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The Tragedy of the Unexamined Cat: Why K–12 and University Education Are Still in the Dark Ages and How Citizen Science Allows for a Renaissance

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At the end of the dark ages, anatomy was taught as though everything that could be known was known. Scholars learned about what had been discovered rather than how to make discoveries. This was true even though the body (and the rest of biology) was very poorly understood. The renaissance eventually brought a revolution in how scholars (and graduate students) were trained and worked. This revolution never occurred in K–12 or university education such that we now teach young students in much the way that scholars were taught in the dark ages, we teach them what is already known rather than the process of knowing. Citizen science offers a way to change K–12 and university education and, in doing so, complete the renaissance. Here we offer an example of such an approach and call for change in the way students are taught science, change that is more possible than it has ever been and is, nonetheless, five hundred years delayed.

THE TRAGEDY OF THE UNEXAMINED CAT

When the Western Roman Empire fell, most scientific inquiry simply stopped. It stopped for a thousand years and, because much of the knowledge of antiquity was lost during those years, might actually be said to have gone backwards. When science was reborn in the renaissance, beginning in the 1400s, less was known about the world in general and the living world in particular than was known 1,200 years earlier. For example, the workings of the heart and blood vessels were far better (if still imperfectly) understood in 150 AD than they were when Leonardo Da Vinci first began his dissections (e.g., 8). When the knowledge of antiquity was rediscovered during the renaissance, it was initially taken as gospel to be taught rather than a starting point from which further inquiry could continue. During dissections, a professor would stand and read from an anatomy book from antiquity (by Galen) and the students were meant to find in the body being dissected those features that were mentioned in the ancient text. The problem, though, a problem that seems silly in retrospect, was that the knowledge of antiquity was not perfect. If the students saw something in a body that was not in the text (such as a hint as to which direction blood flowed), that observation was to be discarded. The body could lie; the thousand-year-old book was true. Fortunately, beginning in the late renaissance, scholars (professors and graduate students) began to add to and improve ancient knowledge rather than simply taking it as the complete and revealed truth. This break was revolutionary, but incomplete.

In the renaissance, the training of graduate students began to involve having them do new science, searching for yet-to-be discovered truths (while necessarily mastering both what is already known and the methods with which scientists search for the truth). But this new form of simultaneous learning and discovery was never extended to the rest of education. Nor was it extended to the ways in which scholars engage the public. As a result, most science education as it is practiced today focuses on the facts. Most science education proceeds exactly in the way that it would have at the end of the dark ages. In too many instances, a teacher or professor stands in front of students and asks them to look to the world to see what is already known. The world is dissected to see what others discovered years before. In many cases this dissection is literal (and hence remarkably similar in appearance to the end of the dark ages). A cat, for example, or a fetal pig, is set out on a table and the students gather around to dissect the animal and, in doing so, see what the book says should be there, inside.

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If something in the cat deviates from what is in the book because of, say, a congenital deformity, the student with the deviant cat is asked to look at a neighbor's cat.

Our dark ages approach to science education is problematic because much of what we know to be true today will prove to be wrong (the appendix, for example, long held to be vestigial, appears to have an important functional role; 17). It is problematic because most of what is knowable is not yet known. Even by conservative estimates, the majority of insect species, be they deadly, beneficial, or otherwise, are not yet named (18). More fungal species were recently found in the dust inside North American houses than there are named species of fungi in North America (1). Most importantly, it is problematic because, like math, the key attribute of science that is useful to the average person in his or her life is not the facts (which nonetheless need to be grasped) but, instead, the scientific process and the general rules science offers for laying hold of the unknown features of the world. Many of the most important challenges facing humanity today, challenges of public health (e.g., flu and vaccination, the overuse of antibiotics), global change, or even agricultural sustainability, are challenges in which key decisions are made by stakeholders (citizens) who are not scientists, stakeholders who need to understand how science works (and, surveys indicate, do not).

So what do we do? We take a step that is 600 years overdue: we integrate citizen science into the classroom. Education reforms since the mid-nineteenth century have been slowly paving the way for citizen science in classrooms. First was a shift from "memory culture" and studies of classics and languages to adding science to the classroom curriculum in the mid-1800s (7). Then, in the early 1900s, John Dewey emphasized that classroom science should have real-world focus. By the 1960s, there were reforms to emphasize hands-on experiences, science literacy for all, and the development of critical thinking and reasoning skills. The current ideal is inquiry-based education, in which teachers aim to have students re-discover, on their own, what is known (e.g., 11). Such an approach is a simulation that teaches the process of science, but its lack of authenticity makes it fall short of the revolution for which we might hope, a real renaissance. Citizen science is science in which the public or classrooms participate in the scientific process, whether in collecting data, generating hypotheses or analyzing data. Citizen science is science that students and teachers can be involved in long after they leave school. It is science that allows anyone to be part of discoveries and, simultaneously, to learn about how science works (while still learning the facts).

In the last years, citizen science has become recognized as a key component of how we understand the world. Recent studies, for example, show that two-thirds of the field-based discoveries about monarch butterflies involved the public (16). In ornithology, half of what is known about migratory birds and climate change is based on data from bird watchers, even though citizen science is not explicitly credited in most scientific papers (5). In addition to producing new knowledge, citizen science has been viewed as science education in informal settings (2). Citizen science produces social capital, which includes increased public understanding of science (3, 9), greater scientific thinking (19, 10, 15), greater personal agency (6), and political participation leading to more accountability and industrial compliance with regulatory agencies (4, 12, 13, 14). But citizen science projects have been slow to be integrated into classrooms. The trickle of projects into classes is useful, but we need something more comprehensive.

Here, we offer the hypothesis we ourselves have begun to test, and that we hope might be more generally considered, namely that through engaging children, their teachers, and the public in learning about science by doing science (real science, science that yields new truths, science that is published in peer-reviewed journals), one can simultaneously improve the scientific knowledge of children and the public, make new discoveries, and engender a culture in which children and adults are willing and able to facilitate future discoveries. The barriers to doing so are non-trivial. In the U.S., for example, teachers are poorly paid, have large class sizes and must work in a framework in which very few of the minutes of the day are flexible. With our hypothesis in mind (but also those barriers), we have begun to work with teachers to co-create lesson plans and modules that allow teachers to incorporate citizen science directly into the classroom. We are working with teachers on real science about root microbes, belly button microbes, face mites, mammals in backyards, fossils, and more. As we do, we have simultaneously begun to study how to best craft these modules so as to empower teachers to pursue discoveries that by definition are unpredictable, even within the context of standardized school environments that are regulated by the need to meet curricular goals and benchmarks. Finally, we are studying how each of these projects scales, which ones spread easily from classroom to classroom and country to country, which fail to do so, and why. We began this work in K–12 classrooms (middle schools in particular), and soon many of the modules were being used in university classrooms. We are now extending our reach to university classrooms, where citizen science can be built upon into papers led by individual classes (www.studentsdiscover.org).

In the end, what we hope for is something far more radical than what we could ever achieve on our own: a reinvention of science education in schools, undergraduate classes, and informal settings. The scope of such an endeavor is perhaps best noted in the context not of what we have so far achieved but instead in the context of what we have collectively failed to achieve. Here, let us return to the example of the dead cats. All around the world cats are dissected in classrooms. The number of cats that are dissected is immense, in the millions. When these cats are dissected, no data are collected, ever. The cats are studied like the bodies of renaissance humans and then discarded. This is particularly tragic if one remembers that most of what is knowable is not yet known, even with regard to cats. New discoveries await in the bodies of cats, discoveries students could be making but are not, likely because neither they nor their teachers have even considered this as an option. The most interesting of these discoveries are the ones we cannot anticipate, but there are some we can anticipate. Among the most challenging diseases of humans, and mammals in general, to study are rare congenital diseases. Collectively these diseases affect many individuals, but the genetic underpinnings of these diseases are hard to understand because, in order to know which genetic variants might cause one of these diseases, one needs to study the bodies and genes of many afflicted individuals. A simple answer exists. When students study cat dissections, if they were to look for cats with congenital problems, document those cats, and take tissue samples of those cats (which they or someone else could sequence), we could start to understand the origin of such diseases. Instead, most rare congenital disorders are not well understood and will not be for decades, and nothing new is learned from the millions of dead cats. There are barriers to implementing this example, but they are surmountable with the citizen-science approach.

Historically, having a citizenry aware of the scientific process might have been a luxury. One could argue that most important decisions made with regard to science were made by relatively few stakeholders: the powerful few. Increasingly, however, the big decisions with regard to climate change, public health, water resources, and agriculture are being made by everyone who votes or chooses what to purchase. As a result, the future of the life we depend on very much depends on democratizing not only scientific knowledge but also science itself. A great deal more than the pursuit of beautiful science depends on our ability to fulfill the final step in the renaissance.

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