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Advancing Girls in the Science Classroom

Justin LaManna, PhD

Data recently summarized in the *Status of Girls in Wisconsin* report shows that girls and boys in Wisconsin schools perform similarly with respect to science achievement in lower grades.[1] **The majority of girls and boys in the 4th grade in Wisconsin were assessed as being proficient in science in 2014**, when looking at their scores on the Wisconsin Knowledge and Concepts Examination (WKCE) exam.[1] The WKCE science exam ranks students based on their performance as either minimal, basic, proficient, or advanced. **However, by the 8th and 10th grades a higher proportion of boys compared to girls tested at an advanced level in science.** In fact, the greatest proportion of boys (43.4%) by the 10th grade were at the advanced level while the majority of girls were about evenly distributed between proficient (36.1%) and advanced (36.3%).[22] We see a similar trend when looking at mathematics in Wisconsin with the only difference in that both boys and girls perform slightly worse in mathematics compared to science, but we still see the disparities arise (see 2014 *Status of Girls in Wisconsin* report for specifics).

By the 10th grade, **43.4% of boys were at the advanced level in science,** whereas **girls were about evenly distributed between proficient (36.1%) and advanced (36.3%).**

Seeing changes in girls' attitudes toward science by the 8th grade (age 13) is nothing new, and not unique to Wisconsin. Numerous studies have documented a low interest or indifference to science in many girls by the 7th and 8th grades in the United States.[10,4] Many researchers have attempted to elucidate the reasons for this waning interest in science around the ages of 13 and 14, but no single answer seems to prevail. One explanation that appears to have more support than others is that girls with an aptitude for science seem to give up more easily than boys with the same aptitude.[4] This low level of confidence in their abilities might stem from society's expectations or the belief by the girls that either they are born to be good at science and mathematics or they are not. **While boys often believe they can become good at something through practice, girls often think skills are innate so, if they fail, they stop trying.**[4] The differences in mindset between girls and boys could stem from how we praise good behavior in girls, but often give boys feedback about how they can become better if they just "do this or that."[4] Additional research is needed in this area to see if even the most subtle of behaviors like how we speak with girls vs. boys is altering their career paths.

However, we are still faced with the fact that the recruitment and retention of women in the sciences is a priority for the United States now. If the United States wants to remain competitive in the rapidly growing global economy we must access intelligence and creativity from both women and men in the sciences. The National Science Foundation (NSF) has funded many programs in hopes of achieving this goal. For instance, in 2011 NSF in collaboration with the White House Council on Women and Girls and the White House Office of Science and Technology started the NSF Career-Life Balance Initiative. This program is a 10-year initiative to bring about more flexibility when it comes to researchers fulfilling their obligations within grant awards, such as being able to take time off for maternity leave without the risk of losing their awarded funds.[20]

IF THE UNITED STATES WANTS TO REMAIN COMPETITIVE IN THE RAPIDLY GROWING GLOBAL ECONOMY WE MUST ACCESS INTELLIGENCE AND CREATIVITY FROM BOTH WOMEN AND MEN IN THE SCIENCES.

It remains clear that we not only need to focus on women, but equally on girls in hopes of encouraging students early on to see science as a potential career choice. **When females become engaged with science younger they might be more likely to take science related AP classes in high school that could better prepare them for an undergraduate and ultimately graduate degree in the sciences.**

Currently we see good enrollment of women in undergraduate programs in the life sciences like biology and psychology. According to the National Science Foundation, about half of science and engineering (S&E) undergraduate degree seekers since the late 1990's have been women.[12] However, when looking at the specific disciplines in science, women tend to choose degrees in psychology, biosciences, and social sciences and few choose the physical sciences. For instance, looking across the different degree levels in physics from undergraduate to doctorate degrees, only 20% of these are being awarded to women.[12] This is discouraging since we need diversity in areas like chemistry, physics, and space science to develop new technologies and remain competitive in global markets. We can speculate as to why women avoid areas like the physical sciences and engineering, but we really need to start with why girls lose interest in the sciences when they approach the 8th grade. **What happens both socially and academically that changes the amount of interest girls demonstrate for the sciences, especially the physical sciences like chemistry and physics?** This paper will not focus on the social aspects, but believe this is an integral part of the solution and hope that other institutions and researchers will make recommendations based on behavioral data of girls approaching the 8th grade. We need solid recommendations about what can be done to make social aspects complement and enhance girls' willingness to engage in the sciences.

My recommendations will focus on academic strategies that can be implemented to excite and excel girls in the science classroom. **I believe changes in how we teach science is one of the key components necessary for girls to continue on a path in which they see science as a useful and necessary tool for their everyday lives and possibly as a career choice.**

Only 20% of degrees in physics are being awarded to women.

The recommendations below come from the cumulative knowledge gained by reviewing literature published on strategies to encourage girls in the sciences, curriculum from successful after school programs in science, and ability based curriculums like that developed at Alverno College in Milwaukee, Wisconsin. **These recommendations are predominately for girls in grades 7th–12th, but could be beneficial for younger girls and boys as well.**

1. USE INTERDISCIPLINARY SCIENCE INVESTIGATION

Interdisciplinary and integrated sciences are a great way to show students the connections that exist between the science disciplines. **Researchers have found that women scientists often use an interdisciplinary approach to problem solving and their research frequently integrates more than one discipline.**[16] [15] It seems reasonable that all students would benefit by this approach, but this might be especially appealing to girls by allowing them to see how science in the real world is a combination of disciplines like chemistry, biology, physics, and so on. At Alverno College we have developed The Girls' Academy of Science and Mathematics, which is a Friday evening program for high school girls in their junior year that integrates biology, chemistry, and mathematics. Each student is initially assigned to one of three courses: biology, chemistry, or mathematics, and after one semester switches into a new course. After a year in the program each student will have completed two of the three courses. In the last six weeks of the program girls from all three courses are combined into new groups of three students, one from each course, and they work together on a combined research project. For example, one year they had to develop, create, and test a skin moisturizer using information they learned in courses taken throughout the year. Students in The Girls' Academy have consistently praised the program and attend voluntarily without any special incentives or rewards. The Next Generation Science Standards collaboratively developed through The National Research Council, the National Science Teachers Association, the American Association for the Advancement of Science, and Achieve emphasize the importance of an interdisciplinary and integrated approach to encourage learning in primary and secondary education.[13] Below are two examples of how we have used an interdisciplinary approach to science in the Girls' Academy of Science and Mathematics at Alverno College and such approaches could be easily adaptable to any science classroom.

+ In the Girls' Academy biology course students design a small experiment in which they test the effects of exercise on blood pressure. Students learn to measure each other's blood pressure using a stethoscope and sphygmomanometer. This initially integrates physics and biology, but in the end combines physics, biology, and mathematics because stu-

dents use basic inferential statistics (t-test) to see if the change in blood pressure is statistically significant. We make students aware of this integration which helps students see how many areas of science work together to achieve outcomes.

+ In one exercise in the Girls' Academy mathematics course, students combine basic descriptive statistics with investigating the idea of human symmetry and beauty. One group of students ranks images of humans from least beautiful to most beautiful. Then a different group calculates the degree of facial symmetry for each photo without knowing the other group's ranking. Students then graph the photo's symmetry score against the photo's beauty ranking to look for a correlation. This activity allows for integrating mathematics and biology into a hands-on activity (see benefit of hands-on activity in #3) that helps students see how the sciences are dependent on mathematics and how mathematics becomes less abstract when applied to achieve topic based outcomes (see #2 below).

2. IMPLEMENT A TOPIC BASED SCIENCE CURRICULUM

Topic based curriculums are an extension of the integrated science investigation described above. By topics based curriculum we mean a curriculum that is built around an idea or topic that students relate to and find exciting. This can help students feel more connected to the science by seeing its direct applications. **Studies have shown that one possible reason for women not choosing science as a career is a feeling of disconnect between themselves and the subject matter.**[17] Many science classrooms often emphasize being as objective as possible, and this can result in students feeling less connected to the science, and sometimes less interested. **This can be overcome by using a topics based curriculum that allows students to see the direct connections between what they are learning in the classroom and the overall topic of focus, but still retain the objectivity needed to avoid biased observations and conclusions.** Below are two examples of a topics based curriculum. One is from the Girls' Academy of Science at Alverno College and the other is from a specific course at Alverno College, Science and Women (SC-112).

+ The Girls' Academy of Science and Mathematics has a topic based curriculum with the science of beauty being the overarching topic in each class. Students are excited by the program because they see how the science is directly related to a topic that many high school students care about, beauty. All lessons are tied to the topic and we make the connections explicit so that students can form sound relationships between the science and the topic of beauty. This uses a constructivist approach to learning. Constructivism is a theory of knowledge in which the student learns new information by

connecting it to previously learned knowledge.[14] In the biology class students investigate the structure of skin and what components are essential for maintaining a healthy dermis and protective epidermis. In the chemistry class students learn how moisturizers are used to give the epidermis a healthy appearance, what chemicals are used to create effective moisturizers, and how these chemicals work together as well as create a skin moisturizer in the laboratory.

+ Another example of a topic based curriculum can be found in Alverno's Science and Women course that is offered to non-science majors. This course is designed to give students a foundation in the biological sciences with an emphasis on the role of women in all aspects of science from research to choosing science as a career. The biological content is taught through use of human biology as the main topic. For example, when students learn about cellular communication and osmosis we use a gestational diabetes

case study to demonstrate how this basic biological concept, osmosis, can disrupt homeostasis in humans. The case study teaches students that excess sugar in the blood can promote water leaving cells via osmosis resulting in the high blood pressure, dehydration, tiredness, and excessive urination, which are seen during gestational diabetes. Students gain a new appreciation for a mechanism like osmosis that many of them have already heard about at some point in the past, but never knew how it could result in such signs and symptoms as those found in the case study.

3. EMPHASIZE HANDS-ON DISCOVERY BASED SCIENCE ACTIVITIES NOT ONLY HYPOTHESIS BASED SCIENCE

Students are taught early on in middle or even elementary school the appropriate methods for "doing" science. Students are usually first introduced to the discovery based approach to scientific investigation. Discovery based science is grounded in inductive reasoning and draws generalizations based on careful and detailed observations. This is often the type of scientific approach implemented in the elementary grades and experienced during science activities outside of class time when visiting zoos, aquariums, science museums, and parks. The second approach to doing science is the hypothesis based approach. Hypothesis based science utilizes the scientific method and is grounded in deductive reasoning where the logic flows from the general to the specific with the formation of hypotheses. This approach is often the one students associate with the main way of doing science and dominates most science classrooms from mid-

dle school on. Hypothesis based science is an extremely useful tool when trying to develop and test hypotheses for natural phenomenon and is at the core of most all science inquiry. However, it is only one way of approaching science and relies on using reductionism in the formation of the hypothesis. **Researchers have found that women in science are often motivated to investigate complex systems and use a less reductionist approach to solving problems and prefer a more integrated and holistic science.**[17] This is directly in agreement with the discovery based approach to doing science. In this approach students are encouraged to make detailed observations and ultimately describe and understand the nature of interactions to generate generalizations based on the data obtained during observations. In fact, many famous scientists like Jane Goodall spent years in the observational stage of discovery based science. In hypothesis based science we often fail to encourage students to stay in the observational stage of the scientific method. Many science classrooms and laboratories are more concerned with students generating sound and testable hypotheses and often neglect the early steps of the scientific method of making observations. **By encouraging girls to use both discovery and hypothesis based scientific approaches, we can advance those students who are excited by making detailed observations and we can help students understand the nature of interactions between variables in complex systems.** It seems to reason that if many women scientists use a more holistic approach to science and less reductionism, we would want to provide these opportunities to girls in schools as well.

4. DEVELOP SCIENTIFIC PROBLEM SOLVING AND ANALYSIS ABILITIES THROUGH INVESTIGATING REAL WORLD PROBLEMS

Strong problem solving and analysis abilities are essential characteristics for anyone wanting to pursue a career in the sciences. Numerous educators and institutions have emphasized the importance of students developing abilities as a major part of their learning experience. Alverno College developed its ability based curriculum in 1973 and it has been used as a model by many educators and institutions wanting to adopt ability based education (www.alverno.edu/academics/resourcesforeducatorsresearchers). As science educators we often teach students how to become problem solvers and analyzers through the use of laboratory exercises rich in scientific content as well as problem solving and analysis opportunities. For example, in many introductory biology laboratories students investigate the concept of osmosis and diffusion by using dialysis tubing placed into solutions with varying degrees of osmolarity. Students not only practice their problem solving and analysis abilities during these exercises, but they also are expected to learn the concepts of osmosis and diffusion as well as obtain an understanding of the function of dialysis tubing. The main problem with expecting students to develop problem solving and analysis abilities during these laboratory exercises is that students often do not feel a strong connection to the topic of osmosis and diffusion, especially with respect to dialysis tubing that many students have never seen before. A better approach to having students develop these abilities would be to use real world problems that students can connect with and these problems can be related to science or not. Since the abilities are transferable, the students will get more out of science laboratories when they can utilize abilities they have developed under more familiar contexts during their science laboratory exercises. Below is one example of how we utilized a real world problem to help high school students develop problem solving and analysis abilities in the Girls' Academy of Science and Mathematics at Alverno College.

+ During one of our first several meetings of the Girls' Academy we introduce students to a basic problem solving framework that was developed at Alverno College. Next, we have the students use this framework to solve a problem that is unrelated to science, but connected to something they already know and understand. This way they can focus on the ability and not feel any disconnect between themselves

and the exercise which could happen if too many unfamiliar variables are in place during introduction of a new topic. During our most recent year students had to design a way to close a bracelet with a spring-ring clasp while not looking. This problem came from a vision impaired student that commented on not being able to purchase many bracelets due to the traditional spring-ring clasp that is found on the bracelets. Students developed many different approaches, but most importantly they applied a problem solving framework (developed at Alverno College) and used this exercise to become better problem solvers by creating something that was actually used in the real world. Investigating real world problems also has the advantage of bringing the students closer to the ability and seeing how becoming better problem solvers and analyzers can be utilized to obtain applied outcomes.

5. REQUIRE GROUP WORK IN LABORATORY SETTINGS ESPECIALLY IN THE PHYSICAL SCIENCES

Social interaction ability is one of the essential abilities students develop during the undergraduate degree at Alverno College. The college saw as early as 1971 the importance of this ability in the development of a well-rounded person who was to become a vital and active member of the community. Social interaction abilities allow us to share information, experience new ideas, and collaborate as scientists. **Group work is an excellent way for students to feel a connection to the material and an increased motivation to learn through the shared experience of the group.**[5] **Research has shown that individuals experience less anxiety and have a more positive attitude toward a task if it is done in a group as compared to individually.**[19,9] Since many students find laboratory work to be intimidating, especially in areas like chemistry, group work would be an excellent way of reducing the anxiety students feel. Unfortunately, many of us have images of chemistry laboratory as an individualized effort in which you work tirelessly at your bench in hopes of obtaining the appropriate yield to pass the exercise. This approach to doing science is far from what researchers have found to be used by real women in science. **Women in the sciences often collaborate with others and find the social aspect of a scientific community to be intellectually stimulating and an essential part of science.**[15] We need to encourage group work in science laboratories to help students see that science is not a solitary endeavor as often painted by images of scientist working away in an empty laboratory at all hours of the night. Over ten years ago Alverno College redesigned many of its science laboratory spaces to have collaborative benches in which students work as a team of four students; they face each other to promote group interaction, the sharing of information, and the laboratory experience.

6. ENCOURAGE STUDENTS TO BUILD THEIR SCIENTIFIC KNOWLEDGE THROUGH SHARING OF INFORMATION

Studies dating back to the early 1980's revealed the vital role that social interactions played in the learning of girls and women.[6,3] The term "rapport talk" was coined by Deborah Tannen to define the type of learning commonly used in female dominated groups in which students share information from past education and personal experience.[18] In rapport talk students build a connected understanding of a topic through this sharing of information in a small group setting. Each student contributes knowledge to the discussion by adding to the conversation until the group reaches a combined understanding of the topic being discussed. Rapport talk provides the student with multiple chances to make connections between the new material and previous learned information. These connections are not only good for learning, but more than likely help reduce the distance between the student and the subject matter. This could be an excellent way to make students feel less disconnect between themselves and science, especially in areas like the physical sciences that have often been characterized as predominately "masculine" and have problems recruiting women.[2] The connections made during rapport talk mirror the approach that constructivist learning advocates when faced with new information or problems. **Many studies have shown that people learn best by**


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linking new information to what they already know and reflecting on their new understanding. Rapport talk not only gives students the chance to make these connections, but also allows them to see and reflect on the connections others are making and how these connections are useful to their learning as well. We traditionally do more what is defined as "report talk" in science. In report talk one person reports to a group and individuals in the group sit taking notes until the end and then are asked for questions. This is more common in male dominated groups and science has been a male dominated field for so long it makes sense that this is the way most of us have learned to communicate to others about our science.[6] However, if we want to encourage girls to feel more connected to science we should utilize more rapport talk and less reporting in the science classroom and laboratory.

7. PRACTICE WRITING SCIENCE REPORTS AND PAPERS IN FIRST PERSON

In the past most science papers and laboratory reports were written in third person. In fact, you can still find laboratory manuals today that require students to write all reports in the third person. Third person writing conveys a feeling of objectivity that is at the core of sound scientific research. Recently, many disciplines within science have abandoned this requirement and allow authors to submit manuscripts in first person. The life sciences have been allowing authors to write in first person for more than ten years. However, many chemistry and physics journals still require third person writing, but we are starting to see change. Most science is done collaboratively and first person allows authors to convey this and it is an easy way to make the authors feel more connected to the manuscript and ultimately to their research. We have talked a lot about this feeling of being connected to the science as one of the main ways of increasing the chances girls will see science as integral to their lives and as a possible career choice. First person writing is just one more way that educators can help students build these connections to science. This is a fairly straight forward strategy that could greatly benefit girls and ultimately science as well. First person articles and laboratory reports in science are not any less objective than the more traditional third person writing that has dominated for so long. In primary and secondary education the increased feelings of connectedness that comes along with first person writing in science probably outweighs the benefit of practicing third person writing by having students use this perspective in laboratory reports and papers.

8. COLLECT BOTH QUALITATIVE AND QUANTITATIVE DATA

When collecting data during science experiments we often go to great lengths, and expense, to collect quantitative data. Quantitative data are at the heart of scientific hypothesis testing and are obtained in a variety of forms from simple counts to more sophisticated measure like mass spectroscopy. Quantitative data are inherently objective and allow us to formulate unbiased conclusions. However, they can be limiting in that not all traits or attributes of a system can be measured. **If we want students to really understand complex systems like rainforests or cells we must embrace all forms of data, even the type we cannot directly measure and quantify.** Qualitative data fall into this type of data. Qualitative data can be subjective and therefore many scientists have trouble accepting these data as part of their research. However, we know the importance of subjective data just considering symptoms of diseases. Symptoms, unlike signs, cannot be measured and are often subjective based on the patient's own interpretation of their physiological and psychological states. We have all been faced with trying

to quantify a symptom in the past; just think about medical professionals asking you to rate your pain on a scale from 1 to 10. Research done on women scientists reveal that they accept things like symptoms as real data and include these in their analyses and conclusions.[16] This seems to fit well with the type of sharing of information mentioned above, rapport talk. **We need to encourage young students to see the importance of collecting both quantitative and qualitative data.** Students often need practice at collecting qualitative data since many of them do not have practice with these types of data. In many of our introductory laboratory and science courses at Alverno College, we provide students with the opportunity to develop their abilities of collecting qualitative data and give feedback on their progress. **Students need to be encouraged to think beyond what they can see and measure. Students often forget to record things like smell, texture, taste, and color.** Young students can be given simple things like candy to describe or flowers (where appropriate). They normally will start out with just a few observations, but when encouraged to return to their test subject and try again, they will get better at making these observations. Making detailed observations, both quantitative and qualitative is the first step in the analysis process. Once students get good at this they can move on to making inferences based on these observations and start to become more analytical, which will help them during their scientific pursuits. **If we want girls to feel more connected to science in hopes of an increased interest, we should encourage collecting as much data as possible during scientific investigations.** This will give them a more holistic view of the science and ultimately enable students to see the science with more clarity and connectedness.

9. EXPOSE STUDENTS TO CURRENT WOMEN IN SCIENCE AS ROLE MODELS

Role models have been shown to be an excellent way of getting students to see themselves in future career roles.[21] **Studies have shown that role models are particularly helpful at encouraging girls to form a positive connection with science.[8] If we want more women in science we should expose girls to women scientists so they form this connection between themselves and the career.** They will see others like them (female) in this role, and this could increase the chances that they would consider science as a potential career choice. Also, we believe it is important for girls to see living and everyday role models, not just biographies of famous women in science, especially non-living famous women scientists. At Alverno College in our Science and Women course, we have groups of students interview a current woman in science. Students consistently praise this assignment saying they never knew how much scientists are just like them and how

differently they view women in science after the interview. This is a straightforward lesson that could easily be added to any science course in middle or high school. Also, with the use of social media and tools like Skype™, students can interview a woman in science without ever leaving the school grounds. We found the interview assignment to be more impactful than having students research and create a biography poster or paper on a famous woman in science. According to their comments, they found the biography assignment useful for learning about a famous woman in science, but did not demonstrate an excitement for the scientist that is often displayed after the interview assignment. One criterion we have for the assignment states that each student in the group must ask at least one question during the interview and the interview must be live, either in person or using a tool like Skype™. The students can pick any woman they want who is currently in a science role like educator, college researcher, professional, or private industry. Having this flexibility allows students to choose a woman they feel is the best role model for them. For instance, if a group of students is composed predominately of students of color, we often see them interview a scientist who is in the same racial ethnic group as they are. **Women of color are the most under-represented group in science so any strategy that can increase their positive feelings toward science is critical for the science classroom.**

10. TALK ABOUT SCIENCE AS A CAREER AND NOT AN ALL-CONSUMING LIFESTYLE

The stereotype of science being a 7 day a week 24 hours a day lifestyle is often all too real. We see a leaky pipeline in science with women holding tenure track faculty positions feeling less supported by their institution than male faculty, some leave their careers to focus on family early on in the junior faculty timeframe.[7] This is a terrible loss of creativity, but college and

university tenure tracks often demand that scientists commit all of their time during their assistant professor stage to advancing their career. This leaves little time for starting a family; by the time women enter into tenure track positions, they are faced with the reality of choosing to start a family or focus on the all-consuming path towards tenure and promotion. The traditional demands and competition of the tenure track are more than likely a product of science being a male dominated field. In the past, males starting in tenure tracks relied on spouses at home to raise and care for children. However, women entering tenure track positions today more than likely do not have such a luxury as a spouse who can stay at home to care for children. The National Science Foundation has started the Career-Life Balance Initiative to allow women with NSF awards to post-pone their award during maternity leave and not risk losing the money.[11] This is new and in the past no such accommodations were available to women. However, we are far from making significant progress in the area of enabling women to have a science career as well as time for a family. **Colleges and universities need to make changes to their systems originally designed by males for males. Women should have access to on-campus day cares at affordable rates, flexibility to step out of tenure track time lines during maternity leave and resume on the same path when returning, and a normal work week with time off. We need to start on this path by changing how we see scientists, and this should start with children.** We should talk about science as a career choice and role model scientists as having a life outside of the classroom and laboratory. Hopefully the more we come to expect scientists to have a balance between work and outside life, the greater chances this could become a reality.

Increasing the number of women in the sciences is an ongoing pursuit that will more than likely take decades to accomplish. However, we need to start early with girls in middle and high school if we ever want to achieve this goal. If we only implement strategies at the college or career level we are needing to undo years of learned stereotypes and limited approaches to science. **We need to encourage girls at younger ages to see science as a potential career path and equip educators with strategies and tools that encourage girls instead of alienating them.** Science has been male dominated since the scientific revolution on the 17th century. We have developed our scientific curriculums and focus without considering girls and women as potential learners and researchers. Incorporating the strategies outlined in this paper is one way to broaden our vision of science and promote a more interactive and holistic science that everyone will enjoy.

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