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BOARD # 56: Spreadsheets in Civil Engineering: Fostering Proficiency through Practical Applications in Statics

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Spreadsheets in Civil Engineering: Fostering Proficiency through Practical Applications in Statics

Abstract

Spreadsheets are ubiquitous in civil engineering offices and are an important tool for data management, engineering calculations, visualization, and report generation. Proficiency in working with spreadsheets also improves productivity and streamlines the quality analysis/quality control process. Cultivating proficiency requires students to integrate spreadsheet usage into their daily activities. While first-year and second-year students may sporadically utilize spreadsheets in their science laboratory courses, they do not necessarily apply spreadsheets in an engineering context.

To better align spreadsheets with the practical experiences of civil engineering students [1], a series of statics-related assignments were incorporated into a second-year civil engineering course at Saint Louis University, Missouri, United States. Students utilized spreadsheets to solve problems related to centroids and moments of inertia, equilibrium of a particle, shear force and bending moment diagrams, and truss analysis. Most students were concurrently enrolled in a statics course where they solved similar problems using pen and paper calculations and submitted their work.

This research assessed student work, evaluated learning outcomes, and analyzed student feedback regarding the application of spreadsheets to statics topics. A survey was developed to collect students' opinions about competency in spreadsheets, their use in statics, and their utility in understanding concepts. Pre-test and post-test survey analysis revealed an improvement in students' self-reported spreadsheet proficiency, with students notably viewing spreadsheet-based statics problem-solving as a form of hands-on learning. Assessment of students' homework assignments revealed that the majority of students had met the learning outcomes related to the use of spreadsheets and were also able to solve statics problems correctly.

Introduction and Background

Spreadsheets are versatile tools in civil engineering offices, utilized for cost estimating, engineering calculations, project management, and data visualization. Their widespread availability across engineering firms and clients facilitates collaboration between multiple teams. However, while first-year and second-year students may occasionally use spreadsheets in science laboratory courses, they often lack opportunities to apply these tools in engineering contexts. Providing early exposure to spreadsheets is important as it could improve student preparedness for advanced coursework and future professional practices.

To better align spreadsheets with the practical experiences of civil engineering students, a series of statics-related assignments were incorporated into a required civil engineering course for second-year students at Saint Louis University, Missouri, United States. Students were asked to utilize spreadsheets to solve problems related to centroids and moments of inertia, equilibrium of a particle, shear force and bending moment diagrams. The learning objectives of the course related to understanding the fundamentals of computer programming and applying basic features of productivity tools. The majority of students enrolled in this course were concurrently enrolled in statics course, and few students have already completed statics. This paper assesses students' work and analyzes students' feedback regarding the use of spreadsheets, the use of spreadsheets for statics, and the utility of spreadsheets for understanding statics concepts.

The remainder of the paper is organized as follows: First, a brief review of research on applications of spreadsheets in civil engineering education is provided. Then, the civil engineering computing course is described, and an overview of statics-related assignments is provided. Following this, students' statements in the pre-test and post-test surveys along with other papers' findings are reviewed. Finally, directions for future research and the next steps of this work are discussed.

Literature Review

To the best of the authors' knowledge, existing literature has not addressed two key areas: the use of spreadsheets specifically for solving statics problems, and the impact of spreadsheet-based civil engineering problems on improving spreadsheet relevance for first- and second-year students. While several researchers have explored spreadsheet applications in engineering education, their focus and findings differ from the present study's objectives. Ristroph [2] provided examples of applications of spreadsheets and Visual Basic for Applications (VBA) scripts for solving engineering economics problems as well as the development of graphics in Excel. The paper did not report students' feedback or offer an assessment of students' learning. Bermúdez et al. [3] described their efforts to incorporate spreadsheets in an undergraduate hydraulic engineering course to facilitate calculations and numerical simulations. Their work did not report students' feedback or an assessment of students' learning. Liu [4] shared several examples of utilizing spreadsheets for teaching topics related to engineering mechanics, vibration, and machine design. Students' feedback or assessment of their learning was not reported. Pickel et al. [5] developed a physical model along with an accompanying spreadsheet to improve students' understanding of the relationship between applied load and beam deflection. They reported students' feedback about the activity but did not discuss students' feedback on utilizing spreadsheets. Okudan and Ogot [6] reported their efforts to teach project management concepts to students using spreadsheets. While several studies [7-11] have reported their efforts to incorporate spreadsheets in various engineering courses, these efforts do not reflect the impact of these educational interventions on students' competencies with spreadsheets. In summary, while previous research has demonstrated various applications of spreadsheets in civil engineering education, the specific impact of using civil engineering-related problems to foster spreadsheet proficiency among early-year civil engineering students remains unexplored. This study addresses this gap by introducing statics-related problems in a course related to fundamentals of computer programming and productivity tools and assesses students' learning and perceptions of their competencies with spreadsheets.

Computational Tools in Civil Engineering Course

The course is a required class in the civil engineering curriculum, and the majority of civil engineering students enroll in this course in the fall semester of their second year. The course is three credit hours and meets twice a week in 75-minute sessions in a computer lab. The prerequisite for this course is Calculus I. The course introduces students to several computer programs, including Mathcad and Microsoft Excel. In terms of spreadsheets, students are expected to apply functions, create a PivotTable, use the Solver to solve for equations and optimization problems, record and utilize macros, and code with Visual Basic for Applications (VBA) to complete analyses, visualize data, and automate tasks. The students enrolled in this course are typically concurrently enrolled in other civil engineering courses that include statics, GIS and surveying, and construction and project management courses. Students have already completed the introduction to civil engineering course, and a drafting and 3D modeling course in the spring semester of their first year.

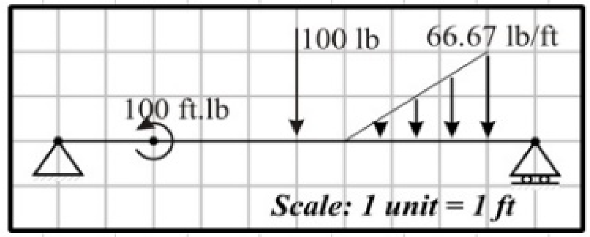
Statics-Related Assignments

Five sets of homework assignments related to statics were introduced in the course, requiring students to: 1) determine the centroid of a composite section, 2) develop shear force and bending moment diagrams for a simply supported beam, 3) develop shear force and bending moment diagrams for a cantilever beam, and a simply supported beam, and 4) calculate the area moment of inertia of a composite section about the x- and y-axes, and 5) solve a problem related to equilibrium of a 3D particle. The classwork and homework assignments followed the class modules functions in spreadsheets and plotting in spreadsheets. During class sessions, students worked on one example problem for each type of statics-related activity. On average, each problem was completed within 30 minutes and during a single classroom session. Following each class session, a homework problem was assigned to students related to statics problems solved in the class. Figure 1 provides an example of the homework problem related to shear force and bending moment diagrams for a simply supported beam. In this problem, students were expected to determine the magnitude of the support reactions and then conduct intermediate calculations to determine the magnitude of shear force and bending moment at various distances, so that they could connect them to create a plot.

Preliminary Findings

The proposed activities were implemented in the fall 2024 semester. There were 19 students enrolled in the course. Three students had previously completed the statics course, 14 students were enrolled in the statics course concurrently, and two students had not enrolled in statics yet. This was unexpected as students enrolled in this course usually have succeeded in statics or are enrolled in statics concurrently. These two students were asked to follow along with the activities in class and complete the in-class work; however, they were exempted from homework assignments.

Draw the shear force and bending moment diagrams for the simply-supported beam.



x (ft)	DF (lb/ft)	CF (lb)	CM (ft.lb)	V (lb)	M (ft.lb)
0.00				0.00	0.00
0.00		80.00		80.00	0.00
0.50				80.00	40.00
1.00				80.00	80.00
1.50				80.00	120.00
2.00				80.00	160.00
2.50				80.00	200.00
3.00				80.00	240.00
3.00			-100.00	80.00	140.00
3.50				80.00	180.00
4.00				80.00	220.00
4.50				80.00	260.00
5.00				80.00	300.00
5.00		-100.00		-20.00	300.00
5.50				-20.00	290.00
6.00				-20.00	280.00
6.00	0.00			-20.00	280.00
6.50	-11.11			-22.78	269.31
7.00	-22.22			-31.11	255.83
7.50	-33.33			-45.00	236.81
8.00	-44.44			-64.44	209.45
8.50	-55.55			-89.44	170.98
9.00	-66.66			-119.99	118.62
9.00				-119.99	118.62
9.50				-119.99	58.63
10.00				-119.99	-1.37
10.00		120.00		0.01	-1.37

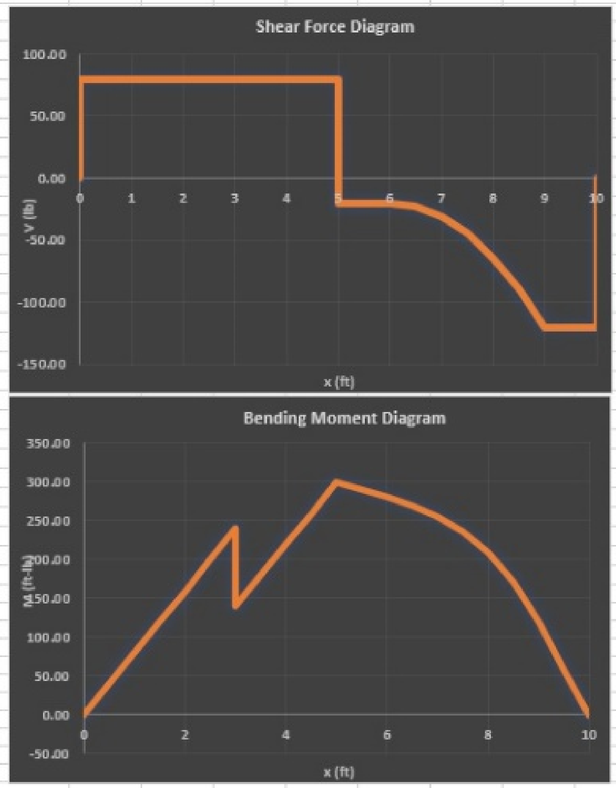


Figure 1. Shear Force and Bending Moment Diagram Homework Assignment

Anonymous pre-test and post-test surveys were distributed to students. 19 students completed the pre-test survey, and 17 students completed the post-test survey. The post-surveys were distributed to students after all the statics-related modules were completed. The students who were not enrolled in statics did not complete the post-test survey. Surveys were anonymous and unpaired. The authors were not able to remove the responses of students who were not enrolled in statics from the pre-test data. This section provides an analysis of the surveys and summarizes instructor observations.

Students’ Perception of Their Competency in Statics and Spreadsheets

A quasi-experimental pre-test/post-test single-group design method [12, 13] was utilized to assess the impact of statics-related assignments on students' perceptions of their competency in spreadsheets, their use of spreadsheets for statics, and the utility of spreadsheets for understanding statics concepts. The pre-test survey consisted of statements one through six, while the post-test expanded to include these statements plus an additional four, totaling ten statements. The authors could not identify a validated instrument related to the use of spreadsheets in civil engineering and developed the survey with questions that focused on competency in spreadsheets (statements one to three), use of spreadsheets in statics (statements four to six), and utility of spreadsheets in understanding statics concepts (statements seven to nine). Students expressed their opinions on the statics-related content using a five-point Likert scale, ranging from 'strongly disagree' to 'strongly agree'. These statements are listed below:

Statement 1: I am confident in my ability to apply spreadsheet skills in my daily activities.

Statement 2: I am confident in my ability to use basic functions and formulas in spreadsheets (e.g., SUM, AVERAGE)

Statement 3: I am confident in my ability in creating and customizing plots and graphs in spreadsheets.

Statement 4: I am confident in my ability to apply spreadsheets to solve homework problems in various classes.

Statement 5: I am confident in my ability to apply spreadsheets to solve civil engineering problems.

Statement 6: I am confident in my ability to apply spreadsheets to solve statics problems.

Statement 7: Excel enhanced my abilities to (design and) analyze structures.

Statement 8: Excel facilitated a more hands-on and practical approach for learning statics concepts.

Statement 9: I found the use of Excel enriching for a better understanding of statics.

Statement 10: Do you have any other comments or suggestions about applying spreadsheets for solving statics problems?

Survey Results

In this section, the results from the pre- and post-test surveys are discussed. The pre- and post-test surveys revealed notable patterns in student responses. Figure 2 depicts the weighted average responses to statements one through six across both surveys, while Table 1 details the response distributions and changes for each statement. The Mann–Whitney U test [14] was utilized to evaluate the null hypothesis that the distributions of students' responses to pre-test and post-test surveys are from distributions with equal medians. The test results indicated that the null hypothesis cannot be rejected for any of the statements one to six, each showing a p-value of at least 0.84. The small sample sizes and difference in the number of before and after responses could likely contribute to this outcome. In the post-survey, one response showed "strongly disagree" for all items. While a validation question could have helped verify if this represented genuine responses, this response was retained in the analysis. This uniform negative response pattern may have contributed to the statistical test outcome. Overall, the responses to the pre-test and post-test surveys revealed a positive change in students' perception of their proficiency with spreadsheets, even though these shifts are not statistically significant.

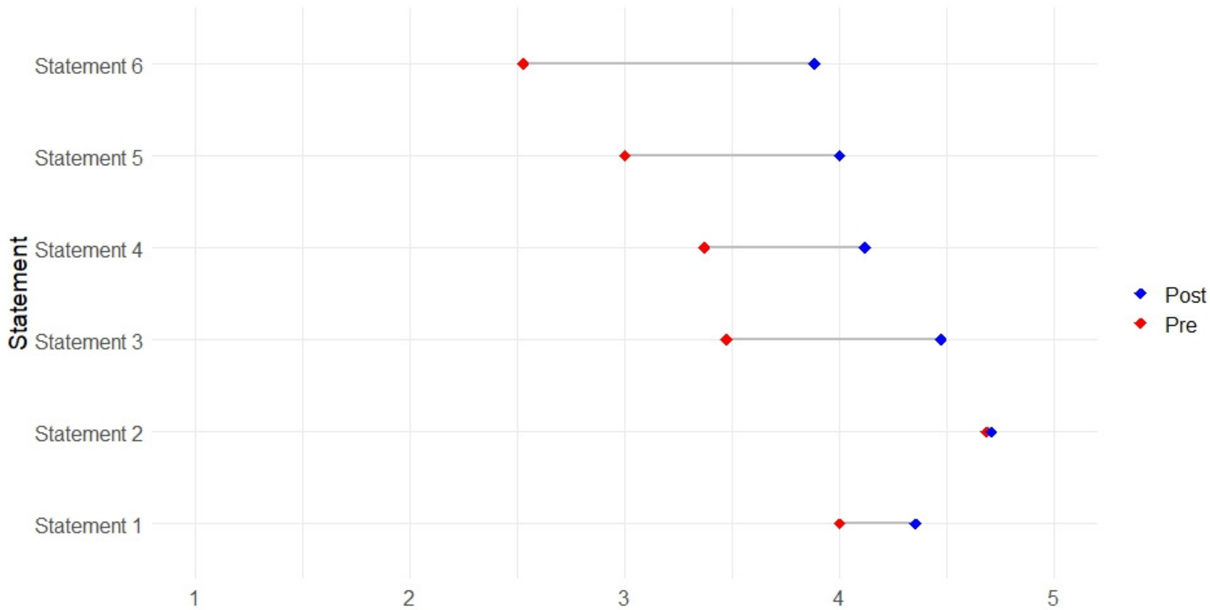


Figure 2. Weighted average response to statements one to six in pre-test and post-test surveys (Strongly disagree, Disagree, Neither agree nor disagree, Agree, Strongly agree)

Table 1. Distribution of Responses in Pre- and Post- Surveys and Changes in Responses

Statement	Strongly disagree			Disagree			Neither agree nor disagree			Agree			Strongly agree		
	Pre-	**Post-**	**Δ**	**Pre-**	**Post-**	**Δ**	**Pre-**	**Post-**	**Δ**	**Pre-**	**Post-**	**Δ**	**Pre-**	**Post-**	**Δ**
1	0%	6%	+6%	0%	0%	0%	16%	0%	-16%	68%	41%	-27%	16%	53%	+37%
2	0%	6%	+6%	0%	0%	0%	5%	0%	-5%	21%	6%	-15%	74%	88%	+14%
3	0%	6%	+6%	5%	0%	-5%	42%	0%	-42%	53%	29%	-24%	0%	65%	+65%
4	5%	6%	+1%	21%	0%	-21%	5%	6%	+1%	68%	53%	-15%	0%	35%	+35%
5	5%	6%	+1%	26%	0%	-26%	37%	12%	-25%	26%	53%	27%	5%	29%	+24%
6	16%	6%	-10%	32%	0%	-32%	42%	24%	-18%	5%	41%	36%	5%	29%	+24%

Competency in Spreadsheets:

Statements one through three focused on students' competency in using spreadsheets. Overall, the post-survey responses showed increased confidence across all competency measures.

Statement One: By the end of the statics module, 94% of students (41% agree, 53% strongly agree) reported confidence in applying spreadsheet skills to daily activities. This represents a notable shift toward stronger confidence, with a 37% increase in students selecting "strongly agree."

Statement Two: Students' confidence in using basic spreadsheet functions and formulas remained consistently high between surveys. The majority of students expressed confidence in both pre-survey (95% combined agree/strongly agree) and post-survey (94% combined agree/strongly agree) responses.

Statement Three: Students' confidence in creating and customizing plots and graphs showed the most dramatic improvement. While no students strongly agreed with this statement in the pre-survey, the post-survey showed 65% strongly agreeing and an additional 29% agreeing, for a total of 94% expressing confidence in graphing skills.

Use of Spreadsheets in Statics:

Statements four through six reviewed students' confidence in their ability to apply spreadsheets in their curricular activities. This category showed the most noteworthy changes between pre- and post-surveys. In the pre-survey, 63% of students indicated they either strongly disagreed, disagreed, or were neutral about their confidence in using spreadsheets for curricular activities. However, by the post-survey, this pattern had reversed substantially: 80% of students agreed or strongly agreed with statements regarding their spreadsheet competencies in academic work.

Statement Four: This statement asked about students' confidence in their ability to apply spreadsheets to solve homework problems in various classes. The results showed a 20-percentage-point increase in positive responses between pre- and post-surveys and a 35 percentage-point increase in the students who indicated they strongly agree with this statement.

Statement Five: This statement focused on students' confidence in their ability to apply spreadsheets to solve civil engineering problems. While in the pre-survey, only 31% of students expressed confidence in their abilities, the post-survey results revealed that 81% of students were confident (combined agree/strongly agree) in their ability to utilize spreadsheets to solve civil engineering problems. This shift demonstrates the impact of the statics module in improving student confidence in their spreadsheet competencies.

Statement Six: This question enquired about students' confidence in their ability to apply spreadsheets to solve statics problems. In the pre-survey, only 10% of students expressed confidence (combined agree/strongly agree) in their ability to utilize spreadsheets to solve statics problems; however, in the post-survey results 70% of students expressed confidence in their competencies, and 24% of students expressed a neutral response.

Utility of Spreadsheets in Understanding Statics:

The post-test questionnaire included three additional statements regarding the utility of spreadsheets in understanding statics, as shown in Figure 3. Students had a positive view of using spreadsheets for solving statics problems, viewed the process as hands-on, and practical learning, and majority agreed that use of spreadsheets improves their understanding of statics.

Statement Seven: This statement focused on students' perception of the role of using spreadsheets in enhancing their abilities to analyze structures. 29% of students agreed with this statement and 23% strongly agreed, while 35% had a neutral response. This level of agreement is not unexpected, given that the classroom example focused on analysis of beams in spreadsheets, without including examples of frame and truss analysis.

Statement Eight: This question asked students to indicate their level of agreement with the statement that spreadsheets facilitated a more hands-on and practical approach for learning statics concepts; 59% of students agreed with this statement and another 23% strongly agreed. Majority of students viewed these activities as “hands-on”, and found them helpful in learning statics.

Statement Nine: The last question asked students to rate how much they agreed that they found the use of spreadsheets enriching for a better of statics. The response was overwhelmingly positive, with 47% agreeing with the statement and 29% strongly agreeing with the statement.

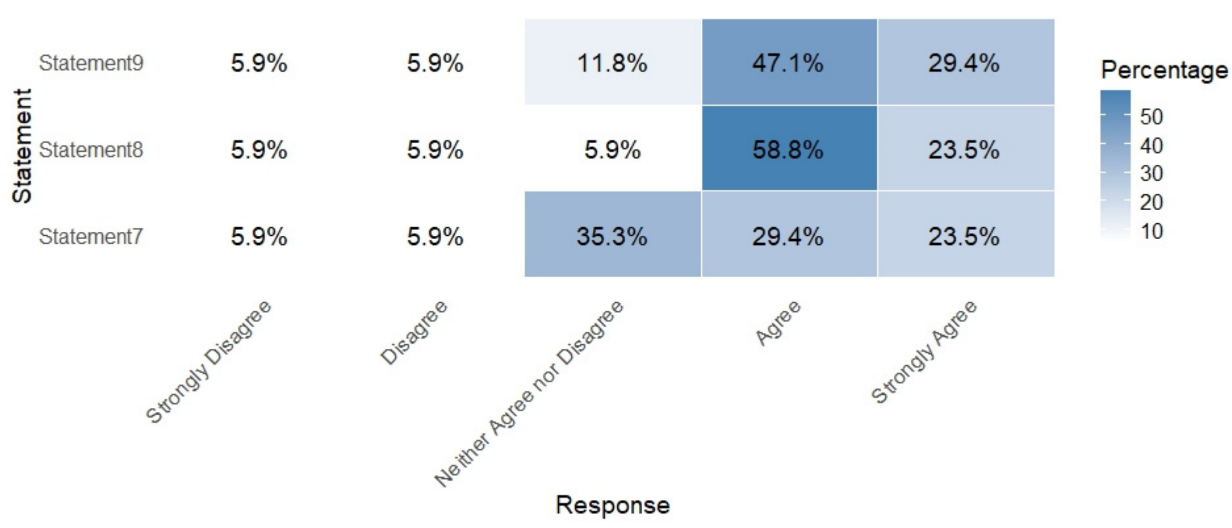


Figure 3. Students Response to Statements Seven to Nine

Assessment of Students' Learning

Students submitted five homework assignments related to 1) determine the centroid of a composite section, 2) develop shear force and bending moment diagrams for a simply supported beam, 3) develop shear force and bending moment diagrams for a cantilever beam, and a simply supported beam, and 4) calculate the area moment of inertia of a composite section about the x- and y-axes, and 5) solve a problem related to equilibrium of a 3D particle.

The primary objective of this course was to teach students to apply spreadsheets to engineering problems. However, from the statics point of view, all students calculated the centroid coordinates correctly, and with the exception of one student, all the calculations for the area moment of inertia were correct. From the perspective of developing spreadsheets, two students submitted spreadsheets with formatting and organizational issues (e.g., missing borders for tables). In general, students completed the assignments related to the centroid of a composite shape and the area moment of inertia without any specific issues. In the statics course, students follow the method of tables to calculate the centroid and the area moment of inertia, which is fairly similar to utilizing spreadsheets for calculating these geometric properties.

The shear force and bending moment diagram assignments presented the students with the most challenges. 17 students submitted this assignment. From a statics point of view, two students were not able to define sections for the beam and calculate the shear force and bending moments. The remaining students calculated the shear force and bending moment values correctly for the boundary points of beam sections; however, five failed to realize that the bending moment diagram for a beam subject to a uniform distributed load is a polynomial, and they needed to calculate bending moments at intermediate points so that the bending moment diagram appears as a curve. From a spreadsheet point of view, six students failed to label the axes of the diagram with correct information.

With regards to the problem related to the equilibrium of a particle, all the students calculated the components of the resultant force correctly; however, three students made an error in determining the magnitude of the resultant 3D vector. Students demonstrated correct formatting and proper spreadsheet usage in their work.

Instructor Observations and Study Limitations

In previous offerings of this course, students were concurrently enrolled in statics or mechanics of solids courses. This semester, for the first time, two students had not yet enrolled in statics. These two students were exempt from submitting homework assignments related to statics; however, they voluntarily submitted work related to centroids and area moment of inertia. Prior to each in-class activity, the instructor dedicated a few minutes to providing a quick refresher on the procedure for solving the statics problems. These two students appeared to follow along with the rest of the class during in-class activities; however, it was clear that they did not have the background knowledge to truly understand the concepts and fundamentals. Including statics-related work for students who have not yet enrolled in statics is not an equitable and fair use of in-class time. An alternative for future course offerings could be to assign group projects to students that involve statics calculations. The students who have not yet enrolled in statics could contribute to other aspects of the project.

A limitation of this study is that it did not evaluate whether using spreadsheets to work on statics problems in the programming course improves student performance in the Statics course. Based on instructor observations, a few students occasionally commented to peers that using spreadsheets helped them better understand statics concepts. While these informal observations are promising, they should be evaluated in future studies using appropriate instruments and measurement methods. Additionally, one can argue that working on Statics problems in spreadsheets provides additional practice, which should lead to improvements in student learning.

Summary and Future Work

This study investigated the integration of statics-related problems into a second-year civil engineering computing course to enhance students' spreadsheet proficiency. A pre- and post-survey of students' perception of their spreadsheet competencies revealed that the majority of students perceived their spreadsheet skills improved and gained more confidence in utilizing spreadsheets to solve civil engineering problems. Additionally, the survey revealed that students perceived solving statics problems in spreadsheets as a hands-on and practical approach to statics problems. Assessing the students' work demonstrated that students were able to calculate the correct answers for problems related to centroids, moment of inertia, and the equilibrium of a particle. However, several students made statics and spreadsheet-related errors when developing shear force and bending moment diagrams for a cantilever beam subject to concentrated and distributed forces.

Building on these findings, future work will explore three key directions: (1) the implementation of both semi-structured and unstructured spreadsheet templates to assess higher-level competency development, (2) the expansion of problem types to include unit vectors, particle equilibrium, and truss analysis, and (3) the adoption of paired pre/post-test methodology to enable more rigorous statistical analysis of learning outcomes. Additionally, future studies should investigate whether this integrated approach leads to improved performance in concurrent statics courses.

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