Paper ID #17754

Incorporating Bio-Related Integrated Research in Undergraduate Kinematics of Mechanisms Course

Dr. Nina Robson, California State University, Fullerton

Dr. Nina Robson is an assistant professor in the Mechanical Engineering Department at California State University, Fullerton.

Dr. Madeline E. Rasche, California State University, Fullerton, Chemistry and Biochemistry Department

Madeline Rasche earned her Ph.D. in Biochemistry from the University of California at Riverside and was an Assistant and Associate Professor of Microbiology at the University of Florida for ten years before serving as a National Science Foundation program director for one year. In 2008, Dr. Rasche joined the Chemistry and Biochemistry Department at California State University, Fullerton as a Full Professor, where she directs a research program that uses biotechnology, biochemistry, and computational approaches to understand the molecular basis of microbial methane production. .

Vishalkumar Jayantibhai Ahir, California State University Fullerton
Iulian Mocanu

Incorporating Bio-Related Integrated Research in Undergraduate Kinematics of Mechanisms Course

N. Robson, M. E. Rasche, I. Moccano, V. Ahir

Abstract

The paper describes part of our efforts to develop curricula specifically designed to challenge engineering students to cross boundaries and solve problems in different disciplines. Specifically, the paper discusses results of introducing faculty on-going research in the areas of human and protein kinematics into a junior mechanical engineering Kinematics of Mechanisms course, with the main goal of preparing the students to be critical thinkers, cross-disciplinary problem solvers and life-long learners. In the paper the term "integrated research" is used to refer to all categories of research involving integrated multiple disciplines. The Kinematics of Mechanisms is a lecture course which presents knowledge on the analysis, design and construction of mechanical systems, such as serial and parallel linkages, cams and gear systems and robot manipulators, to name a few. During the Fall 2016 semester, new experiences in the form of interactive activities, including research projects were developed and incorporated within the course. These activities were specifically designed to enhance the students' knowledge of how the above-mentioned mechanical systems appear in other domains, such as Biomechanics and Biochemistry with the goal of giving the students the opportunity to not only cross boundaries, but also integrate and use current knowledge in their own area to solve research problems in other disciplines.

Results related to the three desired learning outcomes (critical thinking, intellectual maturity, and responsibility for own learning) were assessed through anonymous surveys. The results were based on students' as well as faculty perception. Part of the assessment was indirect and required the students to outline questions that they were asking themselves while working on each project. A comparison between the results from two sections of the class, both taught during the Fall 2016 semester, one with and one without the incorporated new activities, showed that presenting a series of multidisciplinary projects designed specifically to complement each other, improves students' critical thinking, intellectual maturity, and responsibility for their own learning. The intellectual growth was the category that improved the most, based on students' and faculty perception. In addition, the difference in students' performance on the project content and presentation between the two sections resulted in a difference of about 20%. This shows that the developed methods prove efficient not only for learning new material, but also in transferring learned skills to tasks of greater difficulty, i.e. interdisciplinary activities that are not necessarily within the typical mechanical engineering kinematics of mechanisms domain.

The idea of enhancing a junior mechanism kinematics course with research activities related to application of gained knowledge in different domains is novel and provides interesting and promising perspectives, showing that such activities increase the students' knowledge and interest in learning, and at the same time enhance their critical thinking and intellectual growth.

Although the new projects and lectures were developed specifically for mechanical engineering students, with sufficient changes the activities could be adopted in Health and Kinesiology, Biology, Biochemistry or Biotechnology courses in future. This will allow for continued data collection to assist our efforts in the development of curricula specifically designed to challenge students to cross boundaries and solve research problems in other disciplines.

Keywords: kinematics of mechanisms, protein kinematics, biomechanics, biochemistry

Introduction

Involving undergraduate students in research projects can be seen as a form of inductive teaching [1], an instructional strategy that comes close to emulating research and is frequently cited as an effective way to link faculty research to undergraduate teaching. Unlike traditional teaching methods, inductive teaching introduces topics by presenting specific observations, case studies or problems. Theories are taught or the students are helped to discover them only after the need to know them has been established. Bransford, Brown, and Cocking [2] have surveyed extensive neurological and psychological research that provides strong support for inductive teaching methods. Ramsden[3], Norman and Schmidt [4] and Coles [5] have also demonstrated that inductive methods encourage students to adopt a deep approach to learning. Felder and Brent [6] show that the challenges provided by inductive methods serve as precursors to intellectual development. Prince and Felder [7] review applications of inductive methods in engineering education, and state the roles of other student-centered approaches, such as active and cooperative learning, in inductive teaching. Sabatini [8] discusses several examples of how undergraduates and high school students can be involved in engineering research. The National Science Foundation (NSF) Research Experience for Undergraduates (REU) program [9] promotes and supports research involvement, and this activity clearly has the potential to benefit students. Pascarella and Terenzini [10] note several positive outcomes for students who participate in undergraduate research programs, among them greater retention in the curriculum and greater likelihood of enrolling in graduate school.

On the other hand, Seymour et al. [11] argue that most studies of undergraduate research did not include proper control groups, used biased samples or failed to provide sufficient details of their evaluation methods. Kevin Gibbons et al. [12] have developed an approach to involve a group of senior mechanical students that were taking a specific course in improving a relevant lab learning experience for other undergraduates. Overall academic performance for both two categories has been improved and results have shown that most students who have experienced hands-on work felt that this approach helped them with meeting the course requirements. The idea behind incorporating inductive teaching, such as research and interactive learning techniques, are increasingly critical as industry begins to seek employees who are better problem-solvers and independent workers.

In relation to the above-mentioned, there has not been a great deal of research on the effectiveness of introducing integrated research projects in undergraduate engineering classes. Here, we would like to note that cross-disciplinary knowledge is that which explains aspects of one discipline in terms of another. In this paper we use the term "integrated research" to refer to all categories of research involving integrated multiple disciplines. The term "cross-disciplinary" is used in the paper and in the literature in the same sense [13-15]; however, it has also been used in the past to define a particular type of multi-disciplinary research [16] . Further, it suggests boundaries are simply crossed rather than integrated and thus would appear to emphasize weaker forms of integrated research [17]. While other alternatives have been proposed (Balsiger [18] suggested the use of the term "supra-disciplinary") "integrated research" is already commonly used in the literature [19-22] and therefore is likely to be a well understood term.

The following sections provide an overview of our efforts to improve the learning environment in the undergraduate Kinematics of Mechanisms course at California State University, Fullerton for mechanical engineers through new bio-related integrated research experiences in the form of cross-disciplinary interactive activities and projects. The accomplishments that our working group has achieved so far are discussed at the end.

Motivation, Course Description and Desired Student Outcomes

The Kinematics of Mechanisms is a junior course, which introduces students to analysis and design of linkages, gears, cam and follower systems, robotics, as well as static and dynamic analysis of mechanisms. The existing course material was broken into four main parts, each of which introduced major knowledge in mechanism kinematics necessary for mechanical engineers. At the end of each part, new bio-related research project activities and lectures, were developed and incorporated into the sequence (see below with bold font). These new activities were specifically designed to build upon the existing material and to further enhance the students' knowledge of how the already studied mechanical systems appear in other domains The outline of the enhanced class is listed below:

Part I. Planar Mechanism Kinematics

1. Machines and Mechanical Advantage. Introduction to Linkages. Mobility
2. Closed Loop Linkages: The Slider Crank and Inverted Slider Crank
3. The Four-Bar Linkage
4. Open Loop Linkages: The Planar revolute-revolute (RR) and RRR Chains
5. Cam and Follower Design. Displacement Diagrams
6. Gears and Gear Trains

7. Mechanical Engineering Project 1: Mechanical Device Design and Analysis

Part II. Human Kinematics

8. **Introduction to Biomechanics: Human Kinematics and Motion Capture Systems**
9. **Biomechanics Limb Data used in Mechanical Design**
10. **Biomechanics Project 2: Design of an Articulated Mechanical Leg**

Part III. Robot Kinematics and Protein Motion

11. Forward and Inverse Robot Kinematics
12. **Introduction to Biochemistry: Nano-kinematics and Robot Kinematics**
13. **Simulation of Protein Motion**
14. **Biochemistry Project 3: Mechanism Kinematics in Understanding Protein Motion**

Part IV. Dynamic Analysis

15. Static and Dynamic Force Analysis
16. Mechanical Design and Analysis Project 4: Dynamic Analysis of the Designed Devices

The goal of the project activities was to challenge the students to apply the already gained knowledge on kinematics of mechanical systems during the first part of the class and solve research problems in the area of Biomechanics. The next step was for the students to use knowledge on mechanical systems and Biomechanics to solve research problems in Biochemistry. The last step was for the students to use all the knowledge throughout the semester and solve problems in the area of dynamic force analysis of mechanisms. The projects activities were specifically focused on involving undergraduate students in research and preparing them to be critical thinkers, multidisciplinary problem solvers and independent learners, which were the main desired outcomes.

The course lectures and discussions were mapped to the desired project activities and student outcomes. Specifically, the development process contained the following phases:

- Determine faculty goals and objectives; analysis of potential students (students, who take the course are juniors and do not have a prior knowledge in the field of mechanism kinematics and design and its applications);
- Determine faculty role in the learning process and develop an instructional plan;
- Identify faculty interested in collaborative research and education activities across disciplines;
- Design cross-disciplinary research project activities, assignments, and assessments that are congruent with the three major desired student outcomes: (a) critical thinking, (b) responsibility for one's own learning, (c) intellectual growth, congruent with the discussion project goals.

Project Activities Specific Goals

The goal of the project activities was to augment the existing Kinematics of Mechanisms class with human kinematics and protein kinematics concepts in the form of interactive cross-disciplinary experiences in order to enhance student knowledge in the area of kinematics and prepare them to be successful in their future jobs. Before each project, there were a number of planned activities, such as detailed description of the project with included main objective(s) and recommended research papers and instructions for the successful completion. As a next step, the students were required to come up with possible solutions to the open-ended research projects. To increase the quality of writing [23] and presenting, the students were asked to submit reports, as well as give oral presentations on their projects and critically evaluate them.

Discussion of Projects Sequence

Here, the paper briefly presents the contents of each research project sequence. During the first six lectures, the students were working on the analysis and design of an Articulated Suspension Exploratory Platform ASEP, shown in Figure 1. ASEP is a small robotic rover platform, designed by the faculty and students [23-26]. It is a reproducible, low-cost wheeled robot suited for operation on rough terrains. Currently, there are seven of these platforms at California State University.

Figure 1. The developed Articulated Suspension Exploratory Platform ASEP

Recently, a robotic arm was attached to the ASEP platform and the new arm-rover system was called Articulated Suspension Exploratory Platform System (ASEPS).

Mechanical Design Project 1: Model a rover-arm system able to work in remote and challenging environments

The goal of this project was to propose a design of (i) a passive suspension, capable of moving over rough terrains and (ii) a simple planar serial robotic arm, capable of taking tests from different objects in the environment.

Activity 1: Analysis and design of a rover-arm system: The students were asked to experimentally test the suspension capabilities of the existing ASEPS platforms and based on the results, propose an enhanced design for the multi-bar linkage passive suspension, similar to the one shown in Figure 2 and for the planar two degree of freedom arm, shown in Figure 3.

Next, the students were asked to critically analyze their designs, based on learned design analysis tools and present the results using Excel spreadsheet.

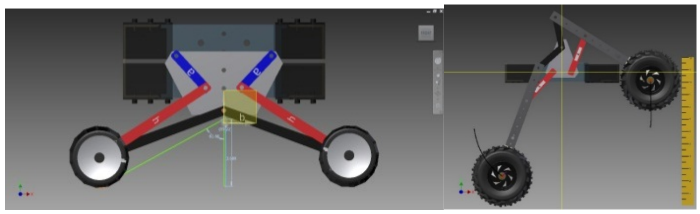

Figure 2. Two examples of multi-bar linkage suspension designs.

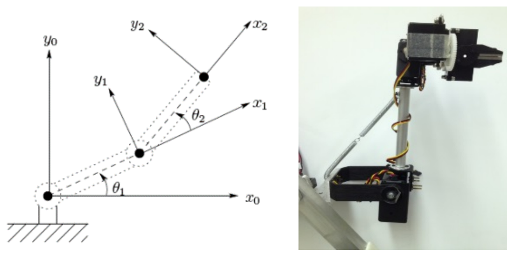

Figure 3. A modification of the ALD5 Lynxmotion robotic arm

During the conceptual design stage, the students used cardboard and snaps to construct their models and were asked to submit CAD drawings, demonstrating their final design results. As a next step, they analyzed their own suspension and arm designs and presented a table of results using Excel.

Activity 2: Gear and gear trains used in the design of the rover-arm system: The goal of this activity was to give the students an insight of the actuation of the platform and the planar robotic arm. For more details, please refer to Robson et al. [30]

While interactive learning materials and techniques exist for introductory design concepts, there are not a lot of accessible materials and activities for more advanced interdisciplinary topics. As mentioned earlier, to further inspire creativity, during the Fall 2016 semester the faculty developed new interactive cross-disciplinary research driven projects and lectures with the main goal of improving students' critical thinking, responsibility for their own learning and intellectual growth. The new activities related to the faculty on-going research in the areas of Biomechanics [31-45] and Biochemistry [46-49] are detailed below.

Biomechanics Project 2: Design of an Artificial Leg for Persons with Reduced Mobility in their Lower Extremity

For this project the students were asked to design and then analyze a lower extremity wearable passive crutch substitute device for a person with reduced mobility in their lower extremity and assess their design. The hip joint was based on a cam and follower system, while the prosthetic knee needed to incorporate a self-locking four-bar mechanism. The design of the prosthetic walker was based on a natural human walking gait trajectory (see Figure 4 on the right), obtained experimentally using a motion Capture System. The following activities, described below, have been developed with regard to the project.

Activity 1: Motion capture systems for obtaining human kinematics data: The students were introduced to experimental work with Qualisys Motion Capture system (see Figure 4) and techniques for obtaining lower extremity human biomechanics data. As a next step, they were asked to design assistive walking devices for people with reduced mobility in their leg, based on the experimental data.

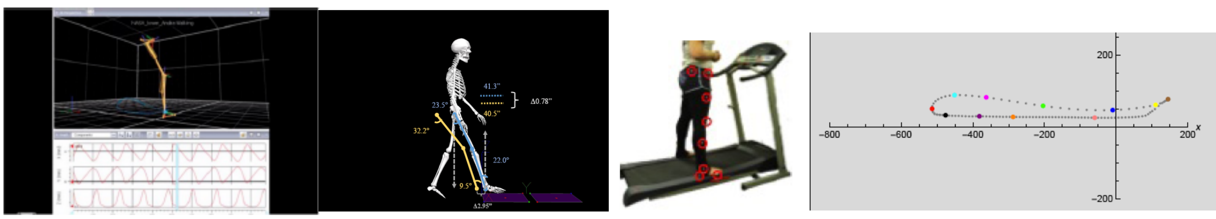

Figure 4. Motion Capture Systems for Obtaining Human Kinematics Data

Activity 2: Human lower extremity motion data: For this activity, the students learned how to experimentally obtain human walking data using Qualisys Motion Capture system (see Figure 5). The students then proposed physical, CAD or 3D printed models of an artificial leg designs for a person with below-knee injuries, based on healthy and impaired foot walking trajectories.

Figure 5. Design of an artificial leg for a person with a below-knee injuries, based on the obtained healthy and impaired foot walking trajectories.

The last series of lectures and project activities were related to Biochemistry, introducing the students to protein kinematics concepts.

Biochemistry Project 3: Mechanism Kinematics in Understanding Protein Motion

The goal of this project was for the students to learn how to model simple protein chains and predict their motion, using the already gained knowledge from mechanism kinematics, robotics and biomechanics.

Activity 1: Protein conformation in drug design using inverse kinematics: Students were introduced to proteins and ways of modeling them as mechanical chains, using mechanism kinematics knowledge. Ways for drug/ligand design, by changing the conformation of a protein segment from unfolded to native state, provided through crystallography imaging was also introduced (see Figure 6).

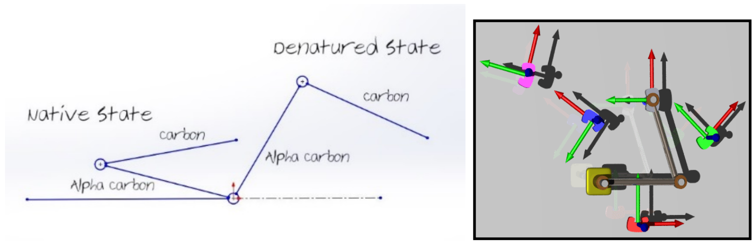

Figure 6. Left: Protein segment in its native and unfolded (denatured) conformation, provided by crystallography imaging; Right: Duality between planar protein segment and robotic chains.

Activity 2: Modeling of protein motion: The duality between simulating the gait-like motion of kinesin protein moving along a microtubule [50] and human walking was presented to students. The addition of ATP and release of ADP cause the system to change configuration (conformation) and move to create the walking like movement (see Figure 7). The students were asked to simplify the kinesin motion, model it as a rigid planar robotic chain and compute the joint parameters, based on the two given kinesin motor heads motion trajectories.

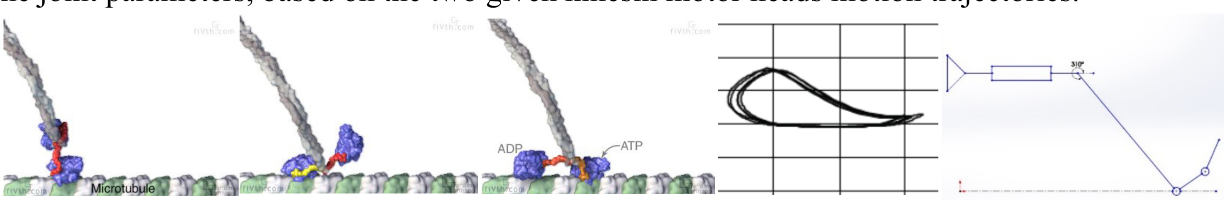

Figure 7. Left: The two motor heads of the kinesin protein work in a coordinated manner to move along a microtubule. Middle: The trajectory of the motor heads is similar to the "teardrop" shape human walking gait. Right: Simplified rigid model of the kinesin protein.

Mechanical Design and Analysis Project 4: Dynamic Force Analysis

Activity 1: Dynamic Force Analysis: The goal of this final project was to provide students with techniques for determining the magnitude, direction and location of forces for the students to be able to calculate and assess the values of the bearing forces as well as input torques for the devices they have designed throughout the semester. For more details on that specific project, please refer to Robson et al. [30] In an earlier semester (Fall 2016) the faculty was able to introduce a project on the dynamic analysis of mechanical systems, rather than protein systems. Introducing the students to simple modeling techniques of the dynamic interactions within protein systems is one of the future goals of this project.

Results on the Effectiveness of the Learning Environment

During the Fall 2016, the four developed integrated cross-disciplinary research projects were presented in Section 1, while four standard challenging projects related only to mechanism kinematics and robotics were presented in Section 2 of the Kinematics of Mechanisms class. Anonymous survey questions, regarding the project specific goals, outlined in the beginning of the paper, were performed in both sections. The questions were related to the effectiveness of the major activities, based on students' perspective (see sample summary of survey questions in Table 1).

Table 1. Summary of Survey Questions

As a result from Challenge 2 activities to what extent did you make gains in:
1. Solving real world problems without direct assistance
2. Working efficiently with others
3. Ability to think through a problem and understand it
4. Ability to present data, calculations and results from analysis and/or design
5. Ability to assess if the results are realistic
6. Ability to define additional work that is needed to refine your results
7. Ability to take decisions and defend them
8. Ability to solve challenging and/or cross-disciplinary projects
9. Share at least three questions that you were asking yourself while working on Challenge 2
10. Additional comments

Table 2 shows the average learning outcomes from the two sections, based on student perception on a scale from 1 (poor) to 5 (excellent). The average student learning outcomes were slightly higher at 3.79 out of 5 for Section 1, versus 3.62 out of 5 for Section 2 (see Table 2). Although more challenging, the material in Section 1was specifically designed to build upon the existing class activities and projects, giving the students the opportunity to explore and learn more. Table 2 also shows the top and bottom scored questions, based on student perception. The Section 2 project activities revealed areas in which the students did not feel comfortable, such as "ability to take decisions and defend them". However, this area appears to be among the top scored question statements for Section 1, which implies that the additional new projects develop critical thinking. The top scored question statement for Section 2 was "make gains in hands-on activity in analyzing a real-world mechanism", while the lowest scored question for Section 1 was "ability to solve a cross-disciplinary problem". We hypothesize that the more the students learn about the multidisciplinary nature of mechanism kinematics and design area, the more they understand how much more knowledge they need to be able to solve such problems.

It is not quite easy to make any conclusion as to which of the project activities revealed more positive qualities. The last column of Table 2 shows similar average learning outcomes for both sections, based on student perception, with Section 1 leading at 3.79 versus 3.62. Based on the total of 3.705 average learning outcomes for both sections, standard deviation analysis shows that 56.14% for Section 1 and 44.55% for Section 2 are above that average. These results show clearly that developing new project activities that successfully complement existing class projects and build upon each other yield positive results.

Table 2. Learning Outcomes, Based on Students' Perception: Results

Major Activity	Top Scored Question	Lowest Scored Question	Average Learning Outcomes (from 1 to 5)
Section 1: Integrated Research	Ability to take decisions and defend them	Ability to solve cross-disciplinary problems	3.79 (25 out of 57 below) 43.86%, 56.14% above
Section 2: Standard Approach	Ability to present data, calculations and results from analysis and design	Solving real-world problems without direct assistance	3.62 (47/56 out of 101 below) 46.53%/55.45%, 44.55% above

The next step was to indirectly assess the three desired learning outcomes, from the faculty viewpoint, outlined in the beginning of the paper. In an effort to get some ideas on enhancing the projects in future, as a part of the survey, the students were asked to identify three questions that they were asking themselves, while working on each project [29]. Next, the students' questions were classified into three major groups, according to the three desired outcomes: *critical thinking, responsibility for one's own learning* and *intellectual growth*.

The *critical thinking* was assessed by the number of students' questions demonstrating their interest in analyzing data, evaluating alternative solutions, taking critical decisions, and communicating design ideas. Example questions are: *Is it possible to go through all the points in the desired gait trajectory taking into account the given constraints? Is the given natural human foot trajectory a combination of the hip and knee joint movement?*

The *students' responsibility for their own learning* was assessed by the number of student questions regarding their desire to learn more, be successful and look for additional sources, out of the class. Example questions are: *Is using a four-bar linkage the best solution? What location of the fixed pivots will help us get closer to the desired human foot trajectory? Am I doing the right calculations? What's the best way to lock the articulated knee joint during the swing phase of the human walking gait?*

The *intellectual growth* was assessed by the number of questions regarding students' desire to propose improvements, find relationships between different concepts and defend their decisions. Example questions are: *How does this model help people in future? What is the best and fastest way to build a model to get an idea if it works? How can I work backwards from knowing the foot-path of a human to designing an artificial leg?*

The results are shown in Table 3.

Table 3. Comparison in Critical Thinking, Responsibility for One's Own Learning and Intellectual Growth between the Two Sections, based on Student Questions

Major Activities	Percentage of students' questions, related to *critical thinking*	Percentage of students' questions, related to *responsibility to ones' own learning*	Percentage of students' questions related to *intellectual growth*
Section 1 Integrated Research	21.67%	15.79%	29.82%
Section 2 Standard Approach	7.9%	11.55%	8.91%

Given the difficulty of carrying out a clean and conclusive comparative study, the best we could do is to compare the results to see if any robust generalizations can be inferred. Based on the questions written by the students, about 67.3% of the student questions in Section 1 and only 28.4% in Section 2 seemed to comply with the three desired outcomes. A simple comparison between the survey results from the two sections show that the percentage of questions related to *responsibility for ones' own learning* for both sections were similar (see the middle column of Table 3). That shows that in both sections the students had similar desire to learn more, be successful and look for additional sources, out of the class. Table 3 shows that *intellectual growth* was the category that differed the most. In Section 1, which offered the new cross-disciplinary activities, the *intellectual growth* of the students was improved with more than 20% (see the last column of Table 3) and the *critical thinking* with about 13% compared to the standard approach presented in Section 2 (see the first column of Table 3).

Table 4 presents a comparison between the average student grades on the projects, as well as the total final class average for both sections. Although the students' scores on the first project (related purely to mechanical engineering) were higher than on the remaining three projects, the students' grades on each project (see the first column of Table 4), as well as the total final class average (see last column of Table 4) show a definite *transfer of knowledge* within Section 1.

Despite the fact that the integrated research techniques, presented in Section 1, were quite challenging and the average students' performance on the project content was lower, the overall total final class average was higher at 83.27% with respect to 76.75% for Section 2 (see last column in Table 4). This implies that introducing cross-disciplinary research projects in junior classes, that build upon each other, are efficient not only *for learning new tasks*, but also for *transferring gained knowledge* to tasks in other domains that are of a greater difficulty.

Table 4. Potential Transfer of Knowledge for the Students from Section 1

Major Activity	Average Student Grades on Each Project	Average Student Grades on Project Content and Presentation	Total Final Class Average
Section 1 Integrated Research	93.03, 78.30, 84.85, 85.8	85.39%	83.27%
Section 2 Standard Approach	93.15, 91.80, 91, 83.3	91.98%	74.75%

Impacts

The challenges provided by inductive methods and incorporating faculty on-going research in education are successful in motivating students, encouraging them to adopt a deep approach to learning and serve as precursors to intellectual development. There has not been a great deal of research on the effectiveness of introducing research projects in cross-disciplinary domains in undergraduate engineering classes.

The integrated research learning environment aims to take the study of engineering kinematics and design to the next level by incorporating novel cross-disciplinary projects related to faculty on-going research in mechanical engineering and bio-related areas, to motivate the undergraduates and prepare them better for their future jobs. The students work in team environments, take the theoretical ideas and implement them into the projects. Our results show that for the limited time of one semester, the incorporation of complementary cross-disciplinary research projects within undergraduate classes brings to students' improved intellectual maturity, critical thinking enhanced responsibility for their learning, as well as higher learning outcomes and overall grades.

It is important to note that the integrated cross-disciplinary research based alternative to undergraduate research engagements is a novel technique that provides interesting and unique experiences for the students. Although the projects presented in this paper were developed for mechanical engineering students within a specific course, with sufficient changes in the activities could be adopted in other classes, such as Dynamics and different disciplines, such as Health and Kinesiology, Biology or Biochemistry, among others. Future plans include more detailed interpretation of the results by taking into account factors that may affect the student performance. Such factors could be the number of students in a particular section or time in which the section is offered, as well as continued data collection to build a larger sample size from other courses and departments to assist in the future development of curricula specifically designed to challenge the students to cross boundaries and solve problems in different disciplines.

Acknowledgements

The authors gratefully acknowledge the support of National Science Foundation (NSF) award Id #1404011 and NSF grant award Id #CHE-1508801.

References

1. Prince M. and Felder R., "The Many Faces of Inductive Teaching and Learning", Journal of College science Teaching, Vol.3 (5), pp.14-20, (2007).
2. Bransford, J.D., A.L. Brown, and R.R. Cocking, "How People Learn: Brain, Mind, Experience, and School", Washington, DC: National Academy Press, (2000).
3. Ramsden, P., "Learning to Teaching Higher Education", 2nd ed. London: Taylor and Francis, (2003).
4. Norman, G.R., and H.G. Schmidt, "The Psychological Basis of Problem-based Learning: A Review of the Evidence", Academic Medicine 67 (9): 557–65, (1992).
5. Coles, C.R., "Differences Between Conventional and Problem-based Curricula in their Students' Approaches to Studying", Medical Education, 19(4): 308–09, (1985).
6. Felder, R.M., and R. Brent, "The Intellectual Development of Science and Engineering Students. Pt. 1: Models and Challenges", Pt. 2: Teaching to Promote Growth. *Journal of Engineering Education* 93 (4): 269–77; 93 (4): 279–91, (2004).
7. Prince, M., and R.M. Felder, "Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases", Journal of Engineering Education, 95 (2): 123–38, (2006).
8. Sabitini, D.A., "Teaching and Research Synergism: The Undergraduate Research Experience," Journal of Professional Issues in Engineering Education and Practice, Vol. 123, pp. 98–102, (1997).
9. Experience for Undergraduates (REU) program. National Science Foundation, www.nsf.gov/home/crssprgm/reu/.
10. Pascarella, E.T. and Terenzini, P.T., "How College Affects Students: A Third Decade of Research," San Francisco: Jossey-Bass, (2005).
11. Seymour, E., Hunter, A., Laursen, S.L. and Deantoni, T., "Establishing the Benefits of Research Experiences for Undergraduates in the Sciences: First Findings From a Three-Year Study," Science Education, Vol. 88, pp. 493–534, (2004).
12. Gibbons Kevin A., Philip Knodel, JoelWilliam Noble, Nathan W. Seibt, "An Approach to Using Undergraduate Student Teams to Develop Undergraduate Laboratory Experiences," American Society for Engineering Education, (2012).
13. Jakobsen, C.H.; Hel, T.; McLaughlin, W.J. "Barriers and Facilitators to Integration Among Scientists in Transdisciplinary Landscape Analyses: A Cross-country Comparison". *For. Policy Econ.*, *6*, 15-31, (2004).
14. Cummings, J.N.; Kiesler, S. "Collaborative Research Across Disciplinary and Organizational Boundaries." *Soc. Stud. Sci.*, *35*, 703-722, (2005).
15. Russell, A.W.; Wickson, F.; Carew, A.L. "Transdisciplinarity: Context, Contradictions and Capacity." *Futures*, *40*, 460-472. *Sustainability*, *3* 1107, (2007).

16. Tress G, Tress B, Fry G., “Clarifying Clarifying Integrative Research Concepts in Landscape Ecology.” *Landsc. Ecol.*, *20*, 479-493, (2004).
17. Burton, R.; Rønningen, K.; Wedderburn, L. “Conducting Integrated Research: A Critical Literature Review of Interdisciplinary and Transdisciplinary Research”, Report 12/08; Centre for Rural Research: Trondheim, Norway, (2009).
18. Balsiger, P.W. “Supradisciplinary Research Practices: History, Objectives and Rationale.” *Futures*, *36*, 407-421, (2004).
19. Janssen, W.; Goldsworthy, P. “Multidisciplinary Research for Natural Resource Management: Conceptual and Practical Implications.” *Agric. Syst*, *51*, 259-279, (1996).
20. Kooistra, M.J.; Kooistra, L.I. Integrated Research in Archaeology using Soil Micromorphology and Palynology. *Catena*, *54*, 603-617, (2003).
21. James, L.A.; Marcus, W.A. “The Human Role in Changing Fluvial Systems: Retrospect, Inventory and Prospect.” *Geomorphology* , *79*, 152-171, (2006).
22. Stevens, C.J.; Fraser, I.; Mitchley, J.; Thomas, M.B. “Making Ecological Science Policy-Relevant: Issues of Scale and Disciplinary Integration.” *Landsc. Ecol.*, *22*, 799-809, (2007).
23. Baumgartner H. and N. Robson, "Mechanical Design of the Articulated Suspension Exploratory Platform ASEP," *SAE Technical Paper* 2012-01-1935, doi:10.4271/2012-01-1935, (2012).
24. Robson N., J. Morgan, H. Baumgartner, “Mechanical Design of the Standardized Ground Mobile Platform SGMP”, *International Journal of Modern Engineering, IJME M12-S-16,* (2012).
25. Morgan J., G, Wright, N. P. Robson, H. Baumgartner and J. Lopez, “Development of a Standardized Ground Mobile Platform for Research and Education”, *Proc. AUVSI Unmanned Systems North America*, Washington DC, (2011).
26. Robson N., J. Morgan, G. Wright, H. Baumgartner, W. Twigge, “Articulated Suspension Exploratory Platform: A Small Size Low Cost Research Platform Capable of Operating in Rough Terrains”, *AUVSI Unmanned Systems North America*, August 6-9, Las Vegas, (2012).
27. Patarinsky Robson N., J. M. McCarthy and I. Tumer, “Failure Recovery Planning for an Arm Mounted on an Exploratory Rover*”, IEEE Transactions on Robotics,* 25(6), pp. 1448-1453, (2009).
28. Robson N. P., J. M. McCarthy, “Second Order Task Specifications Used in the Geometric Design of Spatial Mechanical Linkages”, *International Journal of Modern Engineering*, v.11:pp.5-11, (2010).
29. Robson N., “Enhancing Learning Techniques in Undergraduate Mechanical Design Classes”, American Society for Engineering Education PSW, (2013).
30. Robson N., J. Morgan, H. Radhi, “Development of a Multidisciplinary Mechanical Design Laboratory Sequence based on Faculty Research”, Proc. of *122nd ASEE Annual Conference & Exposition*, Seattle, WA, Paper ID#11160, (2015).
31. Robson Nina, Gim Song Soh, 2016, “Geometric Design of Eight-Bar Wearable Devices based on Limb Physiological Contact Task”, *Mechanism and Machine Theory* 100, pp. 358-367, (2016).
32. Robson N, S. Ghosh, “Geometric Design of Mechanisms based on Virtual Guides for Manipulation”, *Robotica,* pp. 1-16, DOI:10.1017/S0263574715000272, (2015).
33. Robson N., Gaby Martinez, M. Villavecer, J. Chin, B. Holloway, S. Nostrabaldi, L. Tliliyatzi, “Development of a Crutch Substitute for Mimicking Natural Gait”, *International Journal of Robotics and Automation Technology,* vol. 1, pp. 99-10, DOI:10.15377/2409-9694.2014.01.02.6, (2015).
34. Moon, H.S., Robson, N., Langari, R. & Buchanan, J.J., Experimental Observation on Human Reaching Motion Planning With and Without a Reduced Mobility. In: *Robot Kinematics and Motion Planning*, ed. Wayne Adams, pp.1-53, ISBN: 978-1-63483-391-2, Nova Science Publishers, (2015).

35. Moon H. S., N. Robson, R. Langari, Approximating Constrained Hand Paths via Kinematic Synthesis with Contact Specifications, In: *Advances in Robot Kinematics,* ed. J. Lenarcic and O. Khatib, pp.375-384, ISBN: 3-319-06697-4, Springer, (2014).

36. Ghosh S., N. Patarinsky Robson, Development of a One Degree of Freedom Mechanical Thumb Based on Anthropomorphic Tasks for Grasping Applications, In: *Advances in Robot Kinematics,* ed. J. Lenarcic and O. Khatib, pp.335-344, ISBN: 3-319-06697-4, Springer, (2014).

37. Robson N., G. S. Soh, "Dimensional Synthesis of a Passive Eight-bar Slider Exo-Limb for Grasping Tasks", *ASME International Design Engineering Technical Conferences,* (2016).

38. Moon H. S., N. Robson, "Design of Spatial Non-Anthropomorphic Articulated System Based on Arm Joint Constraint Kinematic Data for Human Interactive Robotic Applications", Proc. of *ASME 2015 International Design Engineering Technical Conferences & Computer and Information in Engineering Conference, (IDETC/CIE2015),* Boston, MA, DETC2015-46530, (2015).

39. Ghosh S., 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. of *ASME 2015 International Design Engineering Technical Conferences & Computer and Information in Engineering Conference, (IDETC/CIE2015),* Boston, MA, DTEC2015-46499, (2015).

40. Robson N., J. Allington, G.S.Soh, "Development of Under-actuated Mechanical Fingers based on Anthropometric Data and Anthropomorphic Tasks", Proc of *ASME 2014 International Design Engineering Technical Conferences & Mechanisms and Robotics Conference, (IDETC/MECH 2014),* Buffalo, NY, DTEC2014-34878, (2014).

41. Robson N., G.S. Soh, "Geometric Design of Minimally Actuated Exoskeletons", Proc. of *36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, (EMBC/14)*, Chicago, IL, (2014).

42. Moon H. S., N. Robson, R. Langari, S. Shin, "An Experimental Study on the Redundancy Resolution Scheme of Postural Configurations in Human Arm Reaching with an Elbow Joint Kinematic Constraint", Proc. of *2-nd Middle East Conference on Biomedical Engineering*, Doha, Qatar, DOI:10.1109/MECBME2014 6783253, (2014).

43. Robson N., S. Ghosh, G.S. Soh, "Development of a Sensor-Based Glove Device for Extracting Human Finger Motion Data used in the Design of Minimally-Actuated Mechanical Fingers", Proc. of *3-rd IFToMM International Symposium on Robotics and Mechatronics*, Singapore, DOI:103850/978-07-7744-9-074, (2013).

44. Soh G. S., N. Robson, "Kinematic Synthesis of Minimally Actuated Multi-Loop Planar Linkages with Second Order Motion Constraints for Object Grasping", Proc. of *2013 ASME Dynamic Systems and Control Conference, Human Assistive Systems and Wearable Robots Invited Session*, Stanford University, Palo Alto, CA, (2013).

45. Ghosh S., H.S. Moon, N. Robson, "Reconstructing Human's Hand Motion: Preliminary Results and Applications in the Design of Mechanical Fingers for Anthropomorphic Tasks", Proc. of *ASME International Design Engineering Technical Conferences & Computer and Information in Engineering Conference, (IDETC/CIE2013)*, Portland, OR, DOI:101115/DETC-13700, (2013).

46. Chiem, K.,Jani,S.,Fuentes, B., Lin, D.A.,Rasche, M.E, and Tolmasky, M.E. "Identification of an Inhibitor of the Aminoglycoside 6'-N-Acetyltransferase type lb [AAC(6')-lb] by Glide Molecular Docking". *MedChemComm*. 71: 184-189, (2016).

47. Bobik, T.A., Morales, E.J., Shin A., Casico, D., Sawaya, M.R., Arbing, M., Yeates, T.O., and Rasche, M.E. "Structure of the Methanofuran/Methanopterin Biosynthetic enzyme MJ1099 from Methanocaldococcus Jannaschii". **Acta Cryst**. F70: 1472-1479, (2014).
48. McNamara, D.E., Cascio, D., Jorda, J., Bustos, C., Wang, T., Rasche, M.E., Yeates, T.O. and Bobik, T.A." Structure of Dihydromethanopterin Reductase: A Cubic Protein Cage for Redox Transfer". *J. Biol. Chem.*, 289: 8852-8864, (2014).
49. Wang, S., Tiongson, J., and Rasche M.E. "Discovery and Characterization of the First Archaeal Dihydromethanopterin Reductase (DmrX), an Iron-Sulfur Flavoprotein from *Methanosarcina Mazei*". J. Bacteriol. 196: 204-209, (2014).
50. https://www.youtube.com/watch?v=xlPDEpimzB8 "Kinesin Protein Takes a Walk on a Microtubule".