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Innovative Industry-Related Research Projects for Civil Engineering Undergraduate Students

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Innovative Industry-Related Research Projects for Civil Engineering Undergraduate Students

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Abstract

This paper covers the important aspects of new research methodologies, including the methods and tools, for undergraduate students at a Civil Engineering program. It aims to improve the research competencies of civil engineering students through immersing the students in different types of research exercises. The activities have been exploratory, experimental and theoretical. The focus of the new approach is on developing soft skills, gaining practical and hands-on skills, research management and planning, and presenting the results in an optimum manner. Six undergraduate students from two departments were involved in various components of a research project related to the post-tensioned concrete structures. The core project started in a company specialized in post-tensioning industry.

Initially, the learning objective was to gain a deep understanding of the mechanical properties of concrete and steel as well as the post-tensioning of the concrete slabs. However, the main objective was to get students involved in designing effective test platforms from scratch, to perform experiments with concrete blocks and a special compressible material used in industry. One of the goals was to investigate the friction coefficient of connection between the concrete slab and walls in Post-Tensioned construction. The research involved testing the resistance of concrete blocks against applied loads in variety of conditions. Furthermore, students were to explore the behavior of a compressible material that is used to wrap rebar, as a release detail, for slab and walls in Post-Tensioning construction.-The goals were achieved by establishing a unique testing rig to apply lateral load to the poured concrete specimens that contained the foam-wrapped steel dowel (rebar), which extended into a poured concrete slab.

Consequent research projects have been conducted to construct a model of concrete-foam-rebar media and simulate it using the Finite Element Analysis with ABAQUS© package. The objective has been to refine the model and material characteristics, until a nonlinear analysis and simulation produces valid and comparable results to the laboratory prototype. Structured and neat research methods were tabulated to teach the students as how to conduct research in a more passionate, productive, and useful way. These were conducting the extensive literature review, establishing the complex test rigs, evaluating the sophisticated mesh configurations and performing non-linear analysis.

The most important outcomes of the new research methods were; students' eagerness and enthusiasm to establish the test platforms, learning all the necessary hands-on skills despite obstacles and limitations, learning new simulation packages, and presenting in various

conferences and symposiums in a professional way. The reflections provided by students demonstrated their extraordinary satisfaction of this life-long learning experience, and the importance of their gained skills in future graduate programs and/or high-level industry positions.

Keywords: Undergraduate Research, Civil Engineering, Post-tensioned Concrete.

Introduction

Engaging undergraduate students to perform research in the field of engineering has become a common practice [1],[2],[3]. This is driven mostly by two forces; 1- some students are very interested in the activities outside of the regular courses and teaching, particularly when the investigation on a new topic is involved. 2-The researchers have found a valuable resource (interested and intelligent students) to conduct research and scholarship activity. The interest of students is stemmed in their vison that is focused on their future graduate study or high-level engineering carriers. Instructors, however, are dealing with a challenging task since they are using resources that are not trained for their research. Figure 1 illustrates these challenges.

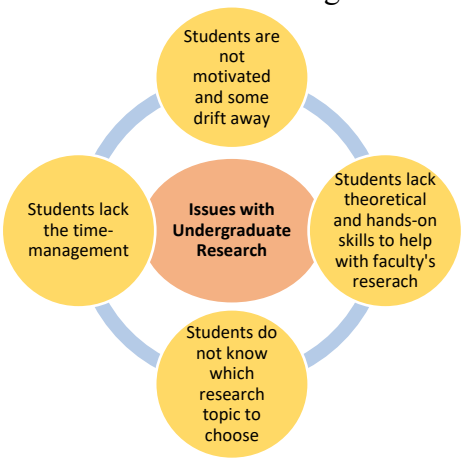

Figure 1- Challenges with undergraduate research.

Research methodology is a process to consistently resolve the technical problems. In order to have successful outcomes or goals, it is vital to acquire correct techniques alongside the methodology. This means selecting the best approaches in conducting research.

The benefits of conducting research with undergraduate students have been reviewed by many researchers. Many benefits have been addressed: such as enhancement of important cognitive and personal skills[1], the enhanced self-confidence in scientific thinking and gaining valuable scientific process skills [4],[5], and academic success[6]. In the fields of engineering, many researchers have evaluated the benefits of engineering of experimentation and have reviewed the theoretical and experimental aspects in engineering design experience. In most cases, faculty members have developed and taught a course (Directed Study) which stems from their own research interests [7],[8],[9],[10],[11]. Furthermore, faculty identified, recruited, and trained students to join their research labs, therefore they enhanced fulfillment in teaching itself [3],[12],[13].

This paper summarizes the important aspects of a comprehensive research project. The activities involved have been ranging from literature review to computer simulation. It then lists various techniques that can be utilized by instructors to achieve the best outcomes.

For all the directed study courses that students took, the following outcomes were set for all the activities combined:

1. Gain a deep understanding of the mechanical properties of concrete and steel,
2. Preform a literature review for the subject of this study,
3. Become familiar with the mechanical behavior of post-tensioning of the concrete slabs.
4. Be involved in designing simple-effective test rigs to perform experiments with small concrete blocks and a special compressible material.
5. Perform the required number of tests and analyze the data obtained from the experiments
6. Write a report.

For the parts involving the computer simulation, items 4 and 5 are replaced with the corresponding simulation related outcomes.

Research Activities

The following items are the core activities of the post-tensioned concrete structures research project conducted with undergraduate students.

1- Initiation of the project

The core project started in a company specialized in post-tensioning industry. The first author has had extensive industry experience in the field of post-tensioned concrete structures. The effects of slab shortening due to concrete shrinkage and post-tensioning compression should be considered in post-tensioned concrete construction used for high-rise buildings, bridges and so on. This is achieved by the proper design of the connection (Release-Connection) between slab and wall, otherwise cracking will develop. Various connection details are used in industry to mitigate the cracking. One permanent Release-Connection involves wrapping the vertical dowel that connects the slab and wall with a compressible material for the portion that is in the slab. The behavior of this connection has not been investigated.

In order to design this connection efficiently, it was decided to perform a real scale experiment in the plant of the company. The experiment provided valuable information, however, further experimental research was found to be essential to address some aspects of the slab-wall behavior observed in the experiment. This initiated the intension of performing further experiments at the authors' university by involving undergraduate students. The main challenge, however, was the lack of space and a testing platform at the university, due to the fact that such research activities had not been undertaken in the department in the past.

2- Acquiring space for the project

The very important component of an applied experimental research project is the space allocated for the project. Department of Civil and Environmental engineering (CEE) has a strong "Bridge Competition Team" and there exists a large facility in which undergraduate students fabricate

steel bridges for the regional and national competitions. In a visit to this facility, the instructor accompanied by one of the students of the bridge competition team, found a useful area that was mainly holding some unwanted scrap metals, and woods. The idea of establishing an experimental lab in that area and making use of unwanted materials was then triggered and later the same student joined the research team.

3- Selection of students

Six undergraduate students from two departments were involved in various components of the project. In addition to five undergraduate students from department of CEE, the second author of this paper from the department of Mechanical Engineering (ME) was involved in selecting an undergraduate student for the project. The ME instructor had already conducted many research projects in the field of Engineering and the student had gained valuable skills when engaging with the computer simulation of the projects. Therefore, the ME student was involved in computer simulation stage of this project and was then attracted towards some aspects of civil engineering.

Almost all students participated in more than one phase of the project. For example, some of the CEE students took part in the design and also building the platforms/test rigs, and the other ones performed some experiments, and presented their findings in undergraduate conferences, whereas the ME student became involved in computer simulation and presentation.

4- Budgeting

The engineering company which was the former workplace of the first author, was contacted for the project's funding support. Previously, the industry connection had been established between the lead author and this company, which is specialized in post-tensioned concrete structures. The company or industry partner was eager to provide some funding to support the research project. In addition, students who worked on the project, by registering in the Directed Study Course (CE and ME 4400), also applied for the Undergraduate Research and Creative Activities (URCA) funds at Kennesaw State University (KSU). During this process, three students were trained to write effective funding proposals that finally resulted in successful funding awards. URCA's grant as well as the company's funding helped the startup and continuation of the project. The industry partner that supported the project was content with the students' achievements, and also benefitted indirectly from the collaboration. A couple of students were sent to the company for the available engineering positions, as well as the internship.

5- Conducting extensive literature review

Students need to learn how to undertake effective literature review while utilizing different online databases. While literature review is very straight forward for the researchers, it is a painstaking task for students. Besides, some students may not know how to conduct the review effectively. They have to learn how to attribute credit for any prior work referred in research. They also need to learn what intellectual property rights are, and how to maintain ethics in research. All students involved in this project learned greatly as how to respect the work of others and how to address those in the new work properly.

6- Evolvement of the experimental procedure

One of the major characteristics of this undergraduate research activity was the process of the growth and development of the different stages of the experimental work that can be evaluated as being innovative, *i.e*., starting from simple and affordable possibilities, and gradually making progress toward using more powerful equipment. Due to the lack of proper equipment, at the start of the project the focus was given to investigating the basic and elementary parameters involved in the complex behavior of the release-connection that was tested previously in the plant of the company. These were:

a) to investigate the friction coefficient of connection between the concrete slab and walls in post-tensioned construction, and testing the resistance of concrete blocks against applied loads in variety of conditions.
b) to investigate the behavior of a compressible material that is used to wrap the rebar, as a release detail, for slab and walls in post-tensioned construction.

The essential equipment required to perform these tasks are loading and displacement-measurement mechanisms. In the absence of the equipment at the beginning, the instructor suggested the idea of using a combination of pulley and small cables mechanism, and the use of sands and light weights to apply loads in small increments. Two students, who were working on the project at the first phase, grasped the idea and used their hands-on skills to fabricate and assemble the system. Experiments were performed, and useful data was gathered. Simple plastic buckets were used as forms to cast cylindrical concrete specimens with the same height of the original full-scale experiments. Pictures presented in Figure 2 show the arrangement of four specimens, and loading. Figure 2 (left) shows the loading on specimen number two (concrete only). The brown box contained sand which was increased incrementally. The force applied was transferred to the specimen via cables and pulleys. A dial gage was used to monitor the movement of the specimen. Figure 2 (right) shows the loading on specimen number four (concrete with foam-wrapped rebar). For this specimen, the box was filled with sand, and additional weights were added. With this system, a maximum load of 270 *lb* was applied until the foam was fully compressed.

Figure 2- Concrete specimens under gradually applied loads.

By receiving additional funding, the testing equipment were significantly improved, and the experimental work evolved to a higher level. Hydraulic jack and load sensors (Load Cells) with high capacity and accuracy were used together with accurate-measurement sensors (transducers). The sensors were connected to the computer using the vendor's software for data acquisition. Students were excited to perform experiments on two specimens having real-life thickness and reinforcement. Instructor and students work together, sometimes even until midnight, to fulfill the experimental tasks. Instructor was not only supervising and teaching various construction methods, but also became involved in doing hands-on activities, and casting concrete with the students. There existed challenges and obstacles during the procedure that were eventually overcome by close collaboration between students and the instructor. In Figure 3 pictures of the evolved testing equipment and specimens are presented.

The lesson learned from this part of practice was that students were eager and passionate about the new ideas. They enjoyed the exercise of being creative and thinking outside the regular subjects that they usually study in everyday courses. They were energized by the fact that the instructor is working shoulder to shoulder with them.

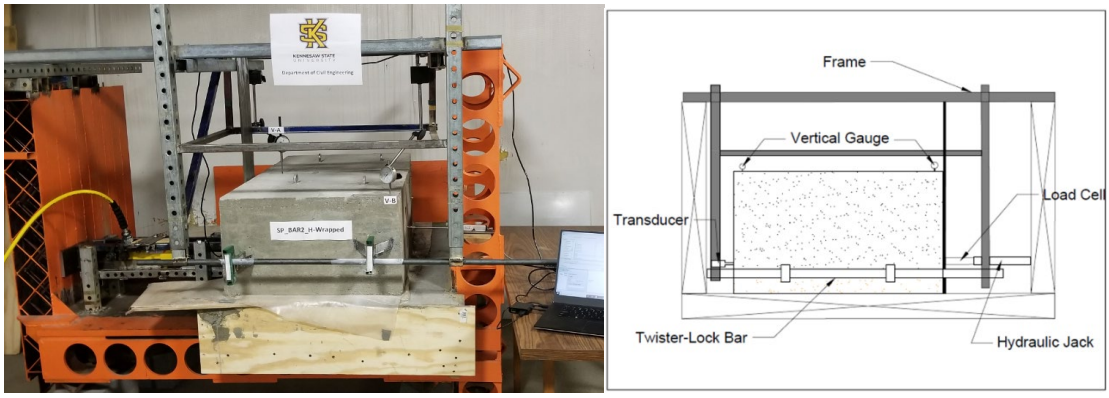

Figure 3- A more advanced setting for the experiments using high capacity loading, and measurement system.

7- Inspiring the team and keeping the passion for fulfilling the outcomes

The most important factor in the success of any research project is the drive and passion to perform the research. Students were informed of the benefits of conducting the research projects, to not only list them in their resumes, but also to gain extensive skills for their future as an engineer or graduate student. Instructors invited the students to have lunch with them and approached them from a personal level. It should be noted that this approach is possible for a limited number of students. The research approach presented in this paper is not usually applicable to a large number of students. Instructors shared their own industrial experience with the students, and they became excited and spent time even on weekends to meet the deadlines. One of the students explained the skills that he acquired to his family, and his father decided to help him to assemble the testing frame on a Saturday. All students showed enthusiasm towards the project and found it very valuable and applied. All students were engaged deeply and followed the instructions to the end.

8- Effect on other faculty and students

Students talked to their classmates about the experience that they had with the research project. They expressed how the research had benefited them and how much skills they gained along the way. One of the students appeared on the university news website, which further encouraged other professors and students to look into the successful methods used during this project.

9- Recording and analyzing the data

Some undergraduate and even graduate students may not know how to use the valuable packages such as Excel©. Through this research, most of students had the chance to use Excel in a more professional way. They learned how to pick the reliable data from the test runs, how to record them in the Excel sheets and how to plot curves and interpret them.

10- Computer simulation

Computer simulation of the experimental models is sometimes part of a comprehensive research study. Since one of the main objectives of this research project was to engage undergraduate students in all aspects of the research, it was therefore decided to train at least one student to perform a Finite Element Analysis (FEA) on one of the experimental specimens. As a heterogeneous and generally anisotropic material with both brittle and ductile failure modes, reinforced concrete is a difficult material to simulate using FEA.

One undergraduate student who had extensive experience in using the package Solidworks© started to work on the project for his three-credit Directed Study course. His work provided a review of general (FEA) techniques and methodologies, how concrete and reinforced concrete are unique, and examples of accurate modeling to assist in further understanding of this subject. A complete overview of FEA was carried out. A general procedure for FEA is consisted of: geometry definition, where the shape and scale of a system are defined; meshing, where the overall geometry is broken down into any number of parts that can be treated as analytical systems; solving, where some type of computational solver is used to evaluate the whole system until equilibrium is reached; and visualization, where the results of the solution are translated to a user-readable format.

The intention was to make the student familiar with the powerful ABAQUS© package which is a world-known software used to analyze complex models in many engineering fields. The student made the initial model (meshing) using Solidworks and then imported the model to ABAQUS/CAE. After learning the basics of the new package, the student discovered about its capabilities and became very passionate to learn more. The student enthusiastically spent hours in excess of a normal course. He learned not only the linear analysis, but also the complex non-linear modeling of the foam (that was used to wrap the rebar in the experimental specimen) as a highly compressible material. The FEA results were not tallied with the experimental findings due to complexity of the foam-modeling, and the time constraints and further investigation should be carried out. The student's experience in this study is considered as one of the examples of the "Students Success" in of engineering programs. Figure 4 presents the transparent mesh

plot of the FEA model (left) as well as the wrapped rebar in the experimental specimen prior to casting concrete (right).

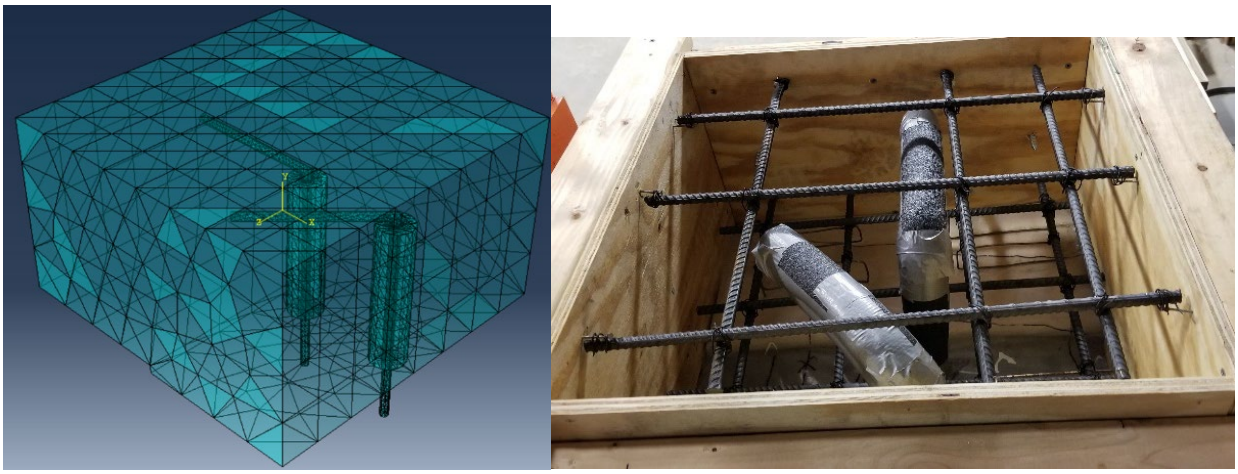

Figure 4 : Transparent mesh plot complex concrete-rebar-foam model, and the real specimen.

11- Presenting the research results

All students presented their research outcomes in engineering conferences. Students were trained as how they should present themselves, how to consider the time for presentation, how to answer the participants' questions and how to use the soft skills they learned for their future career. They learned how to create posters and presentation slides using the Power-Point package. They learned many soft skills along the way, which will be very important for their future as engineers or graduate students.

All students became involved in presenting the various aspects of the project in the undergraduate research symposiums and conferences. Two students had poster presentation in an event in the Georgia Capitol. Along the way they learned:

- how a scientific paper should be written,
- how to address the previous work carefully and select only those which have been relevant,
- how the data should be presented in the paper,
- how the images and tables should be created,
- how results should be placed in the paper in a concise and yet sufficient way,
- how conclusion and discussion should be written to refer to the subsequent parts of the project and also to include the suggestions for other researchers.

Innovative Approaches

In this work some innovative techniques are suggested to overcome the research obstacles. They are summarized in Table 1.

Table 1- Innovative techniques to overcome the research obstacles.

Issue with Undergraduate Research	Useful Methods
Students do not know about the benefits of undergraduate research, and are not sure which research area to choose.	• Connect the students to industry via student organization's tours, competitions, etc. • Bring applied examples in classes, and assign some real-life simple projects in class. • Invite former students or former colleagues to come and present seminars and answer the students' questions.
Literature review is painstaking and it takes a lot of time for students to accomplish it. It is boring for students.	• On the website of the course (*e.g.* Desire-2-Learn or D2L) create a module just for literature review. Place one paper, the summarized paragraph for that paper, and the citation. Explain how the literature review is conducted effectively. • Let students progress by tackling the learning activities, and tasks simultaneously. While they write few literature reviews, at the same time, they can prepare the test materials, and design the computer model.
Students lack technical and hands-on skills.	• Place students with better theoretical knowledge and the ones with more hands-on skills in one team. • Set the outcomes to have both components and have the students teach each other. Have them teach each other how to use various machineries, etc.
Students do not have passion to conduct the research project effectively.	• Make a personal connection. Invite students to lunch. Be present in the lab and run tests together. • Talk about your own research projects, and create a passionate environment. Select the most enthusiastic students for the research.
Students are not capable to resolve the engineering issues and overcome the obstacles. They do not have attention to details and make mistakes.	• Mentor the students effectively. • Instructors should be present to resolve the engineering issues (such as experimentation difficulties, simulation package limitations, *etc*.) and teach the students what tasks should be carried out. • Students are asked to resolve smaller issue to learn and then they get encouraged. • Students should be asked to check each obtained result twice and this should become a habit. • Have the students work in a team and ask them to check each other's work. • Acknowledging the students' achievements.
Students procrastinate and do not know how to manage their time.	• Have continuous meetings. Have them report what they accomplished the week before. • Give them frequent and consistent feedback. • Teach them how to prioritize their daily tasks. • Make the research activities fun. • Students procrastinate less if they work in groups. • Encourage them a lot. Encouragement not only produces more passion, but also makes students to become keen to finish the tasks sooner.

Figure 5 shows some of the benefits of a successful undergraduate research based on the current work.

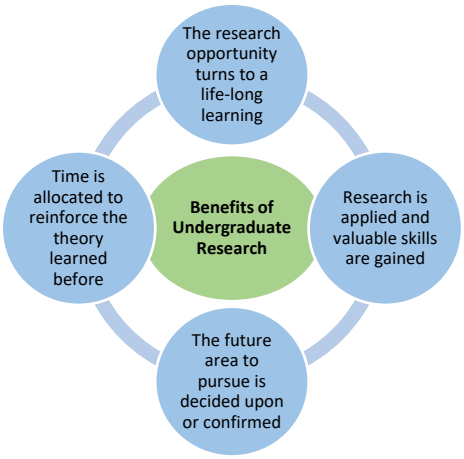

Figure 5- Some of the benefits of a successful undergraduate research.

Conclusions and Discussion

Conducting research with undergraduate students is challenging and yet rewarding, if it is performed effectively. Some of the benefits are: closer integration of teaching and research, helpful influence on promotion and tenure, having the options of publication of research in both engineering as well as education journals and great influence on students' future carrier aspirations. Undergraduate Students who perform research often become passionate in research activity, and grow interest in pursuing graduate programs.

In this paper, various parts of a relatively large industry-related undergraduate research project have been explained. The project was related to the post-tensioned concrete construction. Six undergraduate students from the department Civil and Environmental as well as the department of Mechanical Engineering conducted the research under the supervision of the authors. Innovative methods were used by the instructors to increase the efficiency of the projects and to speed up the process of "testing, data analysis, and presentation" sequence or "simulation, overcoming obstacles, and presentation." Meetings were held between the lead author and the supporting industry partner to encourage them to fund the project. The authors' university supported some other expenses. After space allocation and effective brainstorming, the testing platforms were established and experiments were conducted. The lead author accompanied the students in the lab to conduct the research and to collect the experimental data. Finite element modeling of the reinforced concrete structures started and one student was trained to use the powerful package ABAQUS for the first time, which is rarely used at undergraduate level.

Some innovative techniques are suggested in this work, to overcome the obstacles in conducting research with undergraduate students (Figure 1). These techniques are summarized as follow:

- Connect the students to industry and alumni to give them a sense of purpose and to increase their passion to select a specific research area.
- To ensure a smooth paper writing process, online platforms such as D2L, can be used to direct students towards the goals and to finalize the paper faster.

- Students' efficiency increases if they work in groups. They can learn from each other and gain valuable skills (theoretical and hands-on).
- It is more beneficial for students to get involved in more than one aspect of the project (*e.g.* experimental analysis and modeling) and to perform tasks simultaneously rather than one after another (if possible).
- Making a personal connection with students and encouraging them are very important. It is vital to not only become a role model for them, but also to resolve the issues that they might face along the way. They will be trained to be more careful and responsible and develop good habits for finishing the tasks.

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