ASEE'S VIRTUAL CONFERENCE
At Home with Engineering Education
JUNE 22 - 26, 2020 #ASEEVC
Paper ID #28543

Diagnostic Assessments of Student Attitudes and Approaches to Problem Solving in an Engineering Dynamics Course

Prof. Ning Fang, Utah State University

Ning Fang is Professor and Department Head of the Department of Engineering Education at Utah State University, U.S.A. He has taught a variety of courses at both graduate and undergraduate levels, such as engineering dynamics, metal machining, and design for manufacturing. His research in engineering education are in broad areas of engineering learning & problem solving, technology enhanced learning, and K-12 STEM education. His research in engineering focuses on the modeling and optimization of metal machining processes. He earned his Ph.D., M.S., and B.S. degrees in mechanical engineering. He is a member of the American Society of Mechanical Engineers (ASME) and the American Society for Engineering Education (ASEE).

Diagnostic Assessments of Student Attitudes and Approaches to Problem Solving in an Engineering Dynamics Course

Abstract

Diagnostic assessments help the instructor better understand students' prior knowledge and skills when students take a specific course. This paper reports the results of diagnostic assessments of student attitudes and approaches to problem solving in a sophomore-year undergraduate course called Engineering Dynamics. A 33-item survey instrument called Attitudes and Approaches to Problem Solving (AAPS) Survey developed by Mason and Singh was adopted in the present study. The AAPS survey was administered to a total of 190 engineering undergraduates who took Engineering Dynamics in two recent semesters. Student responses to the AAPS survey in the present study were compared with expert responses. The results show that less than 50% of students in two semesters provided the same responses as expert responses for 8 survey items: No. 12 (28.9%), No. 31 (30.0%), No. 30 (30.5%), No. 9 (40.0%), No. 20 (41.1%), No. 3 (43.2%), No. 5 (44.2%), and No. 11 (46.8%). Among those eight items, four items (Nos. 12, 3, 5, 11) are related to mathematics and equations; two items (Nos. 31 and 30) are related to abstract vs. concrete thinking; one item (No. 9) is about problem solving in different contexts; and one item (No. 20) deals with reflection and self-regulated learning. These research findings as well as their implications and significance are discussed.

Introduction

Engineering Dynamics is a foundational, sophomore-year, required course in many undergraduate engineering programs, such as mechanical, aerospace, civil, and environmental engineering. Built directly upon college-level physics mechanics and engineering statics courses, Engineering Dynamics involves numerous fundamental physics mechanics concepts, for example, Newton's second law, the principle of work and energy, conservation of energy, the principle of linear/angular impulse and momentum, and conservation of linear/angular momentum [1], [2].

Associated with these fundamental physics mechanics concepts, Engineering Dynamics includes a variety of problem-solving approaches. For instance, when applying Newton's second law, a problem-solving approach typically includes: establishing an appropriate coordinate system, drawing free-body and kinetic diagrams, applying Newton's second law to set up mathematical equations, and solving mathematical equations. Extensive research in physics education and engineering dynamics education has shown that problem solving is highly challenging for many students across the entire education spectrum, ranging from K-12 to undergraduate and graduate education [3]-[5]. There is a long-standing need to improve students' problem-solving skills in the engineering education community.

Diagnostic assessments are formative assessments to help the instructor better understand students' prior knowledge and skills when students take a specific course. Diagnostic assessments are important for the instructor to design an optimal course curriculum and develop an effective teaching pedagogy to achieve desired student learning outcomes, including improved problem-solving skills [6], [7].

Research has shown that student attitudes and approaches to problem solving significantly affect the development of their problem-solving skills [8], [9]. This is because student attitudes and approaches to problem solving affect, to a great extent, what they will listen to and what they will not listen to in classroom lectures. Positive attitudes and correct approaches to problem solving serve as a catalyst to foster students' problem-solving skills. Negative attitudes and incorrect approaches to problem solving diminishes student interest and motivation to learn, let alone develop and approve their problem-solving skills.

The present study focuses on diagnostic assessments of student attitudes and approaches to problem solving in an Engineering Dynamics course taught at a public research university in the Mountain West region in the United States. An instrument called Attitudes and Approaches to Problem Solving (AAPS) Survey developed by Mason and Singh [10] was adopted in the present study to answer the following research question:

> What were student attitudes and approaches to problem solving when they started taking Engineering Dynamics courses at Utah State University?

The scope of the present study is limited to investigating student attitudes and approaches to problem solving when they start taking Engineering Dynamics. The significance of the present study is that the research findings from the present study would help instructors: 1) find out students' prior knowledge and skills, and 2) identify what knowledge and skills students need to be improved for effective problem solving in Engineering Dynamics. Future research studies are needed to determine whether student attitudes and approaches to problem solving are correlated to their performance in Engineering Dynamics.

In a similar research study using a modified Maryland Physics Expectation Survey (a Likert-type agree-disagree questionnaire survey), Cummings, Lockwood, and Marx [11] reported that student attitudes toward problem solving in college physics classes were correlated with several exam scores, such as course exam average scores and Force and Motion Conceptual Exam scores. The correlation coefficient R varied from 0.28-0.48. However, the work [11] did not report the p value associated with R. Therefore, it is unclear whether the correlation between student attitudes toward problem solving and their actual problem-solving skills was statistically significant.

In the remaining sections of this paper, the AAPS survey is described, followed by a description of student participants. Then, the results of the survey are presented. Next, the research findings and their implications are discussed, followed by a description of the limitations of the present research. Finally, concluding remarks are made at the end of the paper.

Attitudes and Approaches to Problem Solving (AAPS) Survey

The Attitudes and Approaches to Problem Solving (AAPS) Survey developed by Mason and

Singh [10] was adopted in the present study. Built upon the earlier work by Cummings, Lockwood, and Marx [11] and Marx and Cummings [12], the AAPS Survey consists of 33 Likert-type items to survey college student attitudes and approaches to problem solving in physics. The AAPS survey asks students to indicate their level of agreement with each survey item on a 5-level scale:

A) Strongly Agree
B) Agree Somewhat
C) Neutral or Don't Know
D) Disagree Somewhat
E) Strongly Disagree

The mechanics part of physics is highly similar to Engineering Dynamics. For the reader's convenience, three example items included in the AAPS Survey [10] are shown below:

> Survey item No. 16: When answering conceptual physics questions, I mostly use my "gut" feeling rather than using the physics principles I usually think about when solving quantitative problems.
>
> Survey item No. 17: I am equally likely to draw pictures and/or diagrams when answering a multiple-choice question or a corresponding free-response (essay) question.
>
> Survey item No. 18: I try different approaches if one approach does not work.

Mason and Singh [10] also provided expert responses to each survey item. For instance, expert responses were D/E to survey item No. 16, A/B to survey item No. 17, and A/B to survey item No. 18.

The reliability and validity of the AAPS survey instrument has been validated with extensive research [10], [13]. The Cronbach's alpha, which measures the reliability of the survey instrument, is reported to be 0.82 [10]. The validity of the survey instrument was validated through reviews by other faculty members as well as pilot tests and interviews with a group of introductory students [10].

Student participants

The AAPS survey was administered at the beginning of two recent semesters when students started taking an Engineering Dynamics course at a public research university in the Mountain West region of the United States. The total number of student participants involved in the present study was 190, including 109 students in Semester A and 81 students in Semester B.

The vast majority of students in these semesters were from two departments: Mechanical and Aerospace Engineering (MAE) and Civil and Environmental Engineering (CEE). Before taking Engineering Dynamics, students have taken Engineering Statics and college-level physics class. The same instructor (the author of this paper) taught Engineering Dynamics in both semesters using the same textbook and syllabus.

Results

Each student provided their response to each survey item. For each survey item, the number of students who provided the same responses as expert responses was counted. For example, out of the 190 students surveyed in two semesters, 119 students responded to survey item No. 1 with "Disagree Somewhat" or "Strongly Disagree," which were also the responses by experts. Therefore, the percentage of students in two semesters provided the same responses as expert responses is calculated as 119/190 = 62.6%.

Table 1 shows a total of 8 survey items for which less than 50% of students in two semesters (A and B) provided the same responses as expert responses. These 8 items include Nos. 12, 31, 30, 9, 20, 3, 5, and 11. For item No. 12, only 28.9% of students in two semesters provided the same responses as expert responses. Table 2 shows a total of 16 survey items for which 50-80% of students in two semesters (A and B) provided the same responses as expert responses. Table 3 shows a total of 9 survey items for which more than 80% of students in two semesters (A and B) provided the same responses as expert responses.

Table 1. Survey items for which less than 50% of students in Semesters A and B provided the same responses as expert responses

Survey item number	Percentage of students in Semester A	Percentage of students in Semester B	Percentage of students in two semesters (A and B)
No. 12	25.7%	33.3%	28.9%
No. 31	24.8%	37.0%	30.0%
No. 30	25.7%	37.0%	30.5%
No. 9	35.8%	45.7%	40.0%
No. 20	38.5%	44.4%	41.1%
No. 3	46.8%	38.3%	43.2%
No. 5	49.5%	37.0%	44.2%
No. 11	45.0%	49.4%	46.8%

As can be seen from Table 1, student responses to the same survey item varied from semester A to semester B. For example, 25.7% of students in semester A provided the same responses as expert responses to survey item No. 12. This percentage increased to 33.3% in semester B. For two semesters A and B, 28.9% of students provided the same responses as expert responses to survey item No. 12.

Therefore, the two-semester percentages were employed in the present study to perform analysis. The analysis focused on eight survey items for which less than 50% of students in two semesters provided the same responses as expert responses. These eight survey items represent the major differences between student and expert attitudes and approaches to problem solving.

Table 2. Survey items for which 50-80% of students in two semesters (A and B) provided the same responses as expert responses

Survey item number	**Percentage of students in two semesters (A and B)**
No. 16	52.9%
No. 26	57.9%
No. 6	59.5%
No. 1	62.6%
No. 14	63.7%
No. 33	67.4%
No. 4	70.5%
No. 17	72.6%
No. 13	74.2%
No. 2	74.7%
No. 23	77.4%
No. 27	77.9%
No. 8	78.4%
No. 18	78.4%
No. 24	78.4%
No. 25	78.9%

Table 3. Survey items for which more than 80% of students in two semesters (A and B) provided the same responses as expert responses

Survey item number	**Percentage of students in two semesters (A and B)**
No. 32	81.1%
No. 7	85.8%
No. 10	87.4%
No. 21	87.9%
No. 22	91.1%
No. 19	91.6%
No. 15	93.1%
No. 28	95.2%
No. 29	96.8%

For the reader's convenience, eight items [10] for which less than 50% of students in two semesters provided the same responses as expert responses, as shown in Table 1, are listed below:

No. 12: Physics involves many equations each of which applies primarily to a specific situation.

No. 31: While solving a physics problem with a numerical answer, I prefer to solve the problem symbolically first and only plug in the numbers at the very end.

No. 30: It is much more difficult to solve a physics problem with symbols than solving an identical problem with a numerical answer.

No. 9: I use a similar approach to solving all problems involving conservation of linear momentum even if the physical situations given in the problems are very different.

No. 20: After I solve each physics homework problem, I take the time to reflect and learn from the problem solution.

No. 3: In solving problems in physics, being able to handle the mathematics is the most important part of the process.

No. 5: "Problem solving" in physics basically means matching problems with the correct equations and then substituting values to get a number.

No. 11: Equations are not things that one needs to understand in an intuitive sense; I routinely use equations to calculate numerical answers even if they are non-intuitive.

Discussions

Among the eight items described above, we found that:

- 4 items (Nos. 12, 3, 5, 11) are related to mathematics and equations
- 2 items (Nos. 31 and 30) are related to abstract vs. concrete thinking
- 1 item (No. 9) is about problem solving in different contexts
- 1 item (No. 20) deals with reflection and self-regulated learning

The following paragraphs discuss these research findings. All subheadings are highlighted in italics to improve readability of this section.

Mathematics and equations

In engineering dynamics, students must apply physics mechanics laws and principles, such as Newton's second law and the principle of work and energy, to solve a variety of problems. Each law or principle is associated with its corresponding mathematical equation. As long as a law or principle is applicable, it can be used to solve many problems that are seemingly different in appearance but actually the same in essence.

For instance, the mathematical equation for Newton's second law is $\Sigma \mathbf{F} = m\mathbf{a}$, where force $\mathbf{F}$ and acceleration $\mathbf{a}$ are both vectors. The equation of $\Sigma \mathbf{F} = m\mathbf{a}$ can be applied to many problems that are seemingly different in appearance but actually the same in essence, for example, the block-pulley problem shown in Fig. 1 and the block-ramp problem shown in Fig. 2.

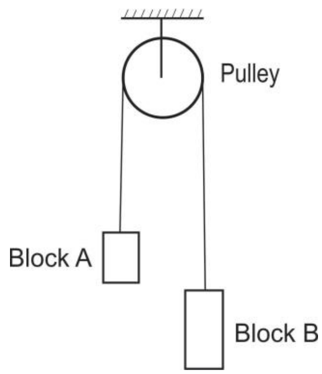

Fig. 1 Block-pulley problem

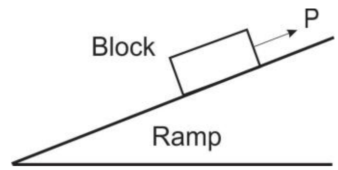

Fig. 2 Block-ramp problem

In Fig. 1, two blocks (A and B) of different weights are connected by a string and pulley. Given the weights of two blocks, determine the tension force in the string once the blocks start moving. In Fig. 2, a block is initially at rest. A force P is applied to the block to move it up along the ramp. Given the mass of the block and the coefficient of sliding friction between the block and the ramp, determine force P so the block can reach to speed V within t seconds.

Both problems in Figs. 1 and 2 are Newton's second law problems and can be solved with the same mathematical equation $\Sigma \mathbf{F} = m\mathbf{a}$. However, to many students, these two problems are quite different. The problem in Fig. 1 has a pulley with no ramp. The problem in Fig. 2 has a ramp with no pulley. Both problems require different mathematical equations to solve. Therefore, in responding to survey item No. 12 ("physics involves many equations each of which applies primarily to a specific situation"), only 28.9% (i.e., less than one-third) of students chose "Disagree Somewhat" or "Strongly Disagree," the responses provided by experts.

Student responses to survey item No. 12 imply that many students judge a problem from its surface or appearance, rather than from its essence or nature. As such, many students thought "'Problem solving' in physics basically means matching problems with the correct equations and then substituting values to get a number" (Survey item No. 5). This perception needs to be fundamentally changed. To develop strong problem-solving skills, students need to be taught that engineering dynamics and physics are not simply a mathematical game playing with many mathematical equations. Effective problem solving requires a solid understanding of physical meaning of each mathematical equation and its applicable range [14]. Problem-solving skills can never be improved by simply "substituting values into an equation to get a number."

Abstract vs. concrete thinking

Student responses to survey items Nos. 30 and 31 show that only one-third of the students surveyed were comfortable solving problems with symbols. In other words, two-thirds of the students surveyed feel challenged if a problem is presented with symbols, rather than with numerical digits. This research finding implies that many students lack abstract thinking skills and prefer concrete thinking during problem solving.

Abstract thinking is a form of thinking that does not focus on any specific examples [15], [16]. In contrast, concrete thinking involves specific examples. For instance, a concrete thinker understands 2+3 = 5 easily, but might have difficulty in understanding a + b = c because a, b, and c are all symbols with no specific numerical digits associated with them. Compared to concrete thinkers, abstract thinkers have a higher ability to generalize their understanding and apply their understanding from one scenario or case to another.

A large number of problems exist in engineering dynamics. Therefore, students must develop abstract thinking skills and get out of their comfort zone (i.e., concrete thinking), so they can apply what have learned from one problem solving to another. However assisting students in developing their abstract thinking skills and finding what education interventions are the most effective are beyond the scope of the present study and need to be addressed in future studies.

Problem solving in different contexts

Only 40% of the students surveyed provided the same responses as expert responses ("Strongly Agree" or "Agree Somewhat") to survey item No. 9 "I use a similar approach to solving all problems involving conservation of linear momentum even if the physical situations given in the problems are very different." This implies, again, that the majority of students (60%) judge a problem from its surface or appearance, rather than from its essence or nature. For effective problem solving, students must develop a solid understanding of the physical meaning of each physics law or principle and its applicable range.

Reflection and self-regulated learning

Only 41.1% of the students surveyed "Strongly Agree" or "Agree Somewhat" with survey item No. 20 "After I solve each physics homework problem, I take the time to reflect and learn from the problem solution." This means the majority of students (nearly 60%) did not reflect on the lessons they had learned from problem solving. A large amount of research has shown that reflection and self-regulated learning play a significant role in learning [17]-[19]. Without frequent reflection and self-regulated learning, learning cannot be reinforced and memory will be lost as time goes by. As a consequence, knowledge transfer, either near or far, will not occur.

Limitations of the present study

The present study has two primary limitations. First, it only conducted diagnostic assessments of student attitudes and approaches to problem solving, rather than performing a treatment (i.e., education intervention) to improve student problem solving. As in a medical procedure, diagnosis is always the first step prior to a treatment. Diagnosis helps a doctor identify what disease the patient has and then select appropriate methods to treat the disease. Without diagnosis, a doctor cannot decide what treatments he or she will do. The present study focuses on diagnosis, rather than treatments.

Second, the sample size (190 students) in the present study was limited. All students were from the same institution. If more and more students from different institutions are involved, the percentage numbers shown in Tables 1-3 might change.

Concluding remarks

In the present study, student attitudes and approaches to problem solving when they started taking an Engineering Dynamics course have been assessed using a 33-item Attitudes and Approaches to Problem Solving (AAPS) Survey instrument. Student responses were compared to expert responses for each survey item.

The results show that less than 50% of the students surveyed provided the same responses as expert responses for 8 survey items: No. 12 (28.9%), No. 31 (30.0%), No. 30 (30.5%), No. 9 (40.0%), No. 20 (41.1%), No. 3 (43.2%), No. 5 (44.2%), and No. 11 (46.8%). Among those 8 items, 4 items (Nos. 12, 3, 5, 11) are related to mathematics and equations; 2 items (Nos. 31 and 30) are related to abstract vs. concrete thinking; one item (No. 9) is about problem solving in different contexts; and one item (No. 20) deals with reflection and self-regulated learning.

The significance of the research findings made from the present study is that they reveal the direction of future efforts to develop education interventions to improve student problem solving. No matter the hands-on or digital online forms they take [20]-[22], education interventions should aim to improve students' mathematical skills, abstract thinking skills, knowledge transfer skills, as well as reflection and self-regulated learning.

If the above fundamental and important skills cannot be enhanced, it would be highly challenging for students to develop strong problem-solving skills. Improving these fundamental and important skills, however, is not an easy undertaking, and requires systematic efforts and collaboration from the entire engineering education community. As numerous factors affect problem solving [8], [9], a single education intervention targeting one skill alone, such as abstract thinking skills, will be insufficient to substantially improve student problem solving.

References

[1] F. P. Beer, E. R. Johnston, and P. Cornwell, *Vector Mechanics for Engineers: Dynamics* (10th edition). Columbus, OH: McGraw-Hill, 2001.

[2] R. C. Hibbeler, *Engineering Mechanics Dynamics* (14th edition). Upper Saddle River, NJ: Pearson Prentice Hall, 2015.

[3] D. Evenhouse, N. Patel, M. Gerschutz, N. A. Stites, J. F. Rhoads, E. Berger, and J. DeBoer, "Perspectives on pedagogical change: instructor and student experiences of a newly implemented undergraduate engineering dynamics curriculum," *European Journal of Engineering Education*, vol. 43, no. 5, pp. 664-678, 2018.

[4] B. Schmidt, "Teaching engineering dynamics by use of peer instruction supported by an audience response system," *European Journal of Engineering Education*, vol. 36, no. 5, pp. 413-423, 2011.

[5] L. R. Barroso and J. R. Morgan, "Developing a dynamics and vibrations course for civil engineering students based on fundamental principles," *Advances in Engineering Education*, vol. 3, no. 1, pp. 1-35, winter 2012.

[6] G. T. G. Shim, A. M. H. A. Shakawi, and F. L. Azizan, "Relationship between Students' diagnostic assessment and achievement in a pre-university mathematics course," *Journal of Education and Learning*, vol. 6, no. 4, pp. 364-371, 2017.

[7] J. Shi, W. B. Wood, J. M. Martin, N. A. Guild, Q. Vicens, and J. K. Knight, “A diagnostic assessment for introductory molecular and cell biology,” *CBE - Life Sciences Education*, vol. 9, no. 4, pp. 453-461, winter 2010.
[8] E. Ince, “An overview of problem solving studies in physics education,” *Journal of Education and Learning*, vol. 7, no. 4, pp. 191-200, 2018.
[9] M. V. B. Reddy and B. Panacharoensawad, “Students problem-solving difficulties and implications in physics: An empirical study on influencing factors,” *Journal of Education and Practice*, vol. 8, no. 14, pp. 59-62, 2017.
[10] A. J. Mason and C. Singh, “Surveying graduate students’ attitudes and approaches to problem solving,” *Physical Review Special Topics - Physics Education Research*, vol. 6, no. 2, 020124, 2010.
[11] K. Cummings, S. Lockwood and D. M. Jeffrey, “Attitudes toward problem solving as predictors of student success,” *AIP Conference Proceedings*, 720, pp. 133-136, 2004.
[12] J. Marx and K. Cummings, “What factors really influence shifts in students’ attitudes and expectations in an introductory physics course?” *AIP Conference Proceedings*, 883, pp. 101-104, 2007.
[13] N. Balta, A. J. Mason, and C. Singh, “Surveying Turkish high school and university students’ attitudes and approaches to physics problem solving,” *Physical Review Special Topics - Physics Education Research*, vol. 12, no. 1, 010129, 2016.
[14] D. Wedelin, T. Adawi, T. Jahan, and S. Andersson, “Investigating and developing engineering students’ mathematical modelling and problem-solving skills,” *European Journal of Engineering Education*, vol. 40, no. 5, pp. 557-572, 2015.
[15] L. Woollacott and D. Snell, “Assessing the quality of student thinking directly: An exploratory study of two cohorts entering engineering education in South Africa,” *South African Journal of Higher Education*, vol. 26, no. 3, pp. 638-657, 2012.
[16] A. Velentzas and K. Halkia, “The use of thought experiments in teaching physics to upper secondary-level students: Two examples from the Theory of Relativity,” *International Journal of Science Education*, vol. 35, no. 18, pp. 3026-3049, 2013.
[17] P. Wallin and T. Adawi, “The reflective diary as a method for the formative assessment of self-regulated learning,” *European Journal of Engineering Education*, vol. 43, no. 4, pp. 507-521, 2018.
[18] M. Tawde, D. Boccio, and K. Kolack, “Two-year community: Resolving misconceptions through student reflections,” *Journal of College Science Teaching*, vol. 47, no. 1, pp. 12-17, 2017.
[19] B. J. Zimmerman, “Self-regulated learning and academic achievement: An overview,” *Educational Psychologist*, vol. 25, no. 1, pp. 3-17, 1990.
[20] M. Ceberio, J. M. Almudí, and Á. Franco, “Design and application of interactive simulations in problem-solving in university-level physics education,” *Journal of Science Education and Technology*, vol. 25, no. 4, pp. 590-609, 2016.
[21] A. Hossain, J. Durfee, H. Bae, and K. Larsen, “Teaching an undergraduate dynamics course for mechanical ‘engineering technology’ students: Successful implementation for students learning,” In *Proceedings of the ASME 2016 International Mechanical Engineering Congress and Exposition, Phoenix, AZ, USA, November 11-17, 2016*.
[22] A. Purwar and C. A. Scott, “An online engineering dynamics class for college sophomores: Design, implementation, and assessment,” In *Proceedings of 2019 ASEE Annual Conference & Exposition, Tampa, FL, USA, June 16-19, 2019*.