# Enhancing Middle/High School Female Students Self-Confidence and Motivation in Pursuing STEM Careers through Increasing Diversity in Engineering And Labor-force (IDEAL) Outreach Summer Program

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## Introduction

Experts anticipate that discoveries in engineering, science, and technology fields will drive huge advancements in human society in the coming decades. Researchers and economists predict accelerating job-growth in these fields as well [1]. For example, the United States Department of Commerce (USDC) has already found that in the first decade of the 21st century the number of employment opportunities in these areas grew at a rate three times faster than in other fields [2]. These new jobs will continue to require employees with knowledge and abilities in science, technology, engineering, and mathematics (STEM) combined with critical-thinking, communication, and collaboration, referred to as "21st century skills" [3]. These future positions will demand not only highly specialized and workers with graduate-level training but a large percentage of workers with mid-level skills and STEM-related competencies [4], [5], [6].

Creating the next generation of engineers and scientists is critical to the U.S. economy, which demands more skilled workers and a wider range of available talent that includes women and minorities. Forty percent of today's jobs require STEM competencies and almost all of the thirty fastest growing jobs over the next decade will require STEM skills. Yet only a quarter of women are currently represented in these fields.

While at the 2015 Frontiers of Engineering Education Symposium (FEES) at the National Beckman Center in Irvine, CA, the authors came to understand the differences in thinking and doing things for middle and high school age students, where males tend to dominate females when working collaboratively on projects and how this reinforces preconceived negative stereotypes. The authors have combined the USDC employment predictions in science, technology and engineering with the FEES calls by integrating research-based high-impact practices into a novel two-week long Increasing Diversity in Engineering and Labor-force (IDEAL) summer outreach workshop designed specifically for female students. The workshop was offered during the summer of 2019 and is a modification of an already developed cross-disciplinary EGGN 122 Early Research Experiences in Biomechanics and Bioengineering undergraduate program [7].

The main objective of the IDEAL program was to explore enhancing middle and high-school female students self-confidence and motivation in pursuing future STEM careers by providing them with team cross-disciplinary research experiences that enhance critical thinking and collaboration skills. Entry and exit summer IDEAL program surveys used to assess the IDEAL program impact showed that the students enhanced their knowledge/skills the most in

understanding STEM research papers, as well as in working collaboratively on a STEM research project. National Science Foundation Middle/High School Student Attitudes Towards STEM (S-STEM) Survey [8] was used to assess the overall impact of the outreach program on the female students' self-confidence and motivation in pursuing future cross-disciplinary STEM careers. The results showed that the 21st Century skills related to critical-thinking, communication, and collaboration was the section with the most radical improvement.

*Keywords:* kinematics of mechanisms, protein kinematics, biomechanics, biochemistry, DNA nano-mechanisms

## IDEAL Online Summer Outreach Program Curriculum Plan and Methods

During the summer of 2019, mechanical engineering faculty and two undergraduate students from both NSM and ECS colleges offered a two-week Increasing Diversity in Engineering and Labor-force (IDEAL) online workshop through Zoom. A total of five middle/high-school female students participated in the program, three of which took the workshop online and two in-person. The workshop introduced the female students to kinematics and biomechanics, mechanism analysis and synthesis concepts and their applications in the areas of mechanical and biomedical engineering, as well as bioengineering. The workshop structure followed the model of a well-developed research-based course with active learning and reading/discussion scientific publications activities. The material was broken into two main parts. The first week of the workshop was focused on mechanism, protein and human kinematics, while the second week was related to lectures, discussions and activities on DNA structure fundamentals and the design of DNA nano-mechanisms, and was based on knowledge gained during the first week. Each of the two weeks concluded with a weekend long collaborative team cross-disciplinary Project Challenge. The overall goal of the two project challenges was to show the students that STEM research is about trial and error and to underscore that STEM research leads to societal benefits and meaningful careers. The outline of the IDEAL online workshop is listed below.

### Week I. Mechanism, Protein and Human Kinematics

1. Introduction to Biomechanical Engineering and Bioengineering. Human kinematics and Biomechanics.
2. Links and joints used in kinematics. Complete Entry Surveys.
3. Lower extremity kinematics and Biomechanics. Research Paper 1 [9] and Paper 2 [10], as well as Weekend Project Challenge 1 introduction.
4. Weekend Project Challenge 1 Discussion: Simulating the gait-like motion of kinesin protein moving along a microtubule [11] using mechanism kinematics and biomechanics knowledge.
5. Individual research on human leg anatomy, four-bar linkage knee design and natural gait phases. Team online discussions.
6. Weekend Project Challenge 1 individual completion.

7. Weekend Project Challenge 1 individual presentations.

Week II. DNA Nano-Structures/Mechanisms

1. Introduction to Bioengineering. DNA origami nano-structures.
2. Design of complex biological nano-mechanisms using DNA.
3. Research Paper 3 [12], Paper 4 [13] and Weekend Project Challenge 2 introduction.
4. Weekend Project Challenge 2 Discussion: Design of complex DNA nano-mechanism for drug delivery.
5. Individual research on how tumor cells receive nutrients and grow, as well as types of chemotherapeutic drugs. Team online discussions.
6. Weekend Project Challenge 2 individual completion.
7. Weekend Project Challenge 2 individual presentations. Complete Exit Surveys.

The general scope of each week and project is outlined below.

**First Week Cross-Disciplinary Research Experiences** The first week cross-disciplinary research experiences were designed to assist the students in successfully completing their first Weekend Project Challenge, outlined below. The students were introduced to the formal design process, and asked to read, understand, discuss two engineering/biomechanics papers and work in teams on the project. Each student had the opportunity to work with experimental motion data, propose a possible design, create a model and assemble small-scale prototypes using simple materials.

*Weekend Project Challenge 1: Modeling Protein Motion using Mechanism Kinematics and Biomechanics Knowledge*

During the first class, the students were presented to their first Project Challenge. The goal was to explore ways of modeling the kinesin protein motion as a rigid planar mechanism, compute the joint parameters, comment on the performance of the proposed model and prepare a presentation in either a movie or PowerPoint format to present to the rest of the participants. As part of the project, the duality between simulating the gait-like motion of kinesin protein moving along a microtubule [11] and human walking was presented to students (see Figure 1). The students were asked to work in teams, use foam board, popsicle sticks and round head fasteners/snaps (or other materials of their choice) to construct a planar model of the protein and clearly present their design results. The results were related to the chosen location of the fixed frame, the locations of the fixed pivots with respect to the fixed frame, the link lengths, as well as how well the model follows the natural “tear-drop” walking trajectory (i.e. how many points on the trajectory does the model go through). Based on the results, students were asked to comment on the performance of their model.

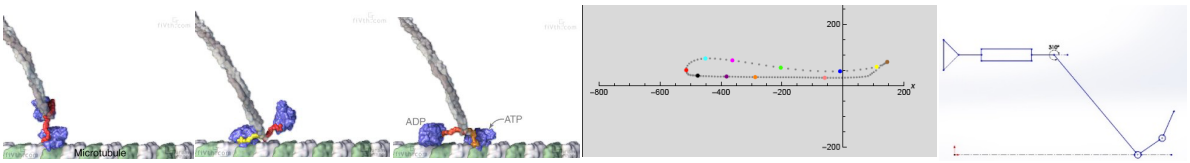


Figure 1. Left: The two motor heads of the kinesin protein work in a coordinated manner to move along a microtubule [11]. Middle: The trajectory of the motor heads is similar to the "teardrop" shape human walking gait. Right: Simplified rigid model of the kinesin protein.

The first week of the outreach workshop concluded with individual final slide and movie presentations on the project through Zoom.

**Second Week Cross-Disciplinary Research Experiences** The second week of the ideal program focused mainly on Bioengineering concepts and was led by one Biology and one Mechanical Engineering undergraduate student. Specifically, the middle/high-school students were asked to read, understand and prepare to discuss two papers related to DNA and DNA nano-mechanisms. To deepen early research experience and empower students' critical thinking, during the second half of the week the teams were asked to define research projects focusing on DNA nano-robot design for drug delivery for a disease treatment of their choice.

*Weekend Project Challenge 2: DNA Nano-robot Design*

The goal of the project was to construct a DNA nano-robot with the goal of targeting and causing cancer death without affecting surrounding healthy cells. The students were asked to use Li et al. [12] and Herrera et al. [13] (see Figure 9) as references for the design and function of their structure.

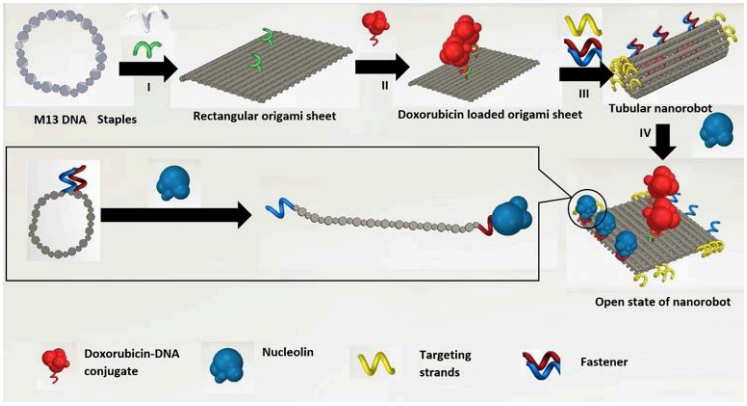


Figure 2. Design of doxorubicin-DNA nano-robot. Illustration of the construction of a doxorubicin loaded nano-robot by DNA origami and its adopted function. (I) Single-stranded M13 phage genomic DNA is linked by short staple strands in the formation of a rectangular DNA sheet. (II) Doxorubicin is loaded onto the surface with affinity to capture strands. (III) Addition of fastener strands and targeting strands on the nano-robot to allow for the self-assembly of the nanotube configuration and direction of the nano-robot (IV) Opening of the nanotube after a conformational change between the fastener strands and nucleolin.

The students were given the opportunity to perform research on how tumor cells receive nutrients and grow in order to understand the possibility of using a nanostructure as a form of drug delivery for cancer treatment, as well as research on chemotherapeutics to decide on what type of medicine the structure will carry. The students were asked to use elastic foam sheet, pipe cleaners and other materials to create a model of the DNA nano-robot containing the drug (pom-poms) inside, as well as demonstrate how the proposed structure detects the infected cells and activates to expose the drug inside. Finally, they had to prepare a PowerPoint Project Presentation with images of the DNA nano-robot and a short video explaining how the structure works. The outreach program concluded with final slide and/or movie presentations of the second project. Figure 3 illustrates examples of student prototype models related to the first and second challenge.

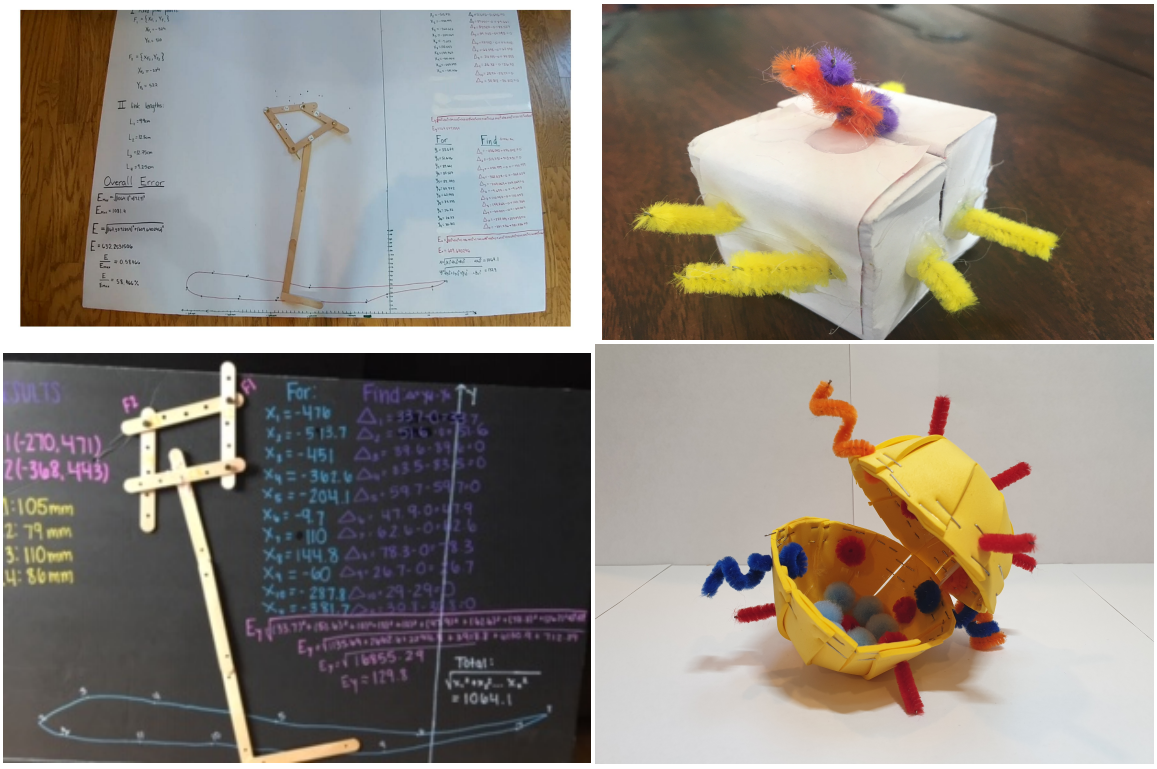


Figure 3. Examples of student models related to the first and second Project Challenge.

## Assessment of the Summer Outreach IDEAL Experiences

Entry and exit surveys used to assess the impact of the online IDEAL summer outreach workshop on the main goals, shown in Table 1, revealed that the female students enhanced the most their knowledge/skills in (i) working on a part of a STEM research project, (ii) reading STEM research papers and trying to understand the main idea, as well as (iii) performing literature review on a stem research topic (see Table 2).

Table 1. Entry/Exit Direct Self-Assessment

**Direct Self - Assessment Summer 2019 Entry Survey**

On a scale from 1-5 (1 low level - 5 high level), how comfortable do you feel in:

1. Performing literature review on a research topic related to science, technology, engineering and math (STEM) _____
2. Reading a STEM research paper and trying to understand the main idea _____
3. Working on a part of a STEM research problem/project _____
4. Using combined knowledge from math, biology and other subjects to solve a problem _____
5. Presenting your STEM research project work/results _____

Table2. Student Direct Self-Assessment Survey Results

| Average score (scale: 1-5) | Working on a part of a STEM research project | Reading/understanding STEM research papers | Performing literature review on a STEM research topic |
|---|---|---|---|
| Entrance survey | 2.8 | 3.0 | 2.8 |
| Exit survey | 4.8 | 4.2 | 3.8 |

In addition, NSF Middle/High School Student Attitudes Towards STEM (S-STEM) Survey [8] was used to assess the overall impact of the outreach program on the female students' self-confidence and motivation in pursuing future cross-disciplinary STEM careers. From the Math, Science, Engineering and Technology, Your Future, and 21st Century Skills sections of the S-STEM survey (see Table 2 below), the results showed that the 21st Century Skills (related to critical-thinking, communication, and collaboration skills) was the section with the most radical improvement. In the entry surveys, all five students had scattered answers between "Disagree" and "Strongly Agree" on the 11 questions. On the exit surveys two of the students answered "Strongly Agree" on all 11 questions, two answered "Strongly Agree" on 9 and one answered "Strongly Agree" on 7 questions. This clearly shows the success of the two-week summer outreach program on boosting middle/high-school female students self-confidence in pursuing future cross-disciplinary STEM careers. The surveys also revealed that at the end of the program, the students did not feel confidence in managing their time when working on their own and in choosing which ones of many assignments need to be done first (refer to questions 46 and 47 in Table 2).

Additionally, the Your Future section (related to interest in STEM careers) of the S-STEM survey [8] showed that for the short time of two weeks, all five middle/high school students became more interested in Mathematics, Medicine and Engineering. Specifically, from scattered

answers “Not at all Interested”, “Not So Interested” and “Interested” in the entry surveys, all five participants chose “Interested” and “Very Interested” in the exit surveys.

Table 2. S-STEM Survey “21st Century Skills” Questions [8]

**21st Century Skills**

| | Strongly Disagree | Disagree | Neither Agree nor Disagree | Agree | Strongly Agree |
|---|---|---|---|---|---|
| 38. I am confident I can lead others to accomplish a goal. | ○ | ○ | ○ | ○ | ○ |
| 39. I am confident I can encourage others to do their best. | ○ | ○ | ○ | ○ | ○ |
| 40. I am confident I can produce high quality work. | ○ | ○ | ○ | ○ | ○ |
| 41. I am confident I can respect the differences of my peers. | ○ | ○ | ○ | ○ | ○ |
| 42. I am confident I can help my peers. | ○ | ○ | ○ | ○ | ○ |
| 43. I am confident I can include others' perspectives when making decisions. | ○ | ○ | ○ | ○ | ○ |
| 44. I am confident I can make changes when things do not go as planned. | ○ | ○ | ○ | ○ | ○ |
| 45. I am confident I can set my own learning goals. | ○ | ○ | ○ | ○ | ○ |
| 46. I am confident I can manage my time wisely when working on my own. | ○ | ○ | ○ | ○ | ○ |
| 47. When I have many assignments, I can choose which ones need to be done first. | ○ | ○ | ○ | ○ | ○ |
| 48. I am confident I can work well with students from different backgrounds. | ○ | ○ | ○ | ○ | ○ |

Finally, About Yourself section (related to confidence and motivation, see Table 3 below) revealed some interesting results. In the entry surveys, all five participants had scattered answers for questions 1 and 2 and “Yes” on question 3. At the end of the outreach program all the students answered “Very Well” on the first and “Yes” on the second and third questions. This also shows the impact of the outreach program on the students’ self-confidence and motivation.

Table 3. S-STEM Survey “About Yourself” Questions [8]

**About Yourself**

1. How well do you expect to do this year in your:

| | Not Very Well | OK/Pretty Well | Very Well |
|---|---|---|---|
| English/Language Arts Class? | ○ | ○ | ○ |
| Math Class? | ○ | ○ | ○ |
| Science Class? | ○ | ○ | ○ |

2. In the future, do you plan to take advanced classes in:

| | Yes | No | Not Sure |
|---|---|---|---|
| Mathematics? | ○ | ○ | ○ |
| Science? | ○ | ○ | ○ |

3. Do you plan to go to college?
- ❍ Yes
- ❍ No
- ❍ Not Sure

## Impact

The authors have combined the NRC strategies with the California Life Sciences Institute calls for authentic collaborative cross-disciplinary experiences by integrating research-based high-impact practices into an outreach workshop on Increasing Diversity in Engineering And Labor (IDEAL) force, involving middle and high-school students mentored by faculty and lower division undergraduate students from the College of Natural Science and the College of Engineering and Computer Science at CSUF. The pilot two-week workshop was offered during the summer of 2019. The curriculum activities are designed to strengthen the students' foundation for authentic cross-disciplinary research. Preliminary assessment of the novel IDEAL online summer outreach workshop shows that the program not only increased the middle and high-school female students interest in Mathematics, Medicine, Medical Science and Engineering, but also enhanced their self-confidence and motivation in pursuing future cross-disciplinary STEM careers.

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## References

[1] National Academy of Engineering, "Grand Challenges for Engineering", *Washington, DC: The National Academies Press,* 2008.

[2] United States Department of Commerce, "The Competitiveness and Innovative Capacity of the United States"*, Washington, DC: United States Department of Commerce*, 2012.

[3] "Partnership for 21st Century Skills", 2004, http://www.21stcenturyskills.org/index.php

[4] Carnevale, A. P., Smith, N. & Melton, M., "STEM: Science, Technology, Engineering, Mathematics", *Georgetown University Center on Education and the Workforce: Washington, DC*, 2011.

[5] Pathways to Prosperity Project, "Pathways to Prosperity: Meeting the Challenge of Preparing Young Americans for the 21st Century", *Harvard Graduate School of Education: Cambridge, MA*, 2011.

[6] MetLife & Harris Interactive, "The MetLife Survey of the American Teacher: Preparing Students for College and Careers", 2011, http://www.metlife.com/assets/cao/contributions/foundation/americanteacher/MetLife_Teacher_Survey_2010.pdf

[7] Nina Robson, Cynthia Gautreau, Madeline Rasche, "Learning through Discovery: Empowering Lower Division Undergraduates to Engage in Cross-Disciplinary Research", *ASEE Annual Conference & Exposition*, Tampa, FL, 2019

[8] M. Faber, A. Unfried, E. N. Wiebe, J. Corn, L. W. Townsend, T. L. Collins, "Student Attitudes toward STEM: The Development of Upper Elementary School and Middle/High School Student Surveys, Paper ID #6955, *ASEE Annual Conference and Exposition,* 2013.

[9] H. L. Xie, Z. Z. Liang, F. Li, L. X. Guo, "The Knee Joint Design and Control of Above-Knee Intelligent Bionic Leg Based on Magneto-rheological Damper", *International Journal of Automation and Computing,* 2010.

[10] S. Ghosh, N. Robson, J. M. McCarthy, "Geometric Design of a Passive Mechanical Knee for Lower Extremity Wearable Devices Based on Anthropomorphic Foot Task Geometry Scaling", *Proc. ASME Int. Design Eng. Conferences*, 2015.

[11] Kinesin Protein Takes a Walk on a Microtubule, https://www.youtube.com/watch?v=xlPDEpimzB8.

[12] Li, S., Jiang, Q., Liu, S., Zhang, Y., Tian, Y., Song, C., Wang, J., Zou, Y., Anderson, G.J., Han, J., Chang, Y., Liu, Y., Zhang, C., Chen, L., Zhou, G., Nie, G., Yan, H., Ding, B., and Zhao, Y. (2018) A DNA nanorobot functions as a cancer therapeutic in response to a molecular trigger in vivo. Nature Biotechnol. 36:258–264.

[13] S. Herrera, A. Serrano, D. Arroyo, A. Alvarez-Loya, M. Rasche, N. Robson, "Development of a DNA Nano-robot for Chemotherapeutic Drug Delivery", *Dimensions: The Journal of Undergraduate Research in Natural Sciences and Mathematics,* v. 21, 2019.