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# An Initial Look at Robotics-based Initiatives to Engage Girls in Engineering

Jennifer Michaeli
*Old Dominion University*

Vukica Jovanovic
*Old Dominion University*, v2jovano@odu.edu

Otilia Popescu
*Old Dominion University*

Ana Djuric
*Wayne State University*

Ece Yaprak
*Wayne State University*



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# AN INITIAL LOOK AT ROBOTICS-BASED INITIATIVES TO ENGAGE GIRLS IN ENGINEERING

Jennifer G. Michaeli, Old Dominion University; Vukica Jovanovic, Old Dominion University;
Otilia Popescu, Old Dominion University; Ana Djuric, Wayne State University; Ece Yaprak, Wayne State University

## Abstract

Over the past 10 years, the use of robotic kits in K-12 Science, Technology, Engineering, and Math (STEM) initiatives as well as undergraduate engineering education has increased significantly. However, a survey of students in grades 9–12 indicated that only 2–3% of women in high school express an intention to study engineering; conversely, 16% of high school men declared that they plan to pursue an engineering degree [1]. In this paper, the authors present an initial review of published literature regarding the use of robotics in schools to identify cases where robotic kits have been used to engage girls in STEM learning and to discuss how robotics has been used or could be used to positively influence outcomes of girls' knowledge, interests, self-efficacy, and attitudes related to careers in engineering.

## Introduction

A survey of students receiving STEM degrees in the U.S. shows that the numbers of technical degrees awarded to women and underrepresented minorities do not accurately reflect U.S. demographics. Based on the U.S. Census of 2010, women account for 50% of the total population and the workforce; however, they represent only 26% of the Science, Technology, Engineering, and Math (STEM) workforce. The total percentage of undergraduate engineering degrees awarded to women was 17.5% in 2008, while the percentage of bachelor's degrees in engineering technology awarded to women in 2011 was 9.5%. Based on statistics from the U.S. Department of Labor, only 11% of Aerospace Engineers and less than 6% of Mechanical Engineers are women [2]. Recent studies have indicated that girls are participating equally in middle and high school studies in science, mathematics, and technology; however, the number of female graduates of engineering programs as well as the number of female engineers in the workforce are still low [3-5].

As reported by McCrea [6], the percentage of U.S. girls interested in STEM careers has not improved in comparison to statistics from 10 to 20 years ago. Furthermore, the number of middle-school-aged girls who reported an interest in STEM subject areas by the time they are graduating high school and entering college have drastically declined, indicating that even in the middle to high school years, female student retention in STEM is not being properly addressed. These are alarming trends and represent a complex problem that will have a dramatic impact on the U.S. workforce and economy.

## Factors Influencing Women in Engineering

Female high school students do not choose to pursue engineering as their career paths for various reasons, many of which are related to their perception of engineering [7]. One of the widespread perceptions is that engineering is viewed as a predominately male field [8]. Additionally, there is a perception that engineering has fewer opportunities for creative development [9]. A 2-year study of 403 students attending community college used a 28-item "perceived chilly climate scale" as a metric to assess the environment for learning and found that an environment that is perceived as "chilly" puts women at an educational disadvantage and many of them decide not to enroll or end up switching majors [10]. These perceptions have been documented in studies on females from elementary school through graduate studies and even through employment [5]. A study funded by the National Science Foundation (NSF) and conducted at the University of Wisconsin-Milwaukee in 2011 surveyed 3700 female engineers and reported that one-third responded that they did not enter engineering after graduation because of their perception of engineering being inflexible or the workplace culture being non-supportive of women [11]. Some researchers suggest that this perception of gender and STEM occurs very early on in life if parents treat their children differently according to their gender and with the choice of toys that children are exposed to for playtime [12].

Women who do pursue careers in STEM fields typically choose careers that have traditionally had higher concentrations of women, such as fields related to health, education, and the social and behavioral sciences [13]. This trend continues even though much higher salaries can be earned by pursuing careers in information technology and engineering. One reason for this seems to be that these fields are male-dominated and women who pursue these careers may be perceived as, or even perceive themselves as, more masculine [10]. Furthermore, women have reported that they do

not feel welcome in college majors and career fields that typically have higher concentrations of men, such as engineering and engineering technology. This relates to the need for a sense of community that is important to women [10]. An ethnographic study of engineering courses reported that women encountered negative behavior from male students [14], [15]. As a result, women may feel compelled to avoid college majors that are traditionally male-dominated in order to avoid these unwelcoming and negative attitudes.

Gender perceptions and masculinity are not the only obstacles to engaging female students to consider engineering careers. A study in 2005 regarding female student interest in pursuing electrical engineering suggests that the dominant factor for the female pupils when considering the academic field of study is not the masculine image of the profession, but rather the level of familiarity with the domain and actual interest in the field [16].

Another factor influencing our young women is the lack of female role models who encourage students to pursue STEM careers. McCrae points out the need for more female -led STEM groups that can attract more girls to technical careers and retain female students who express an interest in middle school but seem to fall off course in high school. McCrae [6] concludes that "an after-school math or science club that's headed up and championed by a female teacher, …, can go a long way in getting girls to consider STEM degrees and careers". He also points to the need to include more hands-on learning opportunities for students to understand how education connects to future careers. For example, robotics labs can help students identify with a career in engineering. Coupling hands-on learning with female-led initiatives could lead to the attraction and retention of girls in engineering careers.

# Methods to Engage Women in Engineering

Universities across the country have started programs such as Women in Engineering to focus on reaching out to high school female students. These programs have resulted in more women enrolled in engineering programs in regional areas [16-18]. These programs use different vehicles for recruitment such as newsletters, websites, face-to-face interaction with program leadership, youth expos, summer workshops [18], peer mentoring, scholarships, visits to schools, one-day conferences [16], and camps. The reason for these various outreach methods is that different women's groups do not respond the same way to any given recruiting method. Although high school students who have better knowledge about engineering were much more likely to report aspirations for studying engineering in college, there is still a gap when it comes to the girls having engineering college aspirations, even when moderated by recruitment [14].

According to White and Wasburn [5] various online recruiting materials have been developed specifically for female audiences and include showcasing successful women in STEM careers. More than two-thirds of online projects reviewed by White and Wasburn focused on technology to increase student engagement, and one-third included goals of career awareness or gender equity awareness. The researchers identified four factors that online activities should incorporate in order to successfully overcome gender-specific issues in career selections: 1) Career Information and Exploration; 2) Personal Identification and Relevance; 3) Real-world Application and Context; and, 4) Social Interaction and Teamwork.

Several studies have reported the effect of mentorship and role models on the future career choices of middle school and high school students, especially in STEM education [6], [19]. A study by Abrams and Fentiman [17] concluded that focusing only on recruiting efforts cannot increase the percentage of women in engineering. Efforts to successfully engage women in engineering must also assist women in the development of a supportive, sustainable network that will increase their chances of successfully completing an engineering degree.

Some studies suggested that one way of attracting women to engineering could be showcasing engineering as more creative and more receptive to female students. One approach to achieve this is to engage girls in cooperative team projects [20], [21]. However, research suggests that teachers are not adequately prepared to address gender-equity concerns in their classrooms [22].

A wide range of K-12 programs across the country are using robotics as a very engaging tool for education, including competitions that challenge students at different levels [8]. Girls do participate in many of these robotic contests as valuable team members and enjoy building and programming robots. However, the effect of these different efforts on engaging the female population in STEM careers has not been well documented.

# Robotic Kits in K-12 STEM

Over the past 10 years, the use of robotic kits in K-12 STEM initiatives as well as undergraduate engineering education has increased significantly. This phenomenon has been motivated by many factors including the diversity of

inexpensive robotic kits and their ease of assembly and programming, as well as documented research that hands-on, project-based learning initiatives provide ways to engage students that traditional learning—including lectures and assignments, as well as advanced methods such as simulations and gaming—cannot.

Robotic kits provide opportunities to help highlight practical elements of the curriculum that can be more easily demonstrated and retained through hands-on learning and can make STEM learning more accessible for all students including female students, underrepresented minorities, and students with disabilities [23]. However, a recent survey [8] about the use of robotics to engage students showed that many educational efforts were primarily focused on using robots to teach robotics, without a broader sense of engineering and career opportunities. Additionally, few studies have been conducted on how robotics can be properly utilized in education in order to engage girls and other underrepresented groups towards engineering.

Robotics is multidisciplinary in nature and fully integrates many engineering subjects. Weinberg et al. [24] presented a model for multidisciplinary cooperation that included various engineering disciplines and computer science, which elevates robotics to a potentially pivotal position in engineering education. As part of their research, they formed a collaborative working group, which they called the Multidisciplinary Project Action Group (MPAG), as a way to bring together faculty members from the engineering and computer science departments who share a common desire to develop and deliver effective, multi-disciplinary learning activities for students in their respective college majors.

Mataric et al. [25] and his colleagues developed an affordable robotic platform and a free, public-domain robot programming workbook. Their intent was to make concepts related to robotics more accessible to educators and students at all levels. These free, detailed resources are valuable for removing barriers of entry for students and educators at the K-12 and university level and to provide direct access to hands-on learning about robotics. These types of robotic kits and resources could be utilized to engage girls in learning about engineering majors and careers.

Thomaz et al. [26] studied children in Brazil and presented an overview of the learning process of children who have been denied access to technology in education, referred to as "digitally excluded", and how educational robots can benefit these children. Their work, referred to as the "digital inclusion project", showed very positive results on impacting student learning and introduction of new technologies when children have little to no prior contact with technologies were introduced to educational robots. The results indicated that this project improved the educators' skills by supporting teaching techniques in the classroom when using the robot as an interdisciplinary tool to address subjects such as Portuguese, Mathematics, Art, and Geography. The study did not specifically target girls, but highlighted how educational robots can have a positive impact on underrepresented students.

A novel study by researchers Lu and Mead [27] presented how a new generation of students perceives human-robot interaction (HRI) and its potential impacts on society. The focus of the study was to teach students how to program robots to express emotion and intent only through the robot's physical actions. The authors believed that exposure to sociable robotics would have the potential to increase interest in STEM-related activities, particularly for girls.

Another recent study [28] focused on the VEX Robotics competition, an international program for middle and high school students, with the same goal of engaging students in the study of STEM; this time, though, through a competition, where students build robots to solve a challenge. Survey data from 341 students and 345 coaches indicated that 94% of coaches reported increased interest in science and technology and 50% reported increased interest in math and science classes as a result of robotics-based competitions. The study even looked at students from different academic levels, and showed that the robotic competition was beneficial for all of them. That is, about 20% of students with high GPAs, and would have pursued a STEM-related college major, even without the robotic competition exposure, reported a change of interest from pure science majors to engineering-based college majors. On the other hand, students with lower GPAs, who were struggling in math classes, reported that participation in robotics competitions encouraged them to study auto/machine-tool technology or electronics, for example, and motivated them to do better in school. Approximately 30% of the participants in the study were female.

A different approach to analyzing the benefits of robotics curricula was presented by KcKay et al. [29]. That study compared formal (classroom setting) and informal (summer camps) learning environments in order to understand the impact of robotics curricula on student learning of science concepts and their awareness and interest in engineering careers. This study of 440 students across four learning sites (two formal and two informal) showed that students in the informal environment did better on content learning than students in formal classroom settings, and they also did better on STEM interest and engagement. The study suggested that the overall better results with the informal sites may be

due to the amount of time spent on the curriculum during the intensive one-week summer camp experience. Approximately 50% of the students were female. The results of the study did not specifically link to the gender of the participants and reported that gender was not a factor when comparing formal to informal setting results.

The research by Takaghaj et al. [30] involved a mentor-supported robotics project. The program used Lego Mindstorms NXT and consisted of an unstructured design project geared for a robotic competition. In addition, girls were supervised in their own schools by a female engineer serving as a mentor. The survey considered both girls-only schools and classrooms with boys and girls in equal numbers. The study showed that this set up was successful in stimulating girls' interest toward STEM careers. As this was a relatively recent study, and the students involved in the survey were basically children that grew up in a highly technological era, the paper mentioned that the girls started the program already knowledgeable about engineering or robotics and had positive images of engineering. Still, the survey results indicated that the program was successful in improving attitudes even further.

Although the actual number has not been reported, the majority of U.S. engineering schools include team-based student competitions in their undergraduate programs. One such example is the VEX Robotics competition, which includes 3500 teams from 20 countries annually [28]. Some of these competitions even feature all-female teams such as the ones for SAE Mini-Baja competition [8]. Qualitative feedback from these events obtained from after-project surveys showed a positive impact on retaining women enrolled in engineering programs. Based on the literature survey presented here, these findings can be attributed to the hands-on aspect of these competitions and the mentoring and community support that comes with a team comprised of all females.

# Conclusions

In conclusion, women are grossly underrepresented in the STEM workforce, especially in engineering and engineering technology. The number of girls in grades 9–12 who have indicated their intentions to pursue engineering is significantly less than their male counterparts. There are numerous factors that have been linked to the low numbers of women in engineering as well as the low number of girls interested in pursuing technical careers, notably the "perceived chilly climate" and lack of female mentors and role models. While the use of robotic kits in K-12 STEM education has increased significantly in the last five years, studies carried out on the use of robotics to engage students focused primarily on using robots to teach robotics, without a broader sense of engineering and career opportunities. Furthermore, few studies have shown the use of robotics to engage female students in STEM, or engineering in particular, and these studies lacked any formal evaluation or assessment. Thus, there is no clear evidence in the literature on whether robotics can effectively engage girls in engineering.

Based on the outcome of this literature survey, the authors intend to collaborate and explore the use of robotics as a hands-on learning tool to effectively engage girls and excite them about the study of engineering and engineering technology and career opportunities in these fields. This proposed study plan will incorporate key findings from this literature survey on how to engage girls in STEM, including the need for female mentoring and female role models, the need for a sense of community and inclusion, the need to overcome the "perceived chilly climate", and the need to feel part of a "greater good". The partnership of Old Dominion University (ODU) and Wayne State University (WSU) brings together two higher education institutions with the infrastructure, assets, capabilities, and expertise necessary to carry out this research through existing cooperative agreements with high schools in Hampton Roads and Detroit Metro Area public school districts.

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# Biographies

**JENNIFER G. MICHAELI** is an Assistant Professor in the Mechanical Engineering Technology Department in the Batten College of Engineering and Technology at Old Dominion University and the Director of the Naval Engineering and Marine Systems Institute. She spent 15 years as a Naval Engineer and Program Manager both in the government sector and private shipbuilding industry, where she provided leadership and technical expertise on the design, construction, testing, and fielding of advanced marine vehicles and related technologies for U.S. and foreign Special Operations Forces. She is a recipient of the ASNE Young Engineer of the Year award and the Navy's RADM Melville Award for outstanding technical achievement. Dr. Michaeli completed her Ph.D. in Mechanical Engineering at ODU, her M.Sc. in Ocean Systems Management at MIT, and her B.Sc. in Naval Architecture and Marine Engineering at the Webb Institute. She is a licensed professional engineer in Virginia. At ODU, Dr. Michaeli's research and teaching interests include topics related to naval architecture; marine engineering; unmanned vehicle design and operations; shipbuilding and ship repair; design, manufacturing and testing of composites and lightweight structures; design optimization; multi-criteria decision modeling; and teaching creativity in engineering. Dr. Michaeli is actively engaged in developing and promoting government-academia-industry partnerships to further the advancement of naval and marine engineering and foster the future professional engineering workforce. Dr. Michaeli can be reached at jgmichae@odu.edu.

**VUKICA JOVANOVIC** is an Assistant Professor in the Mechanical Engineering Technology Department at the Batten College of Engineering and Technology at Old Dominion University in Norfolk, VA. Dr. Jovanovic has developed two new senior elective courses at ODU related to Mechatronics in which she teaches students how to design and build autonomous robots. She is a faculty co-advisor of the ODU IEEE Car team. Her research focuses on mechatronics, product identification, product lifecycle management, assembly systems, automation, and energy efficiency. Previously, she worked in the engineering services, aerospace, and power generation industries. Dr. Jovanovic taught at Trine University in the Design Engineering Technology Department. She was a Graduate Research Assistant at Purdue University in the Product Lifecycle Management Center of Excellence. While working at Purdue University, she was actively involved in the Society of Woman Engineers as a Graduate Relations Director as a resource to undergraduate female engineering students for graduate school events planning and outreach. She also was a member of the faculty at the University of Novi Sad in the Industrial Engineering, department. Prior to arrival in the U.S., she spent five years serving on a European Robotic Association EUROBOT organizing committee. Dr. Jovanovic can be reached at v2jovano@odu.edu.

**OTILIA POPESCU** received the Engineering Diploma and M.S. degree from the Polytechnic Institute of Bucharest, Romania, and the Ph.D. degree from Rutgers University, all in Electrical and Computer Engineering. Her research interests are in the general areas of communication systems, control theory, and signal processing. She is currently an Assistant Professor in the Engineering Technology Department at Old Dominion University in Norfolk, Virginia, and has worked in the past for the University of Texas at Dallas, the University of Texas at San Antonio, Rutgers University, and Politehnica University of Bucharest. She is an active member of IEEE and has participated on the technical program committee for IEEE ICC 2010, VTC 2009 fall, GLOBECOM 2006, and CAMAD 2006 conferences. Dr. Popescu is an IEEE Senior Member since 2005 and is a recipient of the Exemplary Reviewer Award, IEEE Communications Letters Editorial Board (Nov. 2011). She is a member of the IEEE Women in Engineering Society. Dr. Otilia Popescu has taught undergraduate and graduate courses in electrical engineering in areas including communication systems, wireless communications, networking, systems and signals, circuits, and embedded systems. She has introduced a new course on embedded systems for the ECE department at ODU, which she has taught for the past six years. She has also developed MATLAB-based laboratories for the communication courses, and is currently teaching circuits laboratories for the Electrical Engineering Technology program.

**ANA DJURIC** received the Dipl.-Ing. Degree in mechanical engineering from the University of Belgrade, Serbia, focusing on Control Systems; the M.A.Sc. degree in Industrial and Manufacturing Systems Engineering from the University of Windsor, Canada, in the area of Industrial Robotics; and a Ph.D. degree in Mechanical Engineering from the University of Windsor, Canada, in the area of Reconfigurable Robotics. Prior to her arrival at WSU, Dr. Djuric worked in industry for five years. She worked as a machine and tool designer first and then as a Robotics software Analyst. Dr. Djuric worked as an instructor for four years at the Mechanical, Automotive, and Materials Engineering, and Industrial and Manufacturing and Systems Engineering departments at the University of Windsor. Since

the fall of 2011, she has been an Assistant Professor of Engineering Technology in the College of Engineering at Wayne State University. Dr. Djuric is working on undergraduate and graduate research and she is a member of the Council on Undergraduate Research (CUR). Dr. Djuric's research areas include Industrial robots, kinematics, dynamics, control, and advanced manufacturing systems. She has published over 40 journal and conference papers.

**ECE YAPRAK** is a Professor of Engineering Technology in the College of Engineering at Wayne State University. She received her B.S. degree in electrical engineering from the University of Michigan (Dearborn) in 1980, and M.S. and Ph.D. degrees in computer engineering from Wayne State University in 1984 and 1989, respectively. Her research interests include computer networks and communications, especially wireless communications and wireless sensor networks. Her research has been published in the leading scholarly journals in engineering, including the IEEE Transactions on Communications, the IEEE/ACM Transactions on Networking, IEEE Transactions on Education and the International Journal of Modeling and Simulation. Dr. Yaprak's research has been funded by prestigious grants awarded her from the National Science Foundation, the U.S. Department of Energy, NASA, the U.S. Navy, and the business community. She has held eight research fellowships at NASA research centers (John Glenn Laboratory at Case Western, Jet Propulsion Laboratory at Cal Tech, Ames Research Center at Stanford, and the Johnson Space Center at Texas A&M Universities) and the U.S. Navy (at its SPAWAR Research Center in San Diego). She has also served as a Fulbright scholar at the Nokia Wireless Communications Research Center at the University of Oulu in Finland. Dr. Yaprak is currently an ABET IEEE/ETAC Commissioner.