as the center of the ecosystem rather than one member of a system that is interdependent with other organisms such as microorganisms. This tendency to view microorganisms from an anthropocentric perspective may due in part to their development as well as to the way that microbiology is taught in schools.

Bacteria and Viruses: What are They and What Do They Do?

The greatest gaps in participants' knowledge could be found in the area of bacteria and viruses. Specifically, holes in knowledge existed about beneficial roles of bacteria, how bacteria cause harm to the cells in the body, how viruses replicate, and the size differences between bacteria and viruses. Although adults recognized that bacteria play a very important role in the decomposition of organic matter, as well as internally as an aid in digestion through the break down of proteins, starches and fats, students in general held a pathogenic image of bacteria. Bacteria were viewed by students of all grade levels, as causing a more serious illness than a virus. It was also seen as an entity, unlike a virus, which most students thought was a name for a particular type of illness. For example, one middle school student described her beliefs as follows: "A bacteria is like an old germ because it's small. It's not like a sickness or something like that. A virus is like a sickness, like flu or something because I've heard people call that stuff a virus."

This confusion is most likely due to the common use of the word virus to describe a specific set of symptoms. In our culture when a person has cold-like symptoms such as a sore throat, fever, and lethargy it is common to hear people say “I have a virus” rather than saying I have influenza or pneumonia. This trend not to distinguish between the cause of illness (pathogenic microorganisms) and the illness itself, led to a gap in the explanations of how microorganisms replicate and infect cells.

Experts had explicit knowledge of how bacteria reproduce through binary fission and that viruses inject genetic material into a host cell that reproduces and releases newly created viruses. These processes were not as familiar to teachers or students. For example, many teachers were familiar with the basic processes of viral reproduction but could not explain how bacteria reproduce. Students in general could not explain even in the most basic sense how reproduction occurred in either microorganism. Students and teachers lacked a formal understanding of the way bacteria affect cells to cause illness.

Although experts could explain in detail that bacteria colonize within the body and produce toxic waste products that affect the surrounding cells, few teachers and no students provided similar explanations. It was clear that many teachers and students related the negative effects of bacteria to the increase in the number of microorganisms in the body. No clear links were made between the microorganism and poisonous by-products. Although many of the teachers and some of the students had studied microorganisms as part of their science and health education, the lack of clear concepts in this area suggests a lack of experiential and meaningful learning situations.

Students attributed the size of a microorganism to the intensity of the illness it caused. As a result, many students thought viruses were larger than bacteria. Because they lacked concrete examples of microorganisms to refer to when thinking about the size differences, these students tried to make a connection between size (the unknown) and intensity of illness (the known) which was something they had personally experienced. They understood the difference between the symptoms related to a mild cold and those related to a more serious illness such as the flu. Because of those differences they attributed the most severe symptoms with the largest and most serious germ.

In summary, students and teachers exhibited periodic holes or gaps in the knowledge they held about different facets of microorganisms. These gaps can be attributed in some part to the developmental level of the participant. Younger students are less likely to be able to conceptualize the abstract characteristics of microorganisms that they cannot see. However, other explanations are possible. People are continually trying to make sense of their surroundings. Such a process constantly adds to the experiences and concepts incorporated into one's schema. However, this process does not necessarily lead to scientific accuracy. By grasping for new understandings, the participants in this study often used naïve conceptions based on their prior experiences to explain the unknown. In this process, they often created new but inaccurate concepts. These concepts may or may not go unchanged depending on if they are challenged in future encounters with formal or spontaneous information about this topic.

Links to Curricula

The results of this study show that students fall short of having the depth of knowledge to meet the *National Health Standards* that call for students to "understand health promotion and disease prevention concepts" and "make informed decisions" about their health (Joint Committee on National School Health Education Standards, 1995). At the most fundamental level students need to be able to differentiate a virus from a bacterium and be able to describe where microorganisms are found and how they are spread. These concepts lay the foundation for understanding the more complex concepts related to the use of antibiotics, bacterial resistance, vaccines, and immune responses.

These results show that students are closer to meeting the science standards that call for students to begin exploring "specialized cells and the molecules they produce, identify and destroy microbes that get inside the body" (p.137, American Association for the Advancement of Science, 1993) between the 6th- and 8th-grades. The results of this study indicate that students as early as the 5th-grade have distinct images of bacteria and viruses and hold understandings about where germs are found and how they spread. The natural curiosity that students have about their body functions provides an avenue for instruction that can elicit student understandings and build more accurate concepts. At the elementary school level this could be achieved through the use of "teachable moments" that occur spontaneously in the classroom, such as when a student has been to the doctor or dentist as well as through the use of accurate images of microorganisms and their effects on humans. At the middle and high school levels, students could model and discuss the evolution of microorganisms, characteristics, the roles of microorganisms in the environment, and analyze how the information and images received through the media impact their conceptions about bacteria and viruses.

Limitations

This study was undertaken to find out if patterns existed between the conceptions held by students, teachers and people in the medical profession about bacteria and viruses. Care should be taken before making inferences beyond the context of this study due to the limited numbers of participants.

Implications

> Microorganisms, then, play an important part in the cyclical changes that the biological elements undergo on Earth. In this sense they are of transcendental importance in the terrestrial economy, because without them higher order organisms would rapidly cease to exist… Microbes are neither generally good nor bad; they can be either. The important thing, which is not widely realized is that they have an enormous effect on the economy and well-being of mankind. (P. 20, Postgate, 2000)

Given the critical importance of a population that is knowledgeable about microorganisms, this study shows that students and teachers possess significant information about microorganisms while also having large gaps in their knowledge. The findings of this study have implications for science and health instruction as well as the sequencing and content of curricula. Although microorganisms play very critical roles in the environment, students and teachers tend to limit their knowledge of microorganisms to that of human illness. For students of all ages, the media plays an important role in shaping their concepts of microorganisms. Given the prevalence of media exposure in children’s lives, educational programming could assist formal educators in laying a foundation for the further study of microorganisms.

This study suggests that students hold basic understandings of bacteria and viruses at a very young age. Many students believe that viruses are larger than bacteria due to the severity of viral illnesses that students have experienced or been exposed to.

For health care providers, this study has implications for the discourse these professionals have with children. It is apparent that students know microorganisms exist but have little understandings of how to control and manage their exposure.

Neither students nor teachers indicated much awareness of the role of technological advances and microorganisms. There was little expressed knowledge of the dangers of overuse of antibacterial products and germ resistance. The roles of microorganisms in biological weapons as well as the more positive benefits of microorganisms in biotechnology and gene therapy were conspicuously absent.

Recognizing that life on earth would cease to exist without microorganisms, educators have a critical challenge to educate our future citizens about not only the roles of microorganisms in human health but also the larger role of microorganisms in the earth's ecology.

APPENDIX A

Interview Protocol

1. Tell me what you know about germs. *(Probe)*

2. What are some of the names or types of germs that you are have heard of?

3. Are there germs everywhere? If no, where are places that don't have germs?

4. Do all germs make you sick?

5. Where do germs come from?

6. What is the difference between a bacterium and a virus?

7. How do you think media has influenced what you know about germs?

8. Lets talk about your drawings. Tell me about what you drew.

9. How did you come up with these two types of germs?

10. How are these alike/ different?

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