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Physics First, Especially for Girls

Susan B. Lovell

Science Department Chair, Miss Hall's School

Where are the women in science professions? Where are the engineers, the astronomers, and the astronauts? Why do girls, who often dominate science in elementary school, tend to disappear from upper-level science classes in junior and senior years of high school? Girls' participation in physics and computer science peaked twenty years ago and has been declining ever since, despite increased opportunity available due to changes in culture. Something is driving girls away. A look at changes in science education and the specific needs of girls might tell us what.

The High School Science Sequence: Ripe for Change

The standard sequence in high school science of biology in ninth grade, chemistry in tenth, and physics in eleventh used to work well for students. Up until the 1980's, high school biology consisted mainly of studying the visual structures of cells, classifying plants and animals, and learning about human systems and ecology. Depending on the school system, evolution may or may not have been included. There were only two kingdoms; most genetics was based on Mendel, not Watson and Crick; and no one knew what a transposon was except 1983 Nobel Prize Winner, Barbara McClintock. Biology was concrete, touchable, and visual. At the same time, in many school systems, only two years of science were required, and students could choose to skip chemistry and physics altogether, taking geology or anatomy instead.

Biology is not what it used to be. Take a look at most typical high school biology books, and you will see the change for yourself. Classification is crammed into a few chapters in the middle of the book. Early chapters focus on inorganic and organic chemistry. Next come the chapters on the physics of cells, how they are arranged, how they are organized, and how they move. Chapters on the biochemistry of cell membranes and how nutrients and waste pass through them are followed by units on cell thermodynamics, including cell respiration and photosynthesis. By December break students are covering protein synthesis and DNA replication.

There has been an explosion in our knowledge of genetics and physiology at the molecular level. All of these concepts are required knowledge for today's global citizens, where increasingly personal concerns about health, the environment and politics are biochemical in nature. Regardless of the disposition of students when they arrive in high school, however, the current needs of a biology curriculum make it an inappropriate first course. Without chemistry as a prerequisite, too many important and relevant biology topics become incomprehensible or are dropped by biology teachers who didn't bargain for having to teach chemistry concurrently. So let's move chemistry in front of biology, bringing these two courses into better alignment.

What about physics? High school physics can be taught at a variety of levels. Kinematics, the study of motion, is always covered. The laws that we use to understand our everyday world were described by Sir Isaac Newton in the 1600's. We teach kinematics to students now, just as we did in the 1960's and 1970's, and, indeed, as we did in the 1800's. Although Newton also had a hand in the creation of calculus, physics at the high school level does not require it; in fact, for many students it makes more sense when taught at an algebra level. Throw in a little trigonometry and the basic physics concepts that we see and use on a daily basis are covered. So let's move physics to the ninth grade. Students who are interested in more advanced concepts can continue their study of physics in Advanced Placement courses, senior electives, or college courses.

Let's move chemistry in front of biology. Let's move physics to the ninth grade.

Boys and Girls Learn Science Differently

Physics in the ninth grade makes particularly good sense for girls. What? Physics as a best first course for girls? Surely a look into most high school physics classes at coed schools will show that boys outnumber girls. Furthermore, girls are entering careers that require physics, for example engineering, at disproportionately low numbers compared to boys. Before we jump to the conclusion that girls just aren't good at physics, let's take a step back and look at how the current system of biology first, followed by chemistry, is prescriptive for girls being underrepresented in physics and other upper-level sciences.

Boys and girls are different. Twenty years ago a professional educator might risk being burned at the stake for heresy for a statement like that. But scientific studies of girls and boys from infancy to college show it to be true. They learn differently. Their brains and senses function differently, and they attach different importance to the same stimuli. "The difference in what boys and girls can do is not large, but the difference in how they do it can be very large indeed." (Sax)

Eyesight is a good example of the physiological differences in girls and boys. Vision is the quickest, most useful path to the brain for humans. Scientific evidence has shown that the retinas of male and female primates are quite different. Male retinas show a much higher concentration of rods, or M cells, that send their information by a special pathway to the hippocampus, an area of the brain specialized for analysis of spatial relationships and object motion. Girls' eyes are dominated by cones, or P cells, that are specialized for analysis of texture and color. There is little overlap, as would be seen in traits that also differ in males and females, like height or muscle mass. Every step in each pathway, from the retina to the brain, is different in females and males. (Kaplan) Since the same areas of the brain are activated when people are visualizing something mentally as when they are actually looking at it, these differences are important even in imagination. Girls and boys don't only see the world differently from a philosophical viewpoint, they also see it differently from a physiological viewpoint.

Newborn girls, when given a choice between looking at a human face or a moving mobile, will twice as often choose the face. Newborn boys are just the opposite.

Once the input from the senses reaches the brain, the path the data takes is again very different in boys and girls. Boys' brains are very compartmentalized. When performing a specific task, they use just the part of the brain that is designed for that task; verbal and language on the left, visual/spatial on the right. There is little contact or input from the amygdala, the part of the brain that attaches emotion to experiences. Girls, on the other hand, have brains that are less specialized and more collaborative. Girls' brains collect data in the same areas as boys, but all the information, along with input from the emotional sensors in the amygdala,

is then passed along to the cerebral cortex for "discussion." Girls' brains analyze the risks to themselves and to other people and attach a social and emotional importance to each task. In fact, if girls cannot find a social or emotional reason to process the incoming data, they tend to lose interest. (Gur)

These differences have, in the past, been attributed either to socialization or to the effect of sex hormones. Different camps have used their theories to prove that girls and boys are either exactly the same until society imposes gender on them or to suggest that gender-related characteristics limit both girls and boys in what they can accomplish. But these differences in boys and girls brains are clearly not totally due to socialization. They can be seen in babies less than a day old. Newborn baby girls, when given a choice between looking at a human face or a moving mobile, will twice as often choose the face. Newborn boys are just the opposite, choosing the moving mobile two-to-one over the face. (Connellan) These differences are also not based simply on sex hormones. Research has shown that many areas of the male brain contain proteins that are coded for only on the Y chromosome. These proteins are missing in female subjects, who show instead high concentrations of proteins that are coded for on the X chromosome. These particular proteins are missing in the brain tissue of males, even though all male cells contain an X chromosome. (Vawter)

Sex differences in the brains of children are larger than sex differences in the brains of adults, making this an issue of particular importance to education. While the areas of the brain involved in language and fine motor skills mature about six years earlier in girls than in boys, the areas of the brain involved in mechanical reasoning, visual targeting, and spatial reasoning mature about four to eight years later in girls than in boys. (Hanlon) Boys do not use the cortex during these spatial tasks. They use the hippocampus, a primitive area of the brain that is set up for spatial navigation. "The hippocampus has no direct connections to the cerebral cortex and is pre-wired to function as a dedicated microprocessor for spatial geometry, at least in males." (Gron) Why would a man ask for directions? He isn't using the thinking, communicating part of the brain to get from one place to the next! Girls use the cerebral cortex when they are visualizing objects, locations, and motion in space. They use input from multiple sources and take the time to consider all possibilities. The cerebral cortex needs to practice these skills before it can use them effectively. And practice does help. Re-

search in the UK has shown that there is an increase in spatial visualization test scores in girls when training is given in half-hour sessions over a period of weeks. (Jones)

Why Girls Lose Interest in Science

What does this have to do with teaching physics first to girls? Visual targeting and spatial reasoning skills are vital to success in chemistry and biology. Most of this material relies heavily on the ability to imagine structures, motions, and relationships that are sub-microscopic. The mental manipulation of cells and molecules require skills that many ninth-grade girls have not been trained to perform. Several things happen when a child is asked to use a skill for which her/his brain is not yet ready. First, the child struggles, then fails, and eventually, quits. (Sax) Forever after, unless there is intervention, the child is convinced that she/he is "no good" at that task. She/he doesn't like it. She/he starts any new similar task with a negative mindset that almost ensures defeat. Ask the average two-year-old to follow a three-part set of instructions and you will see this in action. The child may be able to complete the first task, perhaps a simple request to go get her/his shoes, but by the time the child has done it, she/he has no memory of being asked to also bring you a coat and find your keys. If a caregiver insists that the child remember and perform these tasks, a tantrum will certainly ensue.

The problem does not show itself in elementary school, where girls often excel at science.

Toddlers can't hold three thoughts, and we would not expect them to. Why then do we expect girls, all girls, to learn and thrive within a high school science curriculum that plays to the strength of boys? The problem does not show itself in elementary school, where girls often excel at science. Science taught in elementary school—with its focus on plants, animals, the human body, balancing and weighing, sound, food science, etc.—is concrete, visual, and relevant. (National Science Resources Center: Science and Technology Concepts for Elementary Schools.) Working in groups and coming to a consensus favors the way girls learn. Objects can be manipulated by hand and content has emotional significance. While many of the boys are getting remedial help with reading and language, the girls are shining in all areas. Ironically, research shows that girls

in the eight-to-ten-year-old range benefit the most from an intervention with spatial visualization training. (Jones) It is the rare school or district that provides this to girls.

The middle school science curriculum becomes more challenging for girls, with such topics as properties of matter, energy, motion and machines, light, space, electrical energy and circuit design. (National Science Resources Center: Science and Technology Concepts for Middle Schools). These concepts require a stronger ability to manipulate objects in the mind, to imagine electrons flowing and waves vibrating through space, to put together puzzles of electrical wires and resistors, and to draw conclusions about the motion of objects. Here, even a mild difference in the ability of boys and girls to conceptualize visual and spatial models becomes much more of a problem. Like a toddler being asked to perform a multiple set of instructions, frustration can set in, and a girl can give way to boys and become the data recorder of the group. The way this material is presented may have little emotional connection for girls, completing the impediment to success. Middle school girls too often come to see themselves as "no good" at science.

Of course many girls escape this trap. They are the lucky ones who are gifted with better spatial visualization than average. Or perhaps their parents, teachers or other caregivers encouraged and empowered them, in small successful ways, to develop spatial abilities while young by providing access and support in the manipulation of three dimensional puzzles, video games with emotional content, trucks and tractors, dolls, (perhaps even dolls riding in trucks!), Lego blocks, and toys with moving parts, etc. Single-player action video games have also been shown to erase the gender difference in spatial visualization. (Feng) Still other girls who did not have these advantages step up to the challenge in middle school, tackling the difficulty, struggling with science more than they are used to, and encouraging the more rapid maturation of their own brains to become better at spatial visualization.

A Physics-First Program

Ninth-grade girls, therefore, come into high school with a variety of skills, including their ability, or lack thereof, to visualize mentally and manipulate objects in three dimensions, skills crucial to success in chemistry and biology. Furthermore, many girls have already decided, from middle

school experiences, that they are "no good" at science. Throwing them into biology or chemistry as ninth graders is not going to improve their feelings of competency. For girls who have struggled with science in middle school, this is the final straw. There is little chance that any science course in the future will change their minds. They are less likely to continue science after their required two years and much less likely to take physics as juniors or seniors.

Ninth-grade girls need a high school course in which they can be successful, a course that is relevant to their lives, and a course that can be organized around developing their spatial visualization skills. An introduction to physics in the ninth grade is a perfect solution. Physics can be taught in such a way that it plays to the strengths of girls. It is a science of stories that are relevant to their lives: e.g., cars accelerating, softballs on a trajectory, rainbows, pillow fights, eyeglasses and cameras, hair dryers, and iPods. It is also a course that works best when students are working and collaborating in groups of three or four—one or two to work data collection, one to start the object moving, one to grab it at the end. Physics is also a link between the visual world and one that needs to be manipulated mentally in order to be "seen." It is a visual, hands-on science, particularly when studying kinematics; yet, by their very nature, these are concepts about objects in motion. Students in physics are asked to visualize what will happen and to discuss the probable motion of an object, and then they see it happen right before their eyes. Add some training specific to the development of spatial visualization skills, and girls can find themselves in a much more favorable position to start chemistry as tenth graders.

Physics can be taught in such a way that it plays to the strengths of girls.

I have seen a physics-first program work for individual girls. Ari came to my ninth-grade class with a mixed set of skills. She excelled in English, history, language and music. She had loved science until seventh grade, when a physical science-based curriculum taught in an uninspiring way rocked her self-esteem. Ari also had some clear issues with imagining motion and position. I recall one day showing her how to attach two pieces of paper without a staple by folding the corner and then tearing a tab in the center of the fold and bending it the other way. She was fascinated by the procedure and spent a long time folding and unfolding it to see how it

worked. Ari also had trouble understanding how it was possible that shuttle astronauts are not weightless at all and only appear that way because they are in freefall. She struggled with the idea that the north pole of Earth was actually the magnetic south pole. All of these concepts require students to mentally imagine and manipulate moving objects in their heads and learn from that process. The physics curriculum we use worked for Ari. It is totally activity based and requires an initial discussion among students that allows them to collaborate to visualize what they think will happen. This not only exposes misconceptions but allows rehearsal in those skills that girls often need to practice. By the end of the year, Ari was leading the discussions, had improved her ability to predict the outcome of motion experiments and, even more important, loved science. Ari will go into Honors Chemistry in the fall.

Physics first also works for groups of girls. Fifteen years worth of transcripts (1995-2009) were reviewed to reveal the following data: of those students who took biology first before the new program was initiated, only 24% graduated with a physics course on their transcript and only 43% took more than the required three years of science. Of the students who took an introductory physics course in ninth grade, 100% had a physics course on their transcript (naturally, it was required), but even more significantly, 27% went on to take the advanced physics course and 74% took four years of science. The number of girls staying in science past the required three years showed a dramatic increase, from 43% to 74%. Only those girls who had spent the entire four years at Miss Hall's School were counted in the study. Although other factors must also be considered in this increase, the physics-first curriculum has had a strong influence in this change.

Our global community needs the voices of women in science. We need scientists who attach emotional and social significance to new technologies and who can work in collaborative ways with other scientists both in the lab and all over the world. Let's keep our girls in the science classroom and get them into science careers by teaching to their strengths and supporting their differences. Physics first. Especially for girls.

Susan B. Lovell is the Science Department Chair at Miss Hall's School, a school for girls in grades 9 - 12, in Pittsfield, Massachusetts.

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