Session 1274

Developing Writing-to-Learn Assignments for the Engineering Statics Classroom

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Abstract
Research in engineering pedagogy has argued for the efficacy of writing as a means to improving student learning in the engineering classroom. Unfortunately there are few models of such assignments. This project, the result of cooperation between faculty in civil engineering and technical communication, was based on a simple approach: the authors asked students to describe the steps they used to set up and solve engineering statics homework problems. As the assignment template stated, "the goal of this course is for students to understand the material, not just to plug numbers into equations. An effective way to demonstrate understanding of the material is to describe how you use it." During the ten-week course, students were asked to articulate the thought processes they used to solve problems so their work would be comprehensible to others. This strategy models, the authors believe, engineering workplace practice; they believe it is a distinct advantage if students can articulate their thought process clearly and concisely when working with other engineers. In this paper, the authors share the assignment template they developed and discuss the evaluation rubric that the instructor used to grade assignments. The authors also identify the learning outcomes specified for the assignment and show how student writing correlated to their performance in the course. Finally they discuss the advantages and disadvantages of the Writing-to-Learn approach in the engineering classroom.

Introduction
This project began with the premise that asking students to write is a means to improve what they learn in the engineering classroom. The premise is not new; advocates of the Writing-to-Learn approach have argued for the incorporation of writing in courses outside of the traditional sites for writing instruction.[1-3] As a result, Writing Across the Curriculum and Writing in the Disciplines programs have been created at universities across the country. While the Writing-to-Learn approach is generally supported, the particular assignments that could represent such an effort are often difficult to obtain. In the case of engineering education, furthermore, the case must often be made that devoting time to writing, time taken away from instruction in technical content, will produce significant improvement in students' understanding.

The Writing-to-Learn approach to which the authors subscribe differentiates itself from a Writing-to-Communicate approach. When engineering educators consider adding writing to a technical course, they frequently believe the best option is to add a formal report, proposal, or series of memos to an existing course. While added formal writing is beneficial to students, the drawbacks include increased instructor evaluation effort and a degree of distinction in the minds of students between their technical work and the writing (which is sometimes looked upon as an annoying, make-work addition). In deciding to develop a Writing-to-Learn assignment, the authors were interested in keeping the evaluation load reasonable while giving students an activity that would be totally integrated with their technical work. For these reasons, the authors considered the homework problem context and decided that was the best area for development. Using writing in the engineering classroom can help students discover what they do and do not know, help them visualize the problems on which they are working, and generally assist them in reflecting on their work in the classroom.

The course selected for assignment development is Engineering Statics. The students enrolled in the course are predominantly civil, mechanical and biomedical engineering majors in the freshman or sophomore year. The course lasts ten weeks and is an introductory mechanics course that covers equilibrium of trusses, frames, machines, and parts of those structures in two and three dimensions. This paper provides the development rationale the authors used for the assignment, discussion of the assignment itself, samples of student responses to the assignment, and analysis of the improvements in student understanding the authors were able to measure as a result of the assignment.

Learning Outcomes and Objectives of the Writing-to-Learn Assignments

While reviewing the desired learning outcomes for the engineering statics course, the authors decided that Writing-to-Learn assignments could help students achieve some of the outcomes and other, longer term objectives. The authors felt that the "explain a problem" format would be the most appropriate type of Writing-to-Learn assignment to support the course learning outcomes.

The authors developed two desired learning outcomes specifically for the Writing-to-Learn assignments in the engineering statics course:

1. Students demonstrate that they understand how they are solving a problem.
2. Students communicate the solution process with sufficient detail that another person can reproduce the solution to the problem.

The authors' goal is that the students understand the material, not just plug numbers into formulas. By requiring students to describe the solution process in detail, the students must reflect on what they have done. In order to perform well on the Writing-to-Learn assignment, students must demonstrate that they understand what they have done. Therefore, the authors' hypothesis is that these Writing-to-Learn assignments encourage students to achieve better understanding of the material.

In addition to the learning outcomes for the engineering statics course, the authors identified two objectives of the Writing-to-Learn assignments for future courses:

1. Students develop a habit of annotating calculations in all courses.
2. Students effectively communicate with other students and instructors when discussing concepts or problems in all courses.

These objectives are not directly measurable; however, they do impact the student's ability to achieve learning outcomes in other courses. It is easier for a grader to identify unreasonable assumptions or misunderstandings of how to apply a method if the calculations are annotated. The grader must be able to identify these problems in order to provide constructive feedback. The authors believe that students should interact with other students and instructors about coursework in order to clarify concepts and to identify solution strategies. Everyone's time is more efficiently used when the students can communicate effectively about what they understand about a concept and how they would approach a problem.

Our ultimate goal as instructors is to help students develop the skills necessary to succeed in their chosen profession. Therefore, the objectives of the Writing-to-Learn assignments for professional practice are as follows:

1. During summer internships and after graduation, students annotate calculations.
2. During summer internships and after graduation, students effectively communicate with co-workers and supervisors when discussing ideas or problems.

In professional practice, design calculations are reviewed for a variety of reasons including peer-review and litigation. It is unreasonable to believe that a practicing engineer will remember specific thoughts about a set of calculations months or years after they are completed. Therefore, annotations are the best way to guide a reviewer through calculations. Most practicing engineers will consult with other engineers about aspects of a project. Under the pressure of deadlines in a design office, effective communication about ideas and problems is a highly beneficial skill.

Assignment Template

In order to achieve the learning outcomes and objectives, the authors chose to use the "explain a problem" type of Writing-to-Learn assignment. As part of a homework assignment, students were asked to provide a written description of one of the homework problems. The particular problem was always selected by the instructor so that every student was describing the same problem. The instructor was careful to choose problems for which answers were provided in the textbook. Therefore, students knew whether they had achieved the correct answer before they began the written description.

The students received the assignment description on the first day of the course (Appendix A). The handout describes the learning outcomes and objectives. In addition, the handout provides examples of well, adequately and poorly written descriptions for an example problem. Students are instructed to provide a written description of the steps used to solve the *specific* problem, not steps to solve the type of problem in general. The written description must be no more than one-half of a page, and may be typed or hand written.

The first term in which this Writing-to-Learn assignment was used was Spring 2003. During that term, students provided a written description of one problem for each homework assignment. There are two homework assignments per week for most of the ten week course. In all, there are seventeen homework assignments; therefore, students produced seventeen written descriptions in the Spring 2003 term. Each set of written descriptions required approximately three hours of instructor time to grade. After the term, the authors decided that seventeen written descriptions resulted in a significant time commitment by the instructor and were probably more than necessary to achieve the desired outcomes and objectives.

The second term in which this Writing-to-Learn assignment was used was Fall 2003. During that term, students provided a written description of one problem per week. In all, students produced nine written descriptions in the Fall 2003 term.

During the first term, the authors noted that several students decided to not prepare written descriptions to submit with their homework. Each written description was worth eight out of one hundred points for the homework assignment. In comparison, the problems were typically worth twenty to thirty points each. Therefore, several students probably found that the eight points were not worth the time required to prepare the written description. To promote increased participation, the instructor increased the value of each written description to sixteen points out of the one hundred for the second term. Homework accounted for 20% of the student's course grade both terms.

Evaluation of Individual Assignments

On the first day of the course, students are presented with the assignment description and grading criteria. The instructor used the same criteria for both terms:

1. Has the student provided sufficient detail that I could reproduce the approach to the solution?
2. Has the student demonstrated an understanding of what is being done in the solution process?
3. Is the description written such that I can understand what the student means?
4. Is the description focused on the approach to the solution of this problem, not the specific numbers of the solution?

Each criteria is evaluated as either + (full credit), √ (part credit), or – (no credit). For the first term, full credit was two points and part credit was one point. These values were doubled for the second term.

The students were informed that each written description should start with a statement of the objective of the problem. If a student did not begin the description with the objective, the student could receive no better than part credit for the third grading criterion. In addition, students were informed that equations with variables were not acceptable in the written description. Equations must be written out (i.e., "force equals mass times acceleration" rather than "F=ma"). If a student used an equation, the student could receive no better than part credit for the second grading criterion. Although not explicitly stated in the grading criteria, grammar and spelling were not considered when evaluating the written description. The authors felt that emphasis on grammar and spelling would detract from emphasis on understanding and articulating the solution process.

Although graders are used to evaluate the homework problems, the instructor chose to evaluate the written descriptions himself. The authors feel that the descriptions should be evaluated by the instructor because of the subjectivity of the evaluation. During the first term, the instructor spent approximately three hours to evaluate all the written descriptions for a single assignment. The instructor would read the description, provide comments and assign marks (+, √, –) before moving to the next student's description. There were 37 students in the course during the first term. For the second term, the instructor modified his approach to evaluating the written descriptions, thereby reducing the time spent to approximately two hours per assignment. During the second term, the instructor first read and provided comments on each written description. After all the descriptions had been reviewed, the instructor assigned the marks. There were 39 students in the course during the second term.

One of the homework problems assigned for written description during the second term comes from Hibbeler[4]: Determine the magnitude of the resultant force $\mathbf{F}_R = \mathbf{F}_1 + \mathbf{F}_2$ and its direction, measured counterclockwise from the positive *x* axis (Fig. 1). Figure 2 is an example of a written description that received full credit for this assignment. Figure 3 is a written description that received only partial credit.

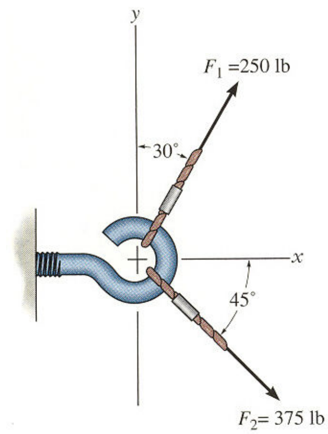


Figure 1. Illustration for a homework problem for which students provided a written description[4].

resultant of what?

The objective is to determine the magnitude of the resultant force and its direction measured counterclockwise from the positive x-axis. First the two known forces need to be resolved into their x and y-components. The x-components can be found by multiplying the magnitude of the known force with the cosine of the angle it makes with the positive x-axis. The y-components are found by multiplying the magnitude of the known force with the sine of the angle it makes with the positive x-axis; however, because F_2 is the in the fourth quadrant, its y-component must be negative.

Next the x and y components of the resultant force must be determined. The x-component is equal to the sum of the x-components of the given forces, and the y-component is equal to the sum of the y-components of the given forces. The magnitude of the resultant force is found by taking the positive square root of the sum of each resultant component squared.

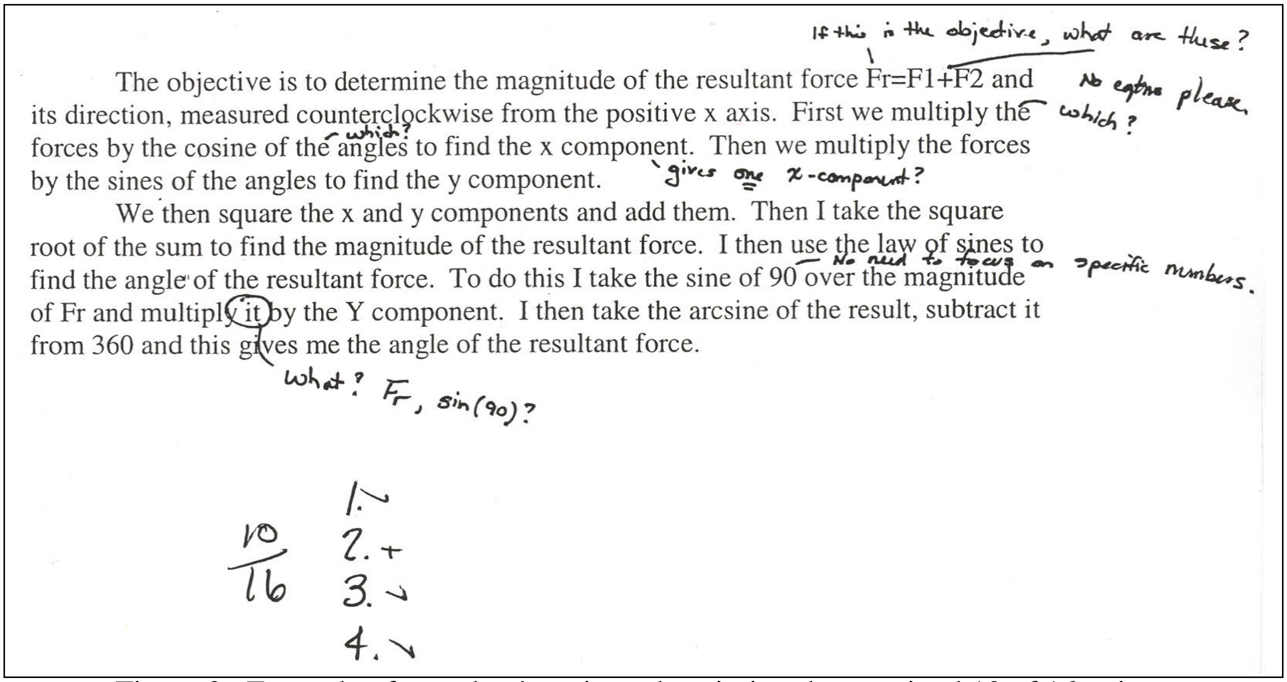
Now the direction of the resultant force must be determined. The angle of? the resultant force is found by dividing its y-component by its x-component and taking the arctangent of the result. This yields a negative angle. The sum of this angle and 360 degrees will give the desired angle measured counterclockwise from the positive x-axis.

16/16

1. +
2. +
3. +
4. +

well done

Figure 2. Example of a student's written description that received full credit.



The objective is to determine the magnitude of the resultant force Fr=F1+F2 and its direction, measured counterclockwise from the positive x axis. First we multiply the forces by the cosine of the angles to find the x component. Then we multiply the forces by the sines of the angles to find the y component.

We then square the x and y components and add them. Then I take the square root of the sum to find the magnitude of the resultant force. I then use the law of sines to find the angle of the resultant force. To do this I take the sine of 90 over the magnitude of Fr and multiply it by the Y component. I then take the arcsine of the result, subtract it from 360 and this gives me the angle of the resultant force.

Figure 3. Example of a student's written description that received 10 of 16 points.

To help students perform better on the written descriptions, the instructor twice spent roughly five minutes of lecture time reviewing examples of descriptions submitted by class members. During both terms, the instructor conducted this review using submissions from the first written description and again using submissions from the third.

Conclusions

After using Writing-to-Learn assignments for two terms in the engineering statics course, the authors have drawn several conclusions. From the first term to the second, the instructor doubled the point value for each written description and roughly halved the number of written descriptions that students performed. As a result, the percentage of students that skipped the written description portion of the homework assignments dropped from 9.8% to 7.7%.

The authors anticipated that the average score on the writing assignments would increase during the term as students became more familiar with how to prepare the written descriptions. However, figure 4 demonstrates that the average score remained within a range of approximately 10% throughout both courses. The lack of significant improvement in average score suggests that students were not able to learn how to improve their performance based on the written comments and the two in-class reviews. In fact, two students provided feedback on this in the course evaluations.

> "Grading of the "Written Solution Description" was not consistent." (Spring 2003)
>
> "Professor Hanson could work on the description for problems we do on the HW. By this I mean when we have to describe how we did a problem in words. My grades for that varied greatly, and I thought I did the same thing each time. Maybe a better explanation would help a little." (Fall 2003)

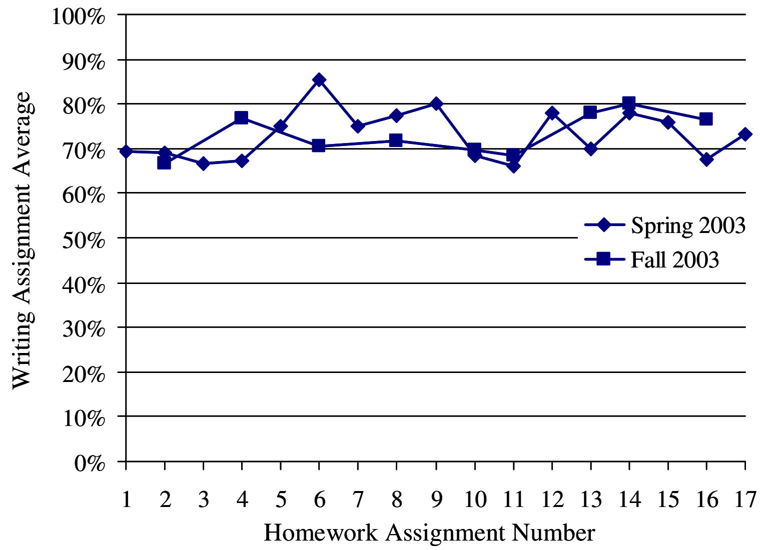


Figure 4. Progression of average writing assignment performance over the course.

The hypothesis of the authors was that these Writing-to-Learn assignments encourage students to achieve better understanding of the material and, therefore, should improve student's performance in the course. To evaluate this hypothesis, the authors have considered the following: correlation between performance on writing assignments and overall performance in the course, final grade distribution, and student comments.

The average writing assignment percentage for each student is plotted versus that student's overall performance in the course in Figure 5. Based on the data from both terms, there does not appear to be a strong correlation between performance on the writing assignments and performance in the course. However, with only one exception, performance on the writing assignments is a lower bound predictor of performance in the course.

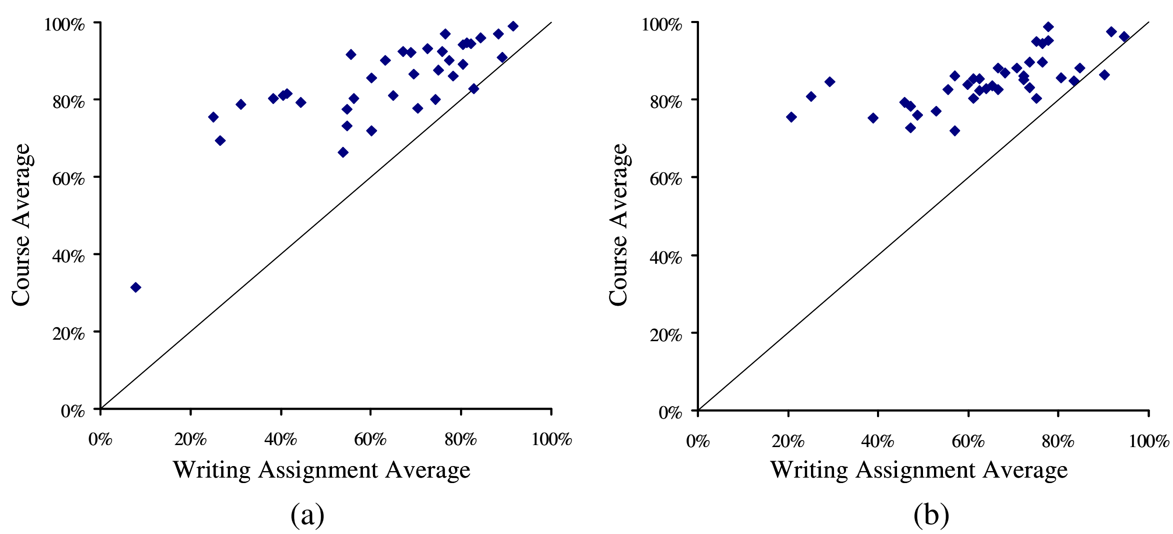


Figure 5. (a) Data from Spring 2003 term. (b) Data from Fall 2003 term.

The same instructor has presented the engineering statics course for three terms, two of which incorporated the Writing-to-Learn assignments. Table 1 presents a summary of the distribution of letter grades for each term. Although the improved performance can not be completely attributed to the Writing-to-Learn assignments, it is not unreasonable to conclude that the assignments are helping.

Table 1. Distribution of course grades for three terms of engineering statics.

Term	Students	A's	B's	C's	D's	F's
Fall 2002	14	14%	50%	29%	7%	0%
Spring 2003	37	43%	32%	19%	3%	3%
Fall 2003	39	21%	59%	21%	0%	0%

Comments by some students in the course evaluations indicate that they believe that they have achieved the course learning outcomes well. Although the Writing-to-Learn assignments are not explicitly mentioned, the comments suggest that these assignments helped.

> "I learned so much in this class that I had never even thought about before." (Fall 2003)
>
> "[The instructor] can make people think and teaches in a way to induce problem-solving behaviors as opposed to the "plug and chug" method." (Fall 2003)

Future Use of Writing-to-Learn Assignments

Because of the impact of the assignment during its first year of implementation, the authors are encouraged to continue using the assignment and even to advocate its adoption by other instructors in the civil engineering department. There are areas that still need improvement, however. These include improving the manner in which the assignment is introduced and modeled for students and reducing the grading load on instructors even further.

After reflection on how the assignments were graded during the first two terms, the authors have developed a detailed rubric for future use in the course (Table 2). The rubric will be presented to the students along with the assignment description at the start of the course.

Grading load continues to be a concern for the authors, but further consideration of the issue has led us to consider new pedagogical strategies. Among these, using Peer Review in the course appears a strong possibility. The authors have considered pairing members of the engineering statics course (freshmen and sophomores) with members of the technical communications course (juniors) so that the more experienced students can provide peer review of the writing assignments. In this way, the instructor does not shoulder the primary responsibility for teaching the engineering statics students how to write a problem description.

This work with developing Writing-to-Learn assignments has led the authors to see potential applications of similar assignments in other courses. To increase the likelihood of achieving the objectives for future courses and professional practice, the instructors are exploring the formal use of Writing-to-Learn assignments in the mechanics of materials course (sophomores after taking engineering statics), structural mechanics course (juniors after taking mechanics of materials), and structural design courses (juniors after taking structural mechanics). These applications will require that new assignments, based on the Writing-to-Learn model, are developed, tested, and documented.

Table 2. Grading rubric to be used in future editions of the engineering statics course.

Criteria	**Full Credit (4 pts)**	**Partial Credit (2 pts)**	**No Credit (0 pts)**
Has the student provided sufficient detail that I could reproduce the approach to the solution?	• Terms used in each equation are identified (i.e., forces that contribute moment in moment equilibrium).	• Terms used are not identified for one equation. • An important step in the solution sequence is omitted.	• Terms used are not identified for multiple equations. • Multiple steps in the solution sequence omitted.
Has the student demonstrated an understanding of what is being done in the solution process?	• Identify sequence by which unknowns are being found. • Each equation used is described.	• One necessary equation is not identified. • One error in the approach.	• Several necessary equations are not identified. • Multiple errors in approach.
Is the description written such that I can understand what the student means?	• Approach described is fundamentally sound. • Description begins with the objective of the problem. • Description no longer than one-half page (if typed, single spaced lines). • Handwriting is legible. • Pronouns have clear meanings (i.e., "that", "it" are easily interpreted).	• Description more than one-half page, but less than full page (if typed, single spaced lines). • One or two sentences do not make sense because of handwriting, ambiguous pronouns, and/or undefined variable names.	• Description more than one full page (if typed, single spaced lines). • More than two sentences do not make sense because of handwriting, ambiguous pronouns, and/or undefined variable names.
Is the description focused on the approach to the solution of this problem, not the specific numbers of the solution?	• All variable names used in the description are defined. • No quantities (i.e., 100 lb, 20°, 3 m) are used in the description. • Details are provided about solving this particular problem.	• One quantity is provided in the description. • Description is about how to solve this type of problem in general.	• Several quantities are provided in the description.

Appendix A – Assignment Description

Assignment:

For the specified problem, describe the steps followed in order to setup and solve the problem. Use no more than half of a page. It may be typed or hand written.

Objectives:

The goal of this course is to understand the material, not just to plug numbers into equations. An effective way to demonstrate understanding of the material is to describe how you use it.

Another motivation for these assignments is to develop the ability to articulate your thought process in an efficient and comprehensible manner. On real projects, engineers' calculations are archived for many years. If there is ever a problem, the calculations are reviewed. Brief notes on the calculations can make the difference when a review board is determining liability. In addition, it is a distinct advantage to be able to articulate your thought process clearly and concisely when working with other engineers.

Grading Criteria:

1. Has the student provided sufficient detail that I could reproduce the approach to the solution?
2. Has the student demonstrated an understanding of what is being done in the solution process?
3. Is the description written such that I can understand what the student means?
4. Is the description focused on the approach to the solution of this problem, not the specific numbers of the solution?

Examples:

The following paragraphs are examples of descriptions of the solution shown on the attached pages.

Good:

The objective is to determine the moment of *F* about the *OA* axis. First, calculate the position vector, *r*, from the origin to the point where *F* acts. This is done by subtracting the Cartesian coordinates of the origin from the coordinates of the point where *F* acts.

Find the moment of *F* about the origin by crossing *r* into *F*. Use the matrix approach to find the cross product. Add products obtained by multiplying diagonals down to the right. Subtract products obtained by multiplying diagonals down to the left. The result is a moment vector in Cartesian coordinates.

To obtain the moment about the *OA* axis, take the dot product of the unit vector along *OA* and the moment vector. To obtain the unit vector along *OA*, calculate a position vector, r_{OA}, from the origin to point A. Calculate the length of r_{OA} by taking the square root of the sum of each Cartesian coordinate of r_{OA} squared. The resulting length is a scalar, not a vector. The unit vector is obtained by dividing each coordinate of r_{OA} by the length of r_{OA}. The dot product is obtained by multiplying *x*-coordinates of the unit vector and the moment vector and summing that product with the products of the *y*-coordinates and *z*-coordinates. The resulting moment value is a scalar. To convert the value to a Cartesian vector, multiply the unit vector by the scalar moment value. The result is the moment of *F* about the *OA* axis in Cartesian coordinates.

Minimally Adequate:

The objective is to determine the moment of *F* about the *OA* axis. First, calculate the position vector, *r*, from the origin to the point where *F* acts. ***[How is this done?]***

Find the moment of *F* about the origin by crossing *r* into *F*. Use the matrix approach to find the cross product. ***[How is this done?]***

To obtain the moment about the *OA* axis, take the dot product of the unit vector along *OA* and the moment vector. Calculate a unit vector between two points along *OA*. Calculate the dot product, which is a scalar. Multiply the unit vector by the scalar moment value to obtain the moment of *F* about the *OA* axis.

Poor:

First, calculate the position vector, *r*, from the origin to the point where *F* acts. ***[What is the objective?]***

Find the moment of *F* about the origin by crossing that into it. ***[I can't understand what this is saying.]*** Use the formula on page 122 to calculate the moment. ***[Does not demonstrate understanding of what is being done in the solution process.]***

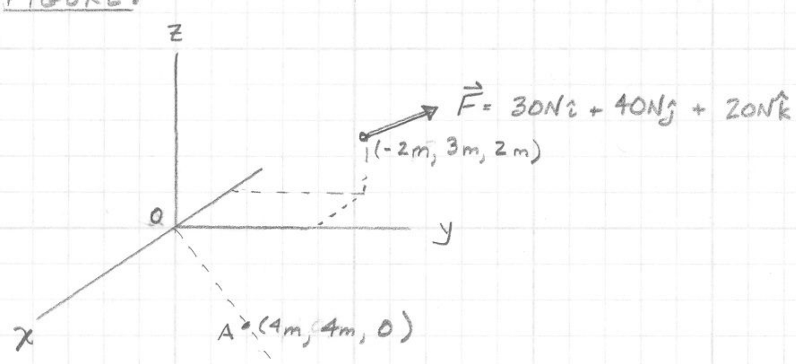
To obtain the moment about the *OA* axis, take the dot product of the unit vector along *OA* and the moment vector. Calculate a unit vector between two points along *OA*. Calculate the dot product, which is a scalar. Multiply 0.7071$\hat{\imath}$ by 56.6 N*m to obtain 40.0 N*m $\hat{\imath}$ for the *x*-component of the moment about the *aa* axis. Similarly multiply 0.7071$\hat{\jmath}$ by 56.6 N*m to obtain 40.0 N*m $\hat{\jmath}$ for the *y*-component of the moment. ***[Too specific. Description should be focused on the process, not the specific numbers.]***

GIVEN: Force F applied as shown below.

FIND: Determine the moment of F about the OA axis.

ASSUMPTIONS:
None.

FIGURE:



FBD's / CALCULATIONS:

Find position vector from a point on the OA axis to the point where $\vec{F}$ acts. Use the origin for simplicity.

$$\vec{r} = (-2m - 0)\hat{i} + (3m - 0)\hat{j} + (2m - 0)\hat{k} = -2m\hat{i} + 3m\hat{j} + 2m\hat{k}$$

Find the moment of $\vec{F}$ about a point along the OA axis, the origin.

$$\vec{M}_O = \vec{r} \times \vec{F} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ -2m & 3m & 2m \\ 30N & 40N & 20N \end{vmatrix} \begin{matrix} \hat{i} & \hat{j} \\ -2m & 3m \\ 30N & 40N \end{matrix} = 60N{\cdot}m\hat{i} + 60N{\cdot}m\hat{j} - 80N{\cdot}m\hat{k} - 90N{\cdot}m\hat{k} - 80N{\cdot}m\hat{i} + 40N{\cdot}m\hat{j}$$

$$= -20N{\cdot}m\hat{i} + 100N{\cdot}m\hat{j} - 170N{\cdot}m\hat{k}$$

Find the unit vector along axis OA.

Calculate the position vector from the origin to point A

$$\vec{r}_{OA} = (4m - 0)\hat{i} + (4m - 0)\hat{j} = 4m\hat{i} + 4m\hat{j}$$

Calculate the length of that vector

$$|\vec{r}_{OA}| = \sqrt{(4m)^2 + (4m)^2} = \sqrt{32m^2} = 5.657m$$

Unit vector.

$$\vec{u}_{OA} = \frac{\vec{r}_{OA}}{|\vec{r}_{OA}|} = \frac{4m}{5.657m}\hat{i} + \frac{4m}{5.657m}\hat{j} = 0.7071\hat{i} + 0.7071\hat{j}$$

Find the moment of $\vec{F}$ about the OA axis.

$$M_{OA} = \vec{u}_{OA} \times \vec{M}_O = 0.7071(-20N{\cdot}m) + 0.7071(100N{\cdot}m) + 0(-170N{\cdot}m)$$

$$= 56.6\,N{\cdot}m$$

$$\vec{M}_{OA} = M_{OA}\vec{u}_{OA} = 56.6N{\cdot}m(0.7071)\hat{i} + 56.6\,N{\cdot}m(0.7071)\hat{j}$$

$$\boxed{\vec{M}_{OA} = 40.0N{\cdot}m\hat{i} + 40.0\,N{\cdot}m\hat{j}}$$

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Author Biographies

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