Work-in-Progress Paper: Fundamentals of Engineering Diagnostic Test (FEDT) Learning Management System (LMS) Module

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ABSTRACT

For this work-in-progress (WIP) paper, faculty from Minnesota State University, Mankato's (MNSU) Mechanical Engineering (ME) and Civil Engineering (CIVE) Programs developed a Learning Management System (LMS) module for Fundamentals of Engineering Diagnostic Test (FEDT) and analyzed the preliminary data obtained from its first run during Fall 2023. The FEDT module is intended to be used for multiple purposes that are explained briefly below.

Both ME and CIVE programs have the mission of graduating engineers that will contribute to their professions, seek leadership positions, and most importantly pursue their education with licensure programs. The Fundamentals of Engineering (FE) exam is the first step that an Accreditation Board for Engineering and Technology (ABET) accredited engineering program awardee or candidate takes towards becoming a professional licensed engineer (P.E.). Thus, both ME and CIVE programs require their seniors to take the FE test in partial fulfillment for a bachelor's degree in engineering. Just like many other engineering programs across the country, MNSU's ME and CIVE programs are also using the FE exam results as program assessment tools.

About half of the Mechanical Engineering FE and Civil Engineering FE exam questions are from courses offered to first-year students and second-year students (on average 43 % for ME, and 54% for CIVE). These are also the topics that MNSU's ME and CIVE program seniors struggled with, historically. The developed FEDT module specifically targets these topics. The author of this paper developed about 200 questions (and their step-by-step solutions) in Mathematics (Algebra, Calculus, Differential Equations, Statistics, and Probability), Numerical Methods, Statics, Dynamics, and Mechanics of Materials. 36 questions were picked from the pool to be provided as a proctored FEDT test. Starting from Fall 2023 semester, both ME and CIVE programs requested their third-year students (Program admitted Juniors) to take the proctored FEDT test. The results of these proctored tests are used as an early- warning system to the program students and instructors. Instructors of the above-mentioned classes can use the results to make improvements of topics that students struggled with the most in the long term. Instructors of the courses that have above- mentioned classes as pre-requisites can intervene in short-term to make-up for the vital contents. Moreover, students will identify the areas that they need to practice more. The students who

already took the proctored FEDT test can use the remaining questions to study for the FE test in their own time. Lastly, the historic trends of FEDT results will be used as an assessment tool for both programs.

INTRODUCTION

All engineering programs of Minnesota State University, Mankato (MNSU) are accredited by the Accreditation Board for Engineering and Technology, Inc. (ABET). ABET is an unbiased non-governmental organization that is founded by six professional organizations (Institute of Electrical and Electronics Engineers, American Society for Engineering Education, American Society of Civil Engineers, American Society of Mechanical Engineers, American Institute of Chemical Engineers, American Institute of Mining, Metallurgical, and Petroleum Engineers) and National Council of Examiners for Engineering and Surveying. ABET's mission is to set standards against which professional engineers in the United States were held for licensure and focus on student experience (1). The National Society of Professional Engineers describes licensure as the credentials to earn client's trust and states that only engineers with Professional Engineer (PE) license have the authority to sign and seal engineering plans. (2). While engineers earn their license from their state's licensure board, they must complete these four steps to ensure their competency: earn their engineering degree from an accredited engineering program, pass Fundamentals of Engineering (FE) exam, gain several years of relative engineering experience, and pass the Principles and Practice of Engineering (PE) exam.

Along with other engineering programs of MNSU, Civil Engineering (CIVE) and Mechanical Engineering (ME) programs are serving their respective professional societies by preparing their students to the above-mentioned path to become licensed engineers. The first step towards licensure for these programs' graduates is to take the Fundamentals of Engineering (FE) test that the National Council of Examiners for Engineering and Surveying (NCEES) offers. CIVE and ME program faculty get students ready for the FE exam in several ways. Both program curriculums are built to cover most FE topics in all entrance, fundamental, and analysis level courses (1XX – 3XX) and offer the remaining topics in restrictive technical electives such as Steel/Reinforced Concrete Design. Faculty from both programs refer to the official FE manual regularly in lectures and use it as a reference document for written exams. Moreover, faculty offers FE review sessions based on student demand.

There is one more service that these programs used to offer to their respective students, and it is unfortunately no longer available. About half of the FE exam questions are from topics of 1XX and 2XX level courses of respective programs (on average 54% for CIVE and 53% for ME). Table 1 provides the CIVE and ME Computer

Based Test (CBT) exam specifications. The topics that are offered in 1XX and 2XX level courses in respective course curriculum are bolded in the table. ME and CIVE programs used to provide a custom design Fundamental Engineering Diagnostic Test (FEDT).

This mock FE test only had questions from the 1XX and 2XX level courses that both program students take together. FEDT were proctored exams that all program admitted students took at the beginning of their junior year. The results of FEDT helped students assess their knowledge on the fundamental level courses both as preparation for their FE exam, and as a review of pre-requisite information of their analysis level (3XX) courses. FEDTs were an important assessment tool specifically for transfer students who took their fundamental level courses at other institutions. Since FEDTs were proctored exams that the majority, if not all junior students took, the results of these exams were also a great assessment tool for the ME and CIVE programs.

CIVE and ME programs used to purchase FEDT service from an external FE/PE preparation company and provided it to their students free of charge. However, this company stopped providing this service after 2016-17 AY. There are several companies that offer FE practice exams; however, none of them proposed affordable options for proctored exams with customized topics for groups. FEDT was a valuable resource for both programs. Due to several reasons that we will outline below, faculty from CIVE and ME programs prepared Fundamentals of Engineering Diagnostic Test (FEDT) Learning Management System (LMS) Modules for their program students.

FE exams have been an ABET recommended assessment tool since they are taken by thousands of students across institutions (5, 6). While the overall FE pass rate may be insufficient to assess the program performance alone, the students' success in individual topics provides valuable feedback (5). For this reason, engineering programs of many higher education institutions are encouraging, if not requiring, their students to take FE exam. Civil and Mechanical Engineering Programs of MNSU are also requiring their seniors to take FE test as a partial fulfilment of graduation requirements. ME and CIVE program students’ performance on their first attempt at the FE exam is provided by NCEES as annual summaries. ME and CIVE programs are also using the provided data for assessment; significantly the ABET Comparator Average Performance Index for individual courses. Both programs are using their respective seniors’ performance in each topic compared to the national average performance and

Table 1. Fundamentals of Engineering (FE) Civil CBT and Mechanical CBT Exam Specifications since July 2020. (3, 4)

	Civil Eng. FE	
	min	max
Mathematics and Statistics	**8**	**12**
Ethics and Prof. Practice	**4**	**6**
Engineering Economics	**5**	**8**
Statics	**8**	**12**
Dynamics	**4**	**6**
Mechanics of Materials	**7**	**11**
Materials	5	8
Fluid Mechanics	6	9
Surveying	**6**	**9**
Water Res. and Envi. Eng.	10	15
Structural Engineering	10	15
Geotech Engineering	10	15
Transportation Engineering	9	14
Construction Engineering	8	12
percentage of total exam	42.7%	65.5%
average	54.1%	

	Mech. Eng. FE	
	min	max
Mathematics	**6**	**9**
Probability and Statistics	**4**	**6**
Ethics and Prof. Practice	**4**	**6**
Engineering Economics	**4**	**6**
Electricity and Magnetism	5	8
Statics	**9**	**14**
Mechanics of Materials	**9**	**14**
Dynamics and Vibration	**10**	**15**
Material Properties and Processing	7	11
Fluid Mechanics	10	15
Thermodynamics	10	15
Heat Transfer	7	11
Measurmnt, Instrmentatn, and Controls	5	8
Mechanical Design and Analysis	10	15
percentage of total exam	41.8%	63.6%
average	52.7%	

compared to their own historic data for assessment of program. Our historic data indicated a decrease in our students' performance in FE questions from 1XX – 2XX level courses since 2019 – 20 AY. While 2019 – 20 AY graduates are the first group of students that did not take the FEDT test that ME and CIVE programs used to offer, there might be many external factors affecting this decrease such as fluctuations in overall (national) pass rates, motivation, and the like (7, 8). Bringing FEDT back as a LMS module should improve both preparation and motivation of the students; hence improve the FE results in the upcoming years. Moreover, CIVE and ME programs are also planning to use FEDT as an assessment tool. Utilizing the FEDT in short-term and long-term improvements of respective programs are explained in detail in the following section.

METHODOLOGY: FEDT LMS MODULE

To prepare the FEDT LMS module, first the author of this paper conducted extensive research on the current and former versions of the Fundamentals of Engineering (FE) tests for both Mechanical Engineering and Civil Engineering Programs. The National Council of Examiners for Engineering and Surveying (NCEES) updated the topics of both CIVE CBT and ME CBT FE tests in June 2020. Moreover, the FE Handbook (reference manual) was updated, and the variety of the question styles was increased.

The goal of this research was to identify these listed changes and select reference books.

This project was funded by a summer grant for course improvement and had a short duration to be concluded. For that reason, for the first stage of the FEDT LSM module, the project only focused on the FE topics from courses that ME and CIVE students take together: Mathematics, Statistics, Probability, Numerical Methods, Statics, Dynamics, and Mechanics of Materials.

Once these courses were identified, the topics from each course were classified under three groups:

- Topics that are in both CIVIL FE and ME FE tests
- Topics that are only in ME FE tests
- Topics that are only in CIVIL FE test.

Please see Table 2 for the topics under each discipline. Once the topics were determined, reliable reference books were selected to examine expected knowledge levels and question types. Based on this investigation and considering the historic FE changes, 192 original questions were created under four submodules: Math, Statics, Dynamics, and Mechanics of materials (Table 3). Three different question types were used for most of these created questions: multiple-choice, multi-select, and arithmetic. The original text of each question was first typed via a word processing program to prevent any data loss due to LMS malfunction. Each question was prepared with a plotted image (if applicable) and a detailed solution. Then the typed questions were transferred to the LMS module. Please see Figures 1 and 2 for example questions. These figures provide how the questions appear during and after the exam.

RESULTS AND DISCUSSION

There are two different planned functions of FEDT LMS module. The first function is the proctored exam. As given in Table 2 questions were selected from each module for a proctored exam. The proctored exam was prepared to have 36 questions. The duration of this proctored exam was set to be 2 hours to better mimic the original FE exam.

In Fall 2023 semester, all program admitted (junior level) ME and CIVE program students were enrolled to the LMS module and were offered several day/time options to take the proctored test. The students were told they did not need to study for the test and were only provided with the NCEES FE Exam Reference Handbook as a resource

during the test. Most of the students were already familiar with the reference book. The students were provided with an overall grade once their proctored exam was over; and detailed feedback once all enrolled students took the test.

Table 2. Topics of selected disciplines for both ME and CIVE FE exams.

Course	ME %	CIVIL %	TOPIC	COMMON?
MATH	5.5 - 8.2 %	7.3 % - 10. 9%		
			Analytic Geometry	YES
			single variable Calc	YES
			multivariable Calc	ME ONLY
			ordinary Diff EQ (homogeneous, nonhomogeneous, Laplace)	YES
			Linear Algebra	ME ONLY
			Vector Analysis	YES
			Numerical methods (approximations, precision limits, error propagation, Taylor's series, Newton's method	ME ONLY
			algorithm and logic development (pseudocode, flowchart)	YES
PROB and STAT	3.6 - 5.5 %	↑ included		
			probability distributions (normal, binomial, empirical, discrete, continuous)	YES
			measures of central tendencies and dispersions (mean, mode, st. dev, confidence intervals)	YES
			Expected value (weighted average) in decision making	ME ONLY
			Regression (linear and multiple)	YES
			Curve fitting	YES
			Goodness of fit (correlation coefficient, least squares)	YES
STATICS	8.2 - 12.7 %	7.3 - 10.9 %		
			resultants of force systems	YES
			equivalent force systems	YES
			equilibrium of ridig bodies	YES
			frames and trusses	YES
			centroid of area	YES
			Moment of Inertia	YES
			Static Friction	YES
DYNAMICS, KINEMATICS and VIBRATIONS	9.1 - 13.6 %	3.6 - 5.4 %		
			Kinematics of particles	YES
			Kinetic Friction	YES
			Newton's second law (force, acceleration)	YES
			Work- energy for particles	YES
			Impulse - momentum for paricles	ME ONLY
			Mass Moment of Inertia	YES
			Kinematics of rigid bodies	YES
			Kinematics of Mechanisms	YES
			Newton's second law for rigid bodies	YES
			Work - energy for rigid bodies	YES
			Impulse - momentum for rigid bodies	ME ONLY
			Free and forced vibrations	ME ONLY
MECHANICS OF MATERIALS	8.2 - 12. 7 %	6.4 - 10 %		
			shear and moment diagrams	YES
			stresses and strains (diagrams, axial, torsion, bending, shear, thermal)	YES
			Combined loading	YES
			Stress transformations and Mohr's circle	YES
			Deformations (axial, torsion, bending, thermal)	YES
			Column buckling	YES
			Statically indeterminate systems	CIVIL ONLY

Table 3. Number of questions created under Question Library of each submodule of FEDT.

Course	TOPIC	Total # of questions created for LSM module	# of questions selected for proctored FEDT
MATH	Analytic Geometry	8	3
	single and multiple ariable Calc	11	2
	Ordinary Differential Equations	4	2
	Linear Algebra and Vector Analysis	6	2
	Numerical Methods	7	1
	Probability and Statistics	13	2
STATICS	System of Forces and Moments	12	2
	Trusses	12	2
	Pulleys, Cables, and Friction	11	1
	Centroids and Moments if Inertia	12	2
	Indeterminate Statics	4	0 (not common for CIVIL and ME)
MECHANICS OF MATERIALS	Stresses and Strains	10	2
	Thermal, Hoop, and Torsional Stress	12	2
	Beams	12	2
	Columns	8	2
DYNAMICS	Kinematics	12	3
	Kinetics	10	2
	Kinetics of Rotational Motion	10	2
	Energy and Work	10	2
	Vibrations	8	0 (not common for CIVIL and ME)

Preview Question

When taking the question, it would appear as:

A stormwater main with an inner diameter of 19 inches is designed to be filled up to two-thirds of its diameter. At its maximum design capacity, what is the approximate area of flow in the pipe (in in^2)?

Your Answer:

Answer units

When grading the question, it would appear as:

A stormwater main with an inner diameter of 19 inches is designed to be filled up to two-thirds of its diameter. At its maximum design capacity, what is the approximate area of flow in the pipe (in in^2)?

⇒ 200.80 in^2

Comment: (given as feedback)

If the flow depth is 2D/3 at the maximum capacity, then the angle α given in the figure below is 2.4619. From the this following formula, we can calculate the area of flow as $A_{flow} = r^2\pi - r^2(\alpha - \sin(\alpha))/2$

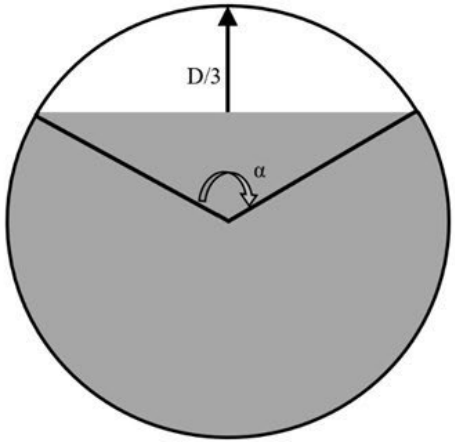

Figure 1. Preview of an example Math problem (analytic geometry topic) along with its solution.

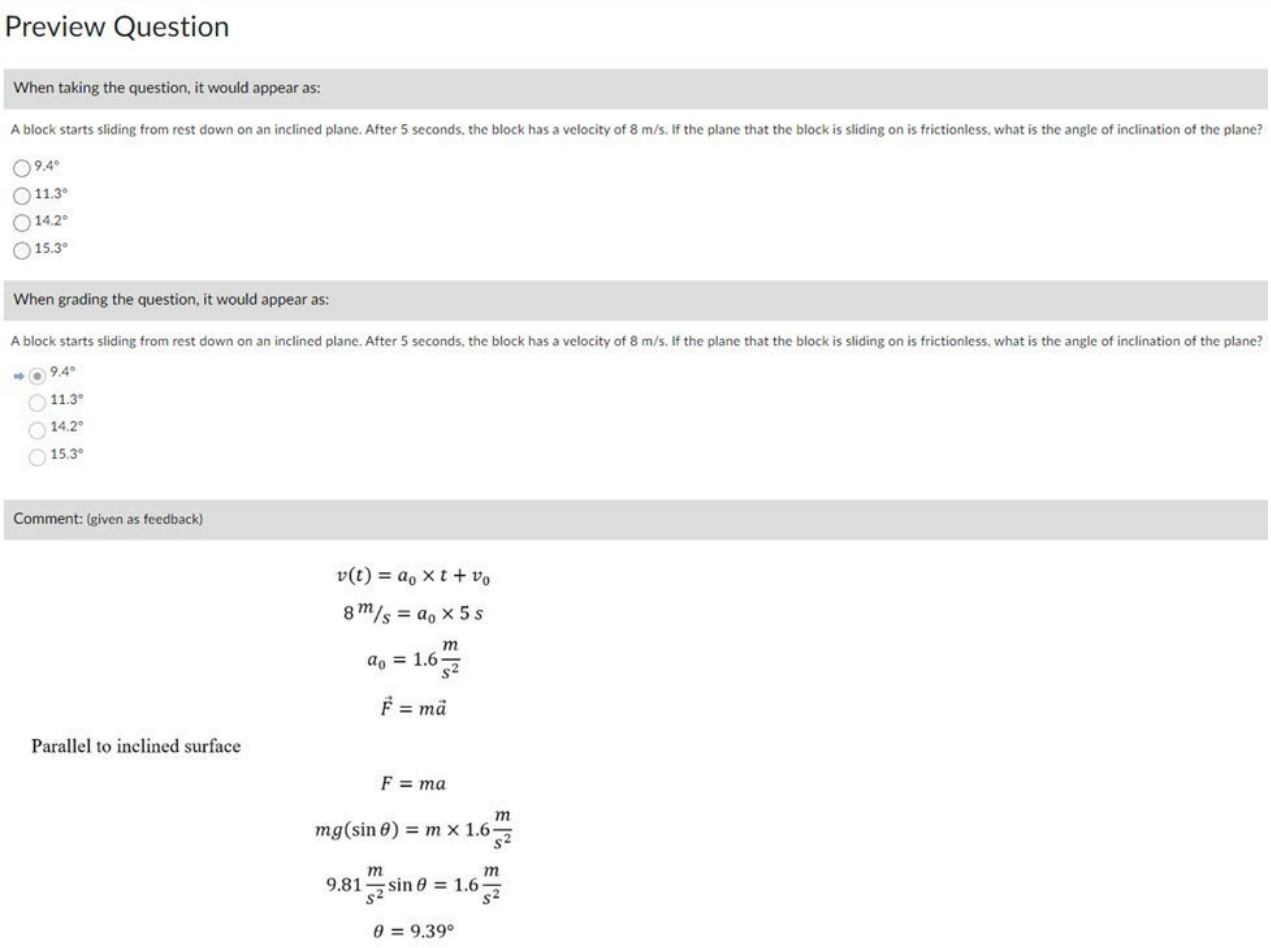

Figure 2. Preview of an example Dynamics problem (Kinetics) along with its solution.

There are engineering programs offering similar competency exams to junior level (program admitted) or rising junior level (ready to be admitted) students. Some of these programs are even using their competency exam as a requirement to register for upper division courses (6). While passing FEDT is not a requirement for our programs, the results of FEDT will still provide valuable feedback to students and faculty that offer relevant courses. ME and CIVE programs have been utilizing the results of the proctored test in the following formats:

- *FEDT As a short-term assessment* tool

Student performances in each topic will be examined by both program faculty each year. If any topic has statistically significant low success rate, then faculty members who offer courses that require this pre-requisite knowledge will be notified. These faculty members may make small adjustments in their course plan to review the topic

or may provide additional resources in their respective courses. This short-term intervention will improve both students' performance in their current course load and in the actual FE exam. Moreover, since the proctored FEDT test is provided at the beginning of students' junior year, their performance in this test will provide students valuable feedback on their knowledge level for fundamental courses. If individual students have significantly low performance, then this test will act as an early-warning system for them. These students may use the second function of this LMS module (explained below) to review topics and set themselves up for success.

Results of the first round of FEDT are provided in Table 4. 30 Juniors from ME program and 16 Juniors from CIVE program took the FEDT test. Since both groups historically take the courses of FEDT topics together, the results of both groups were also studied collectively. The performance of the students in all four disciplines was lower than expected. This might be due to several reasons. Along with lack of knowledge, students may also not be familiar with the question styles or the timing of FEDT. Test takers, especially the transfer students who just started their education in MNSU may not be familiar with the quiz format of our LMS. We believe motivation may also be a factor. Regardless of the reasons, the observed performances are both bad news and good news for our programs. Assuming that the selected questions, which were reviewed by multiple faculty members, were not problematic, the average performance of our students indicated a need for improvement. Whether it is introducing students to the FE format or providing them with the level of knowledge required from these foundational topics, an intervention is necessary. The good news is, now we have a systematic way of assessing and informing our students in a timely manner. Entire junior year will give our programs plenty of time to improve the students' perspective and performance in the actual FE.

Table 4. FEDT performances of Fall 2023 CIVE and ME program Juniors

Discipline	Number of questions	Average performance	Number of 0% success questions	Average performance without 0% success questions
Mathematics	12	39.7%	0	39.7%
Statics	7	25.5%	1	29.7%
Mechanics of Materials	8	36.4%	0	36.4%
Dynamics	9	37.2%	1	41.8%
TOTAL	36	35.6%	2	37.7%

- *FEDT As a long-term assessment tool*

ME and CIVE programs are planning to use the same tests in the upcoming years and

only make necessary clarifying updates between academic years. Using the same exam will provide consistent historic data over the years. In the event of observing a topic that has a trend of overall low performance, ME and CIVE program faculty may analyze the respective courses and use this data as an opportunity to improve the content and the delivery methods. Moreover, if this trend is particularly for the performance of transfer students, ME and CIVE faculty members may work with the MNSU's Transfer Liaison Office to improve the course equivalencies to set the transfer students up for success.

The second function of the FEDT LMS module is a FE preparation resource. Once the students take their proctored test, the entire content of the FEDT module will be available for them. Students can take other mock FE tests that randomly select questions from each discipline question pool. Students will also have shorter tests that only have questions from specific disciplines. Contact faculty will be available to answer FEDT questions during normal office hours and can offer drop-in sessions to work with groups. Although many FE exam preparation tools are offered by third parties, these resources may be costly and inefficient. It was previously documented that access to free FE study resources and studying time are highly valued by seniors or recent graduates of engineering programs (9). Since we offered the FEDT for the first time in 6 years this fall semester, we asked test takers to fill out a survey a few weeks after FEDT sessions (The Project IRBNet ID number is: 2189227). Via this anonymous voluntary survey, students provided us with their feedback on FEDT. 20 ME program and 16 CIVE program students took and completed the survey. First, we asked students if they thought FEDT provided them with valuable feedback. 34 out of 35 survey takers (97%) stated that the FEDT provided them with valuable feedback. Please see a few sample answers that represents most of the surveyors:

Question: "Do you think Fundamentals of Engineering Diagnostic Test (FEDT) provided you with valuable feedback for your level of knowledge on the relevant FE topics? Please provide a Yes/No answer and a brief explanation why."

"Yes, it gave us a good representation for what to expect when it comes to us taking the FE."

"Yes. Showed me that I should review some of my sophomore classes."

"Yes, I just liked how we had the option to take a test in similar format to the FE to just get a feel for what it is like."

In another question we asked surveyors if they reviewed any concepts from the FEDT courses after they took it. 15 out of 36 (41.66%) students stated that they reviewed topics from at least one discipline after taking FEDT. Moreover, students were also interested in using FEDT LMS module as an FE study tool. Please see Table 5 for the detailed data. All surveyors stated that they would use these functions of FEDT LMS module.

Table 5. FEDT Student experience survey results

	If FEDT is available to you to retake at your concenience, would you use this tool for practicing/studing for FE test?	FEDT D2L module can provide you with shorter tests (with solutions) on specific topics (such as Math, Statics, Dynamics etc.) for you to retake at your convenience. Would you use this feature for practicing/studying for FE test?
Definitely	57.1%	71.4%
Very Probably	25.7%	14.3%
Possible	17.1%	14.3%
Probably Not	0.0%	0.0%
Definitely Not	0.0%	0.0%
TOTAL	100.0%	100.0%

CONCLUSION AND FUTURE WORK

The first attempt of the FEDT was successful and received a good reaction from the students. There are multiple actions that we will take in the immediate future to improve the success of this LMS module. There are two questions (out of 36) that none of our FEDT takers could answer right (0% success rate) (Table 4). We will take a closer look at these questions to make sure there are no logical/question format errors. We want to improve the proctored version of the FEDT as soon as possible and stop making changes to it to accumulate historic data. As we accumulate historic data, we will look to see if we observe any trends of low success in any topics that require intervention.

With the approval of IRB, we would like to add student background data to the FEDT test. For the first set of FEDT, we manually divided the students into MNSU students and transfer students' groups after all juniors took the test, which was time consuming and may not be accurate. We would like to add the questions FEDT to obtain this

information and to factor transferred 1XX – 2XX courses for efficient assessment.

Moreover, we would like to add more modules starting from Ethics and Professional Responsibility Disciplines. Since FE results are one of the most effective ways of assessing the ABET Criterion 3: Student Outcomes Item 4 (formerly f), improving the student success rate in this area is critical (10, 11).

We are also working closely with Minnesota State University, Mankato's Memorial Library to support the FEDT LMS module with up-to-date reference books for enhanced student support (12, 13). For university-wide service, we offered to share the relevant portions of the FEDT module with other engineering programs.

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