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Student Interaction and Perception of FE-Based Formula Sheet Use in Engineering Exams

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Abstract

Completion of the Fundamentals of Engineering (FE) Exam is a graduation requirement for students in the Civil & Environmental Engineering program at The Citadel. The FE supplied resource handbook (FERH) contains formulas, standard values, conversions, etc. However, textbooks and the FERH often use different versions of standard equations. To familiarize students with FERH, students in many engineering courses are given a standardized formula booklet for class tests based on the FERH. Some courses allow annotation of the provided FERH to clarify content. Other courses in the program may not use the FERH as a testing resource. This paper will present student perceptions on the use of the FERH in civil engineering courses, the annotation content in a semester's collected formula booklets, and possible correlations between FERH interaction and performance on FE practice exams.

Keywords

FE Exam, Test resources

Introduction

In the United States, professional engineering licensure via state boards consists of three major steps: education, experience, and exams.[1] Colleges and universities play a critical role in the education requirement through curricular development and program accreditation. They can also play a role in assisting graduates in experience acquisition through career support services. The extent to which institutions should include passage of the exams- the Fundamentals of Engineering (FE) and Practice of Engineering (PE)- as a graduation requirement or even emphasize test content in the curriculum is open to debate.[2,3] Regardless of curricular emphasis on FE exam preparation, Civil Engineering programs aim to prepare students for eventual licensure and some have created FE review courses to assist toward completion of the exam requirement.[4] Such a course has been implemented in the senior year at The Citadel, student outcomes of which are still being quantified.

Outside of significant modification of testing format or course content or addition of an FE exam preparation course, there are more minor actions faculty can take to support student FE performance. The method investigated here is the use of the FE Reference Handbook (FERH) in engineering courses. The FERH is a standardized formula book and is the only allowed resource during the FE exam. The 10.1 edition of the FERH consists of nearly 500 pages of content.[5] Via anecdotal evidence, the formulas as presented in the FERH sometimes differ from what is included in engineering textbooks due to use of different variables or algebraic reorganization of equations. These small differences along with the length of the resource may increase student stress while taking the FE exam.

Discussion regarding the purpose and utility of open versus closed book testing has existed for many decades. Early publications include work by Kalish at the University of Hawaii in 1958 and Tanner at Florida State University in 1970.[6,7] Both of these studies concluded there were negligible performance benefits for students on open book versus closed book examinations. More recent studies from 2010 by Agarwal & Roediger and Theophilides & Koutselini showed more in-depth evaluation of the quality and type of student learning from open versus closed book testing scenarios.[8,9] These studies seem to have opposite findings. The prior demonstrated that when students are told to expect an open book test, they may decrease or postpone test preparation and review activities. The latter study concluded that students taking open book exams may show higher levels of critical thinking in test preparation and completion. One relevant study was found in the ASEE Peer Repository on this topic from 2012 where West Point faculty compared student test preparation and performance in an entry -level statics and mechanics of materials course.[10] They found minimal effect on either parameter when the provided test resource was removed. Such minimal performance impacts and sometimes contradictory findings are present across the open versus closed book testing literature. The current work, however, delves further into the topic of student comfort with a provided testing resource and approaches an understanding of long-term retention of course content. This topic has been approached before within ASEE in 2020 by Paquin, Miller & Barron, where the redesign of a helicopter aeronautics course showed student performance improvement when testing resources changed from a student created page to a course provided formula sheet.[11] This study, however, did not approach the topic of student information retention or their continued ability to comfortably access information in the provided formula sheet. The current work begins to address this gap. A potential complement to the current work was published in 2008 in *Applied Cognitive Psychology* that shows no effect on student performance under open or closed book testing scenarios but instead showed repeated testing, especially with provided feedback, enhanced long term retention over repeated studying of the source text.[12] The idea of repeated testing with feedback as preparation for the FE is explored in other work submitted for the ASEE Southeastern Section conference this year. In order to limit the effect of repeated testing on student performance, data in this study is limited to their first attempt, to demonstrate only prior knowledge and ability to utilize the provided FERH.

This paper investigates the effect of FERH use as a testing resource in engineering classes. These courses include topics such as fluid mechanics and surveying which are topics within the FE exam. The study compares student FERH use confidence among classes that used different testing resources. Data collected for this study aims to address two hypotheses: prior exposure to the FERH is hypothesized to increase student confidence using the resource and increase accuracy during FE practice exams; secondly, the effect of different modes of interaction with the FERH in engineering classes is probed. In a single course case study, students were permitted to annotate the FERH, within guidelines. This was implemented as way for the faculty to build rapport with students by giving them a greater sense of control over their testing resource. The second hypothesis is that increased student annotation, which may indicate greater student interaction with the FERH, would yield higher test scores.

Methods

Student Cohort Selection: This study focuses on the current senior-level students at The Citadel in the Civil Engineering major. This group of 36 students took the same sequence of courses in junior and senior years. This includes all taking the CIVL 322 course in Spring 2022 used for the one course case study. As such, they have all had comparable exposure to the FERH in their upper-level engineering

courses. The only exceptions are for Statics and Surveying which students in the transfer program took at another institution prior to enrollment at The Citadel. Further, these students are all enrolled in the CIVL 412 course in Fall 2022 which focuses on FE test preparation.

Perception Survey: A FERH perception survey was administered to the student cohort in Fall 2022. Twenty-seven students submitted perceptions. The survey assessed: (1) student self-confidence using the FERH on topical FE practice tests, (2) their prior exposure/use of the FERH in engineering courses, and (3) Likert scale agreement with provided statements. Items two and three are presented individually, while student self-confidence was related to student performance on FE practice exams.

FE Practice Exam Performance: The student cohort is enrolled in CIVL 412 in Fall 2022. This one-credit hour course is intended to prepare students to take the FE exam. All students in the program are required to sit for the FE exam by the time they graduate. CIVL 412 is structured around practice FE tests created in partnership with PPE Headquarters, an engineering testing preparation company. Every three-week module, students work through a group of topics starting with an initial assessment practice exam, then use "homework modules" to review the key concepts within the topics, and finally take a mastery exam. The goal of this structure is to not only review course material that students have not seen in several years (such as Calculus) but also to familiarize them with FE question formats. The module allows students to re-take tests, though questions are pulled from a larger bank so students may not receive the same questions in their re-take. For the purposes of this study, only the student's first attempt at a practice test is included in analysis, to better isolate their prior ability rather than the effect of the CIVL 412 curriculum.

One Course Case Study: In CIVL 322, an environmental engineering course taken by the student cohort in Spring 2022, students used a provided, abridged version of the FERH, totaling 20 pages. The CIVL 322 formula sheet sourced the formulas and figures relevant to the course topic from the FERH. Students were also allowed to annotate the formula sheet. For the purpose of this course, annotation was defined as: (1) highlighting/circling to draw attention, (2) addition of text to clarify provided information/formulas, or (3) addition of additional formulas/figures in the version provided in lecture. Students were not allowed to copy practice problems or procedures into the FERH.

For this one course case study, the extent to which students annotated the FERH was quantified. Further, student performance on individual topics present on the Final Exam was compared to whether or not they annotated the relevant section of the FERH.

Results and Discussion

Prior Exposure to FERH through Engineering Courses:

Student resources during tests and exams in engineering courses fell into one of four categories: (1) FERH provided and only allowed resource in test, (2) FERH provided and annotated by student, (3) student freely allowed to use class notes or textbook during exam – referred to as "open note", and (4) no FERH provided. For the fourth category, students are most often instructed to create a one-page formula sheet on their own without course emphasis on FERH, however some courses may have entirely "closed book" tests. Anecdotally, closed book exams are not used in the courses probed in this study. The courses included in Figure 1 are grouped into the topical areas of the FE practice exams. The most uniformity in

response occurred for the Geotechnical course where 88% of respondents reported that the FERH was the only resource allowed on exams in unmarked form (Figure 1D). This was followed by the Environmental courses, CIVL 320, 322, and 408, where 69%, 75%, and 69% respectively reported an annotated FERH was used (Figure 1B). The Transportation Engineering courses, CIVL 305 and 302, are also notable as over 60% of respondents said an "open note" resource method was used (Figure 1C). The resource used during exams reported by these majorities align with what the instructor reported the course policy was when the student cohort was enrolled. Further, the courses with the highest reported use of a resource other than the FERH are the Transportation Engineering courses mentioned and the Surveying courses (CIVL 205 and 208). Thus, those topics would be expected for students to have the lowest confidence regarding FERH use during FE practice Exams.

Student FERH Use Confidence and Performance:

As seen in Figure 2, the student FERH perception survey had students rate their level of confidence using a modified Likert scale ("1 Extremely low confidence" to "5 Extremely confident") across seven topical areas. The average reported confidence score is between 2.79 (Structures) and 4.15 (Geotechnical). The medians are all three or four. The lower medians are for Math, Transportation, Structures, and Surveying. This aligns with the relatively lower prior exposure to the FERH through the courses (Figure 1A and 1C).

When student performance on FE practice exams in CIVL 412 is related to the self-reported level of confidence using the FERH, most topics show a positive correlation between confidence and performance (Figure 3). Correlation for the purposes of discussion means a consistently increasing or decreasing median and/or IQR across the subplot (Figure 3). Each topic (subplot) includes multiple items/courses in that discipline. For example, the Water Resources and Environmental category includes hydrology, fluid mechanics, and water treatment technologies. The Surveying practice test performance did not correlate with student confidence using the FERH. As about half of the students reported use of the FERH in their surveying courses while the other half did not use the FERH, the variation in performance with self-reported FERH use confidence makes sense. This data suggests that prior exposure to the FERH boosts student confidence and correlates with increased performance on FE practice exams.

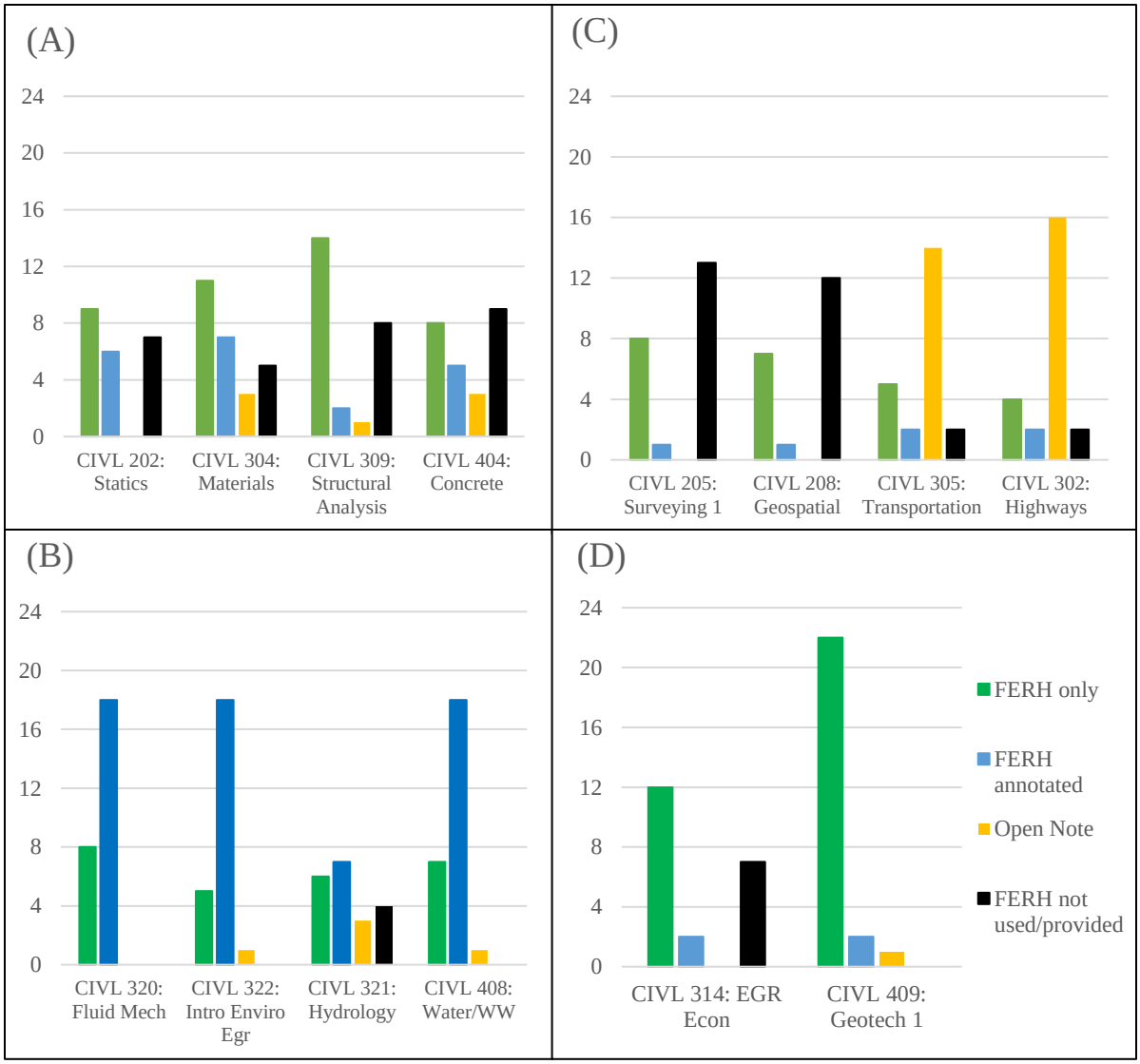

***Figure 1**: Student-reported resources used during course tests and exams grouped by topics: (A) Structural Engineering, (B) Environmental and Water Recourses Engineering, (C) Surveying and Transportation Engineering, and (D) Engineering Economics and Geotechnical Engineering. A count of student reported use by course and category is presented.*

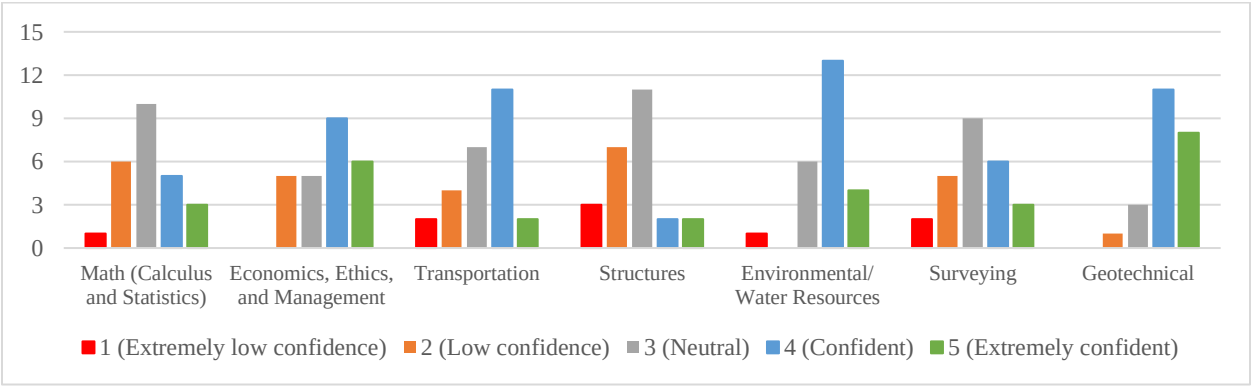

***Figure 2:** Student self-confidence in their ability to use the FERH to solve FE practice exam problems by topic.*

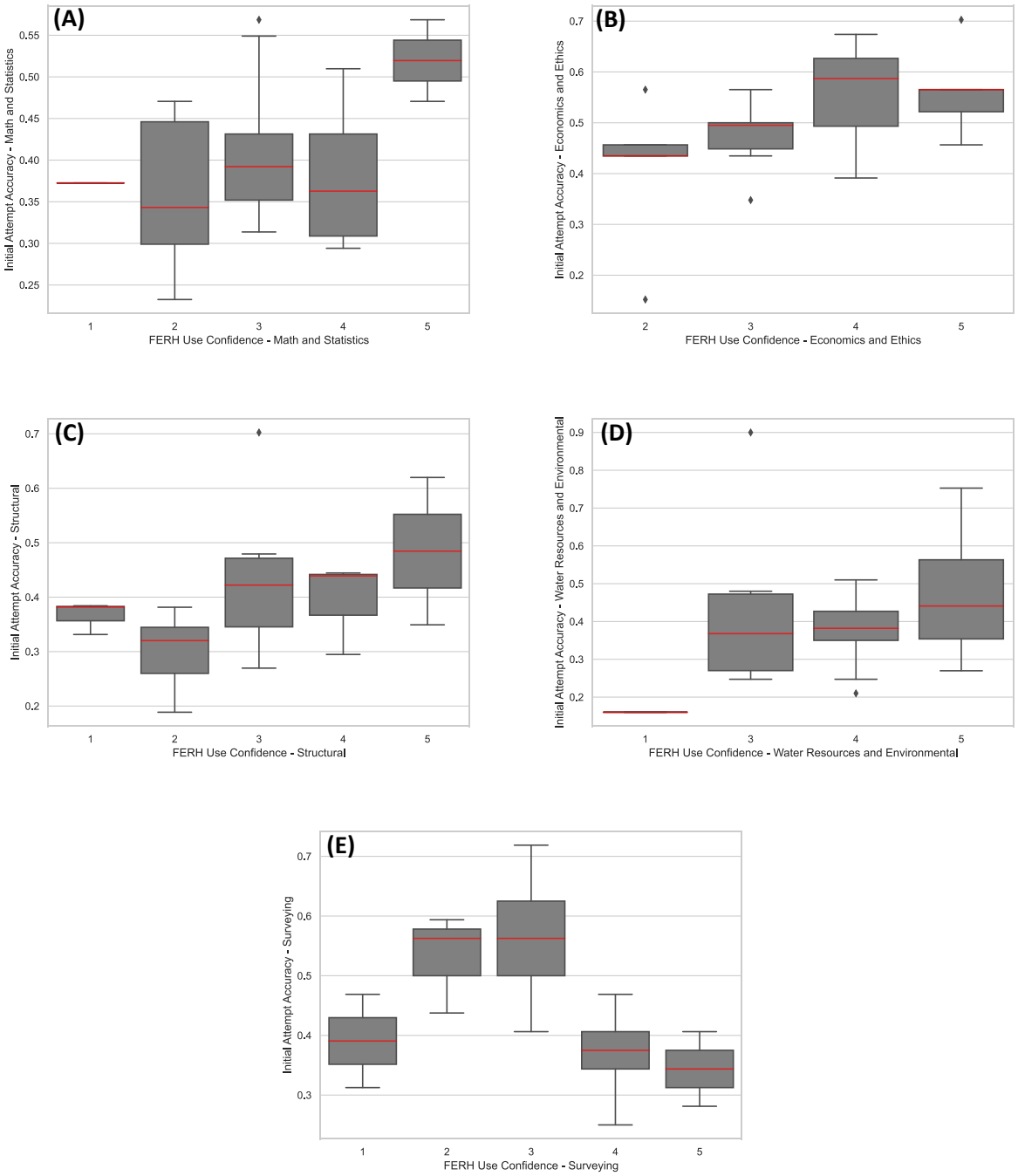

Figure 3: Student accuracy on initial FE practice test attempt by self-reported confidence in FERH use of that topic. Subplots show five topics completed in CIVL 412 by November 2022: (A) Math/Statistics, (B)Economics/Ethics, (C) Structural, (D) Water Resources/Environmental, and (E) Surveying. The red line in the box and whisker plot indicates the median. The box shows the IQR and the whiskers show the upper and lower quartiles. Statistical outliers are indicated as diamonds.

Case Study:

Students in CIVL 322: Introduction to Environmental Engineering, were provided a 20-page abridged FERH as their only resource during course tests. Students are allowed to annotate the FERH to clarify content to increase the utility to the student. Via instructor observation, many formulas in the FERH for environmental engineering topics use different variables or equation configuration compared to the textbook, and thus annotation was intended to help students bridge the gap.

Of 36 students in the class, only one did not annotate the FERH at all. Annotation of the 20-page FERH ranged from one page to 15 pages with an average of 8.4 pages. The most common type of annotation involved writing clarification of FERH equations or addition of the version of the equations as used in class. Only two students added tabs to draw attention to sections of the FERH. The most frequently annotated pages in the FERH covered the topics of groundwater flow equations (81% of students annotated) and dissolved oxygen sag curves (83% annotated). The least frequently annotated pages included data tables related to global warming potential and energy conversion processes, 3% and 6% respectively.

There was no correlation between the student's overall final exam grade and the extent to which they annotated the FERH. Even when analyzing by individual topic on the exam and student annotation of the related page in the FERH, little difference is observed (Figure 4). The range within a topic varied little between annotated or non-annotated conditions, excepting the exposure modeling and the dissolved oxygen sag questions. The medians are within 5% for most topics regardless of annotation condition. The exceptions are (1) the population modeling question where the median accuracy for those who did not annotate was higher and (2) the exposure modeling question where the median was higher for those who did annotate. This case study suggests that the benefit to FERH annotation to enhance resource accessibility is not definitive. It also aligns with other findings where student performance in a course actually improved when the course moved from a student created test resource to an instructor provided one.[11,13]

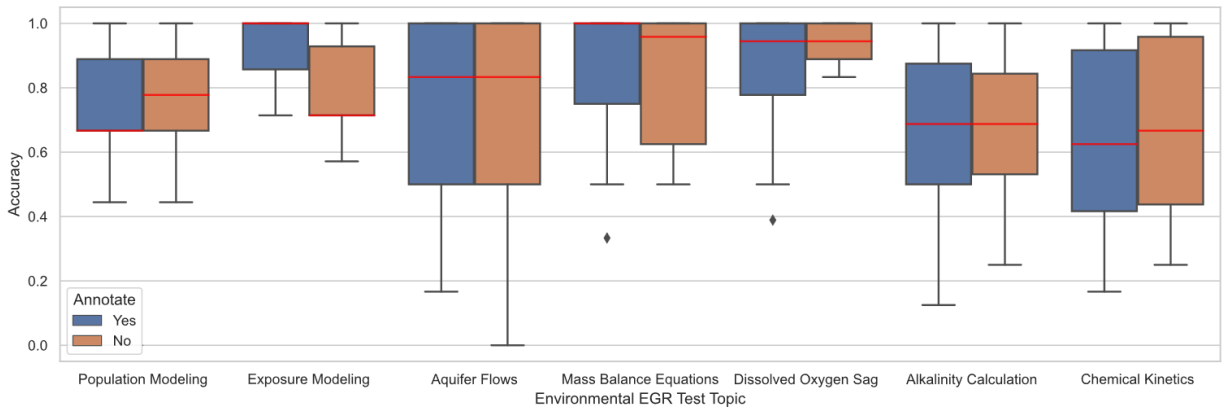

Figure 4: Performance (accuracy) by topics on the final exam grouped by if the student annotated the related page in the provided FERH or not. The red line indicated the median accuracy.

Additional Student FERH Use Perceptions:

In the FERH Perception survey, students were asked to report Likert scale agreement with 13 statements. Results are shown in Figures 5-7. Figure 5 groups statements that relate prior exposure to the FERH and confidence on the FE practice exam. Students tended to agree that prior exposure made them feel more prepared for the FE exam, the median for each of these three statements is 4 (agree). Figure 6 contains statements related to the ease of FERH use and its content. The averages for the five statements range between 3.2 and 3.6, slightly above neutral. Figure 7 groups statements relating to FERH use in engineering technical classes. The highest average (4.4) from any statement was that the FERH should be used in more classes. The responses even suggest that a significant number of students may be using the provided FERH on homework and practice assignments even if not required.

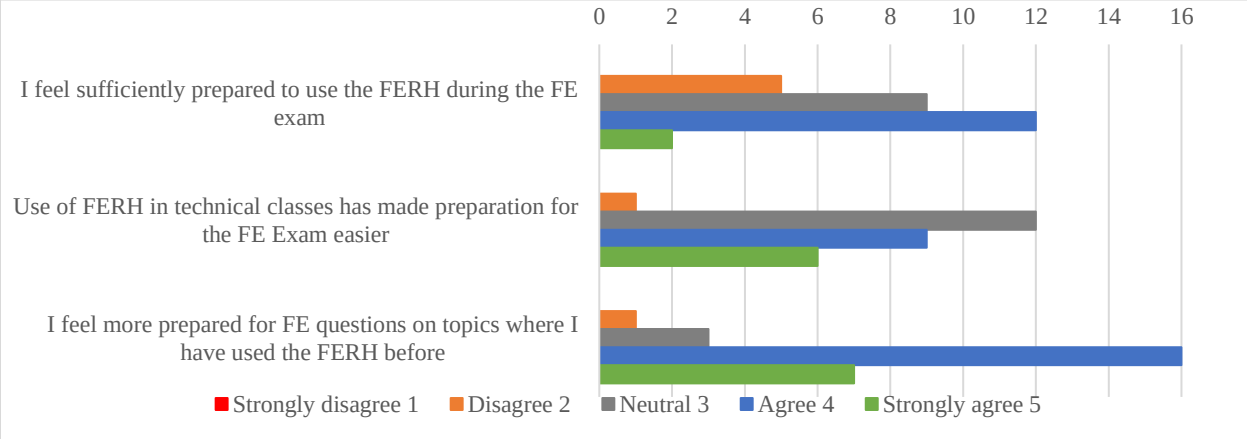

Figure 5: Likert scale agreement from students (N = 28) for three statements relating to their prior FERH exposure.

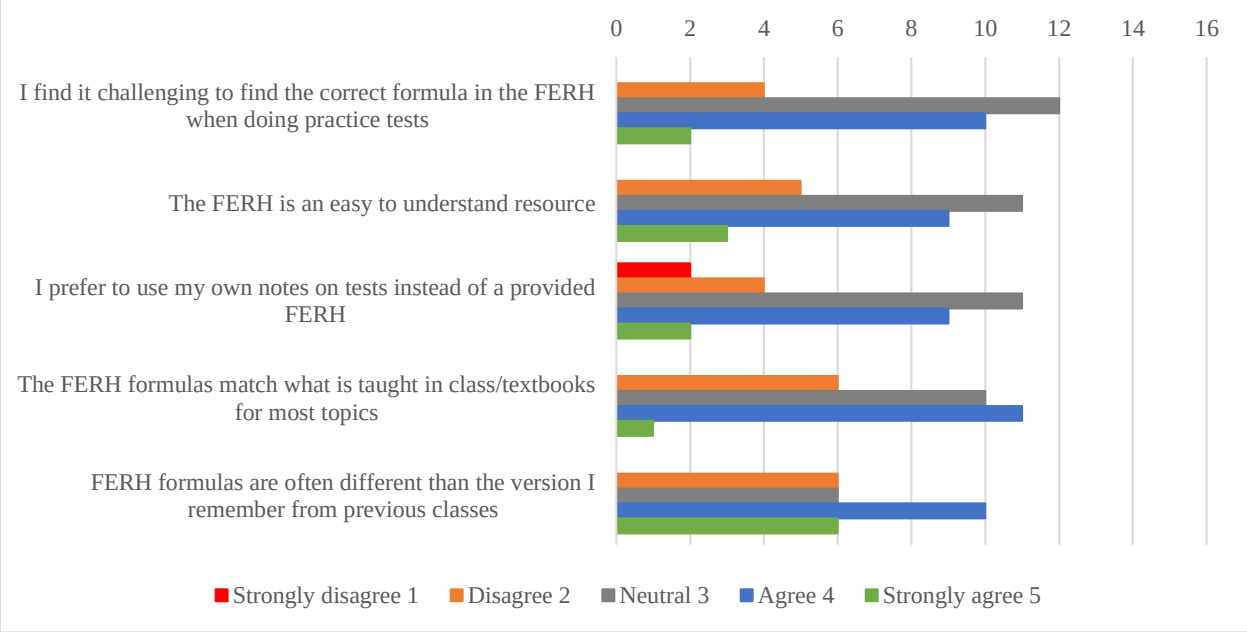

Figure 6: Likert scale agreement from students (N = 28) for five statements relating to the ease of use of the FERH and how they interact with the content.

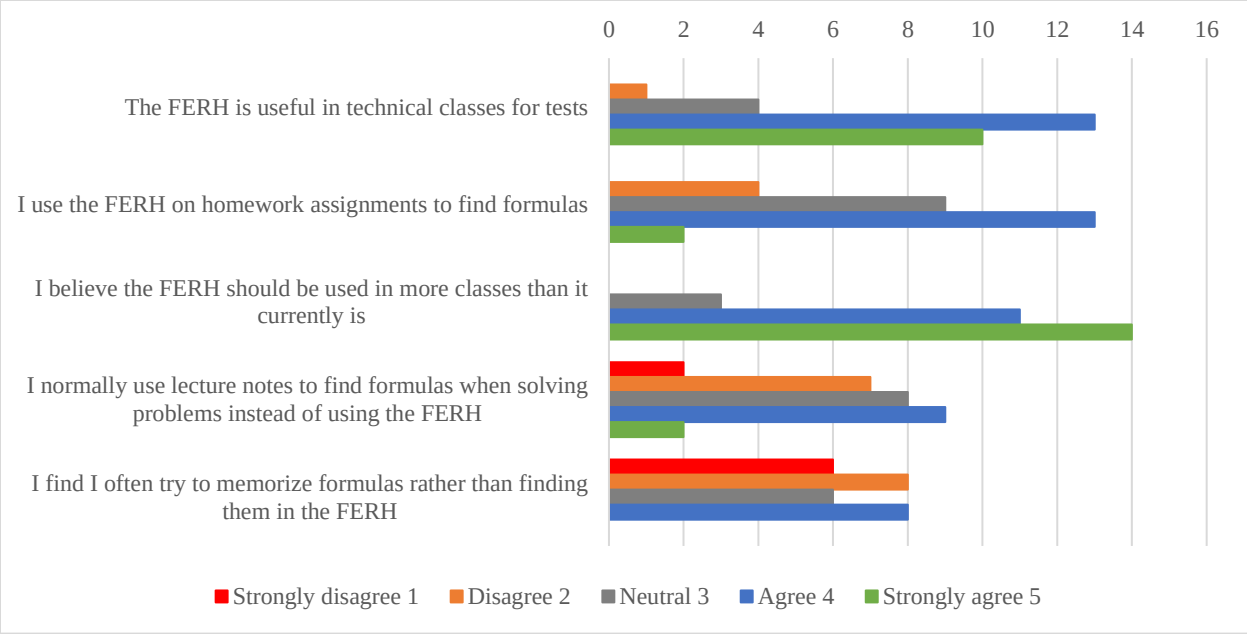

Figure 7: Likert scale agreement from students (N = 28) for five statements relating to the use of the FERH in engineering courses as a resource.

Conclusions

This study analyzes correlation between student performance on tests and student use of the FERH. Two hypotheses were posed: (1) prior FERH exposure will increase use confidence and FE practice test performance and (2) the extent to which students customize – annotate- the FERH will increase performance.

Data suggests the first hypothesis may be true. Students in the study cohort reported higher average confidence in FERH use on topics such as Environmental Engineering and Geotechnical Engineering where the FERH was the primary testing resource during the related lecture courses. Conversely, lower use confidence was reported in Surveying and Transportation Engineering where the FERH was less used in the courses. Further, for courses where the FERH was used, reported use confidence positively correlates with accuracy in FE practice tests. Additional future work should probe the relationship between testing speed, accuracy, and prior FERH exposure. The FE requires completion of 110-questions in six hours, or one question every 3.3 minutes. Prior exposure to the FERH would presumably be able to decrease the formula “searching” duration, thus allowing students more time for computation and answer verification.

The second hypothesis was not supported by the current data. The extent to which students annotated the provided FERH was independent of performance on the final exam in the case study course. While students do seem to show a slight preference for the FERH as a test resource over other resource models and they use the FERH for practice assignments even when not required, they acknowledge that the FERH use has some challenges. None-the-less, student annotation to clarify the FERH do not show improvement. Future work could expand the investigation beyond the single case study presented here, however other work on self-generated test resources does imply the hypothesis is likely false.

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