Physics . . .

A mother cuts an orange in half to demonstrate the concept of hemispheres to her children. (From M. A. Swift, *First Lessons on Natural Philosophy, for Children. In Two Parts. Part First,* new ed., Brown & Gross, 1884, p. 11. Courtesy of the Niels Bohr Library and Archives.)

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is for girls?

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Contrary to modern stereotypes, the laws of the natural world used to be considered a fundamental part of young women's education.

Sometimes history can be quite unexpected. A look to the past can quickly overturn an idea we might think of as having always been true. For instance, although the physics community now struggles with the perception that physics is a discipline for boys, not girls, that stereotype is only about a hundred years old. Once upon a time, physics—or natural philosophy, as it was called until the second half of the 19th century—was a girls' subject.

The US has a long history of science education for women through female academies, seminaries, and colleges. Although science education in the 19th century was most readily accessible to the white middle and upper classes, it was available to Catholics and Protestants alike and even to some elite Black and Indigenous women.[1] The historians Kim Tolley, Margaret Nash, and Jessica Linker, among others, have shown that an important part of education for young girls and women was natural philosophy: the scientific study of physical things, including their composition, behavior, and context. In fact, as Tolley has shown, natural philosophy was considered a more important part of a girl's education than a boy's. More girls than boys took it in schools, and many influential popular science and educational texts were written by women. (See the article by James Secord, PHYSICS TODAY, January 2018, page 46.)

By the early 20th century, however, the present-day notion of physics as a boys' subject had taken hold. So why were things different—and what changed?

Science and God

In the early 19th century, female secondary schools, known somewhat interchangeably as academies and seminaries, enrolled students from their early teens to their early twenties. Around 1800 they generally advertised courses in English, arithmetic, and geography. But geography encompassed far more than the names of countries and their capitals. A course on the subject might include a discussion of minerals, air pressure, the solar system, and other aspects of the physical sciences.

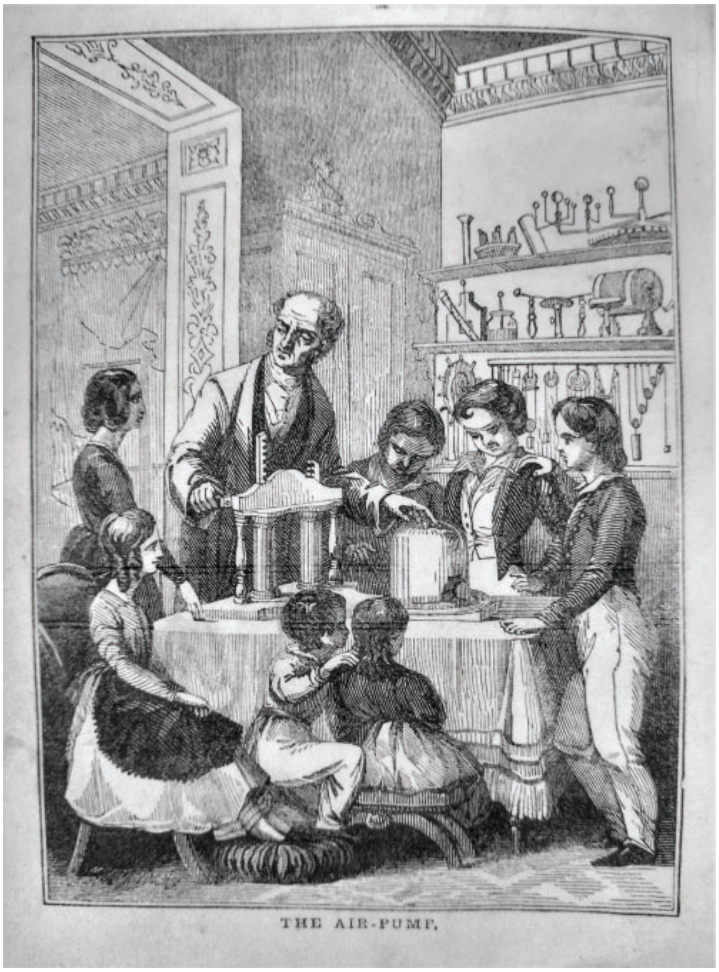

FIGURE 1. A FATHER demonstrates an air pump to his family in the parlor. Other natural philosophical apparatus sit arrayed on shelves in the background. Parlors were often sites of scientific demonstrations, discussions, and early childhood education. (From R. G. Parker, *First Lessons in Natural Philosophy. Designed to Teach the Elements of the Science. Abridged from the Compendium of School Philosophy*, A. S. Barnes & Co, 1848, frontispiece. From the author's collection.)

By the 1820s and 1830s, science curricula were expanding even further. Hartford Female Seminary in Connecticut, at its opening in 1823, offered geography, natural philosophy, chemistry, arithmetic, algebra, and geometry.[2] As Nash discovered in a study of 91 academies, the number offering courses in algebra increased from just 19% in the 1820s to 67% in the 1830s. Moreover, by the 1830s, 72% of academies offered botany, 77% offered chemistry, and 68% offered astronomy.[3] Science was well integrated into female education at the primary and secondary levels.

No science was more widely studied in schools for girls, however, than natural philosophy. Nash's survey showed that in both the 1820s and 1830s, 84% of academies offered natural philosophy. In addition, Tolley surveyed schools in North Carolina, Virginia, and some northern states, and she found that natural philosophy was the most widely offered scientific subject in girls' schools—more commonly taught than astronomy, chemistry, botany, minerology, or natural history. And girls were learning it well: As Tolley's comparison of competitive examinations at 19 Boston schools in 1845 revealed, not only were female students taking the natural philosophy examinations in greater numbers than male students, but they were also outscoring the boys.

Natural philosophy, at its heart, was the study of the laws of nature on Earth and in the universe. A course on the subject would have included lessons on mechanics, machines (as shown in figure 1), light, heat, rudimentary astronomy, and more. But the natural philosophy education of the early 1800s differed in many ways from the physics education of today. For instance, although instructors might perform scientific demonstrations—despite their smaller budgets, many women's academies invested in experimental equipment—students would not have participated in laboratory work themselves.[4] Laboratory education did not develop in the US until the late 19th century.[5] In addition, natural philosophy education at the primary and secondary school levels was largely conceptual. Although the diagrams in figure 2 might look familiar to a modern-day physics student, the numerical calculations would have been absent. The interweaving of mathematics into physics education developed over the 19th century and, as with laboratory education, took hold initially and most quickly at the collegiate level.

But perhaps the biggest difference is in the role of religion: Natural philosophy presented the physical world as evidence of the wonder and extent of God's creation. The link between natural philosophy and religion was part of a larger movement of natural theology, which gained popularity in the UK in the early 1700s and whose proponents argued that the mechanisms or design of nature attested to the presence of a creator. Natural theology was popular in the American colonies and in the US throughout the 18th century; for example, the noted theologian Jonathan Edwards supplemented his biblical study and prayer with study of the natural world. And during the Second Great Awakening, from 1795 to 1837, which saw a revival of many Protestant denominations in the US and a general increased fervor for religion, adherents also encouraged the study of the natural world.[2] Linker has argued that natural philosophy was perceived to boost intellectual and moral fortitude and stand as a bulwark against irreligion and superstition.[6]

It was in part through the moral and religious dimension that natural philosophy came to be closely associated with girls' education. For instance, in 1834 John Ludlow, a clergyman and theologian, declared at the opening of a new female academy in Albany, "The analysis of science and revealed religion will ultimately terminate in the same point. That point, if point it may be called, is the invisible God. He is at the foundation of both. Hence, whether you study science or revelation, it is only perusing different pages in the same great Book, which the Creator has spread out before his intelligent creatures."[7]

A useful education

A look at some of the educational material of the time shows how natural philosophy was taught and why it was such a prevalent subject in girls' schooling. Some commonly used

books include *Conversations on Natural Philosophy, in Which the Elements of That Science Are Familiarly Explained* by Jane Marcet (1826), Richard Parker's *First Lessons in Natural Philosophy, Designed to Teach the Elements of the Science* (1848) and *Juvenile Philosophy: or, Philosophy in Familiar Conversations; Designed to Teach Young Children to Think* (1851), and Mary Swift's *First Lessons on Natural Philosophy, for Children* (3rd edition, 1839). Swift, who served as the second principal of the Litchfield Female Seminary in Connecticut, wrote two primers on natural philosophy constructed as question-and-answer dialogs between children and their parents. Box 1 shows how Swift embedded moral and religious lessons into the scientific discussion: A discourse on prisms, the nature of light, and rainbows turns seamlessly to the biblical story of Noah.

Although Swift's and Parker's books were written for younger children, Swift would certainly have embedded the same moral valences into her lessons for secondary-school-age students. The structure of books for younger children could also mimic the styles of religious education by using a catechism format: a question-and-answer oral dialog in which the student memorized the answers. For older students, Marcet's books took the form of a conversation between the sophisticated and knowledgeable Mrs. B. and two young women named Emily and Caroline. Although Marcet intended her books for a general audience, they were frequently used as textbooks in secondary schools, and their conversational style was later imitated by such textbook authors as Mary Townsend and Elizabeth Cary Agassiz.[2]

Natural philosophy lessons were not only for female students—Swift's, Marcet's, and Parker's books were all directed at both boys and girls. But their social implications differed according to the student's gender, as figure 3 illustrates. At men's colleges, in which a classical curriculum was a marker of higher-class education, science was perceived as having a vocational or lower-class nature. At women's academies, in contrast, science education was more commonly the mark of an upper-class education.[2] Even the same material taught in the same institution would be put to different purposes by male and female students. For example, according to an instructor at the Litchfield Academy, which at that time was coeducational, astronomy was taught to male students for the practical skill of navigation. For female students, the same content was used to display "the wonders of God's universe."[8]

To truly understand the time period, however, we must reject the modern bias that assumes that the male students received a useful science education and the female students an ephemeral one. As Linker has argued, ideas of what made an education "useful" were not the same in the 18th and 19th centuries as they are today.[6] Lessons might be considered useful not just for their applications to practical or vocational labor—or to daily life, as shown in box 2—but also for reasons of culture or ideology. Textbook authors such as Marcet and Almira Hart Lincoln Phelps justified women and girls' education in chemistry, for instance, because it had both domestic and religious uses: cooking, cleaning, and appreciating God's creation. Such reasoning supported a scientific education that far exceeded the minimum necessary for domestic or religious needs alone.[9]

Even so-called ornamental subjects, such as sewing, dancing, and drawing, were often closely intertwined with academic subjects.[10] Consider the importance of illustration in botany, especially in the days before photography. In another example, geography was often taught through embroidery of maps. Geography was touted as encouraging the mental discipline of women and girls, and it was also a convenient way to instill nationalism by depicting the successful expansion of the young country.[11] Natural philosophy education was justified through all the knowledge it taught about the universe: the religious and ethical dimensions as well as the practical.

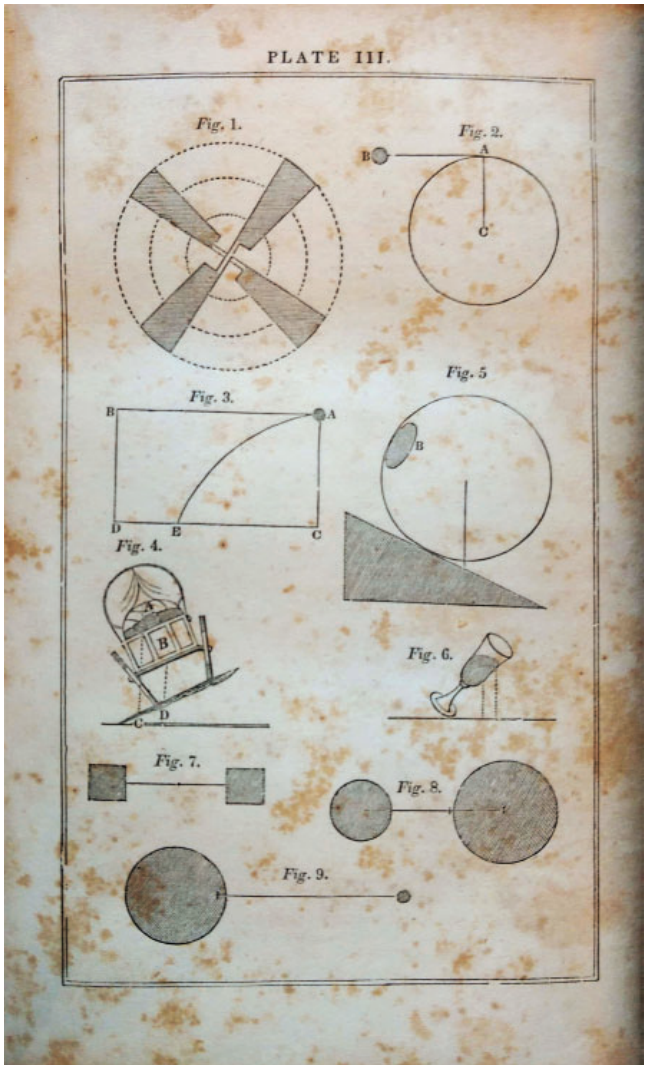

FIGURE 2. ALTHOUGH INSTRUCTION was largely qualitative, Jane Marcet's book on natural philosophy contained many diagrams recognizable to physics students and teachers today. The figures here come from the chapter on compound motion and determining an object's center of mass. (From J. H. Marcet, *Conversations on Natural Philosophy in Which the Elements of That Science Are Familiarly Explained*, Lippincott, Grambo & Co, 1852, plate 3. Courtesy of the Niels Bohr Library and Archives.)

Wives, mothers, teachers

Women had a special role in upholding and transmitting values because they were responsible for early childhood education. Before children even attended a primary school, they often received their first schooling at home from their mother

Box 1. Rainbow connection

A father points out a rainbow to his assembled children. The rainbow, like many other natural phenomena, was used to make a direct connection to faith in the divine. The accompanying text reads in part:

Do you ever see a rainbow when it rains, unless the Sun shines bright?

I do not.

Then what two things are necessary to make a rainbow?

A bright *sunshine* and a *shower*.

Why is the rainbow so beautiful?

It has beautiful bright colors, a splendid arch, and when we see it we remember the promise which God made to Noah, that he would not drown the world again.

Why does the RAINBOW make you think of that promise?

Because God said that the bow in the cloud should be a sign that he would never drown the world again.

Then when we see the rainbow, is it not as if God was speaking that promise to us?

It is; and it should make us very happy, and grateful to our heavenly Father for such kindness to us, whenever we look at the rainbow in the cloud.

(Image from M. A. Swift, *First Lessons on Natural Philosophy, for Children. In Two Parts. Part First*, new ed., Brown & Gross, 1884, p. 43. Courtesy of the Niels Bohr Library and Archives.)

or a female relative. For many poor students, that might be all the education they got, especially prior to the haphazard development of "common"—what we would now call public—schools.[12]

After 1820 dramatic socioeconomic changes in the US reinforced the need for moral education. Westward expansion, increased suffrage, and migration to cities all called into question the strength of traditional systems of social order.[13] Education, through both the family and the rapidly expanding system of formal schools, helped inculcate social norms and prepare children for the increasingly likely prospect of moving away from the community of their birth. As more male heads of households worked away from home, mothers took on an even greater role as intellectual and moral educators. A growing preference for female schoolteachers reflected the idea of the mother as the greatest moral example and influence.

The historian Linda Kerber coined the term "Republican Motherhood" to explain the sentiments of the day. The ideal Republican Mother was a woman who integrated political and domestic values for the purpose of upholding the fledgling republic. She instilled values in her children, kept her husband on the straight and narrow path, and thereby had her role in directing the young country's growth. In fact, the figure of the Republican Mother was used by reformers to justify the expansion of education for women in the decades after US independence. Enlightenment beliefs and the practical necessity of certain kinds of knowledge also contributed significantly to the growth of women's educational opportunities in the 18th and 19th centuries.[14]

But the notion of Republican Motherhood applied specifically to white women, and it argued only for white women's education. Not surprisingly then, white female seminaries, including those in the northern states, largely barred Black women from attending despite decades of activism by Black male and female advocates. One exception was the Young Ladies Domestic Seminary in Clinton, New York, a majority-white female seminary run by a white abolitionist and one of the first racially integrated female seminaries in the North. Black women who attended private seminaries usually went to coeducational institutions run by white abolitionists, such as the Oberlin Collegiate Institute (later Oberlin College) in Ohio.[15]

Only a few Black female seminaries existed; most African American–run schools were coeducational because of a belief in joined education or pragmatism about cost. One of the rare seminaries geared towards Black women and girls was Sarah Mapps Douglass's school in Philadelphia, which placed a strong emphasis on science education. Douglass's seminary was eventually absorbed into the Institute for Colored Youth in the 1850s, where Edward Bouchet, the first African American to earn a PhD in physics, would also go on to teach.[6,16]

Even though the ideal of Republican Motherhood doesn't fit exactly with African American women and children, the historian Kabria Baumgartner has shown that character education for citizenship was also an important part of African American education in the early 19th century. In particular, many African American women advocated an ideology of Christian domesticity, in which women were considered uniquely qualified to provide a moral and educational authority from their domestic domain. Although white female education advocates such as Catherine Beecher supported the same ideology, among

African American women, Christian domesticity could be an empowering tool of community uplift.[15]

Changing times

Women's role as the first teachers of children continued to justify the teaching of physics to girls well into the late 19th century. In an 1887 address to the American Association for the Advancement of Science, the physicist William Anthony said:

> Not only boys but girls should receive [physical science] training in order that the great truths of nature may become the heritage of future generations and be taught to the child from his earliest infancy. . . . I have in mind now a little boy of five years whom I have met this summer, whose father has a mill and machinery in operation, and whose mother is one of those rare women, gifted with a natural insight into physical laws. Partly by being about the mill, but mainly by his mother's teaching, this boy has learned. . . .[17]

FIGURE 3. A NATURAL PHILOSOPHY education had different meanings for boys and girls. Rollo, the fictional main character in a series of popular educational books for children, is helped in his natural philosophy investigations by his knowledgeable mother and sister. But Rollo applies his learning, such as the use of wedges and other simple machines, in industrial applications as modeled by his father and male workmen. (From J. Abbott, *Rollo's Experiments*, Hogan & Thompson, 1841, p. 61. Courtesy of the Niels Bohr Library and Archives.)

But change was afoot. At the dawn of the 20th century, more than half of secondary-school physics students were female, but by 1950 only 20–30% were. As part of a shifting landscape in industry and higher education, many schools stopped requiring physics classes for graduation, and physics began to be perceived increasingly as a masculinized subject.[18]

Many reasons underlie that shift, including changes in wider cultural norms and the professionalization of science—but some have direct roots in secondary schools and colleges. First, over the 19th century, more and more colleges opened their doors to women, and more women pursued postsecondary education. The hallmark of a prestigious college education was a curriculum in the classics, so colleges for women increasingly adopted classics requirements to boost their status, and secondary schools added classes in the classics to stay with the trend. Some schools even encouraged girls to drop science classes in favor of studying Latin or Greek. Thus, even as science classes came to be dominated by boys, the humanities were experiencing the opposite trend. The primacy of classical study in college education has since waned, but the effect of its earlier importance is still felt.[2]

Second, as state governments passed education mandates in the early 20th century, more working-class children attended secondary school than ever before. Many states and schools then restructured their curricula to be more relevant to the working-class students who would presumably never attend college or need to know anything esoterically intellectual. Female students were directed toward classes in typing and home economics—and away from subjects less immediately useful, like physics.

The process of tailoring education to the needs of students was also shaped by the larger and ever-prevalent discussion of

Box 2. Sweet and salty

A girl sprinkles salt in the background as a boy slips on an icy walk. The accompanying question-and-answer dialog touched on the practical connections of natural philosophical knowledge to daily life:

> *What would happen to us if there were no friction?*
> We could not walk a step before we should begin to slip along very fast, and could not easily stop ourselves.
> *How do people increase the friction when the walks are covered with ice?*
> They throw sand, or ashes, or something rough, upon them.

(Image from M. A. Swift, *First Lessons on Natural Philosophy, for Children. In Two Parts. Part Second*, new ed., William J. Hamersley, 1867, p. 83. From the author's collection.)

gender differences. Educators and school administrators feared that female students might be masculinized by scientific study—which by then was fully divorced from religion and sentiment; physics was now physics, not natural philosophy. If girls were to get a scientific education, they thought, better that it be in the domestic science of home economics. Some female scientists even used domestic science as a career strategy. At the collegiate level and above, home economics was often a way for women to work in the sciences on appropriately feminine topics of study (see the article by Joanna Behrman, PHYSICS TODAY, May 2018, page 50). At the secondary school level, however, home economics classes were largely aimed at preparing girls—particularly working-class and African American girls—for their presumed future careers as domestic laborers, wives, and mothers, not scientists.

How can the present be so different from the past? We're no strangers to rapid cultural change in other areas—fashions in clothing, for instance, change extremely quickly. But ideas about who is good at or interested in science feel much more permanent. Even deliberate efforts to make physics classrooms more inclusive struggle against the stereotype that girls don't really belong or want to be there. How instructive it is, then, to think about a time when gendered expectations in science education were the opposite of what they are today. It goes to show how impermanent culture really is, and how much it depends on the context of time and place.

And if culture can change over time, let us undertake the effort to change it for the better.

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