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Should Kinetics Follow Kinematics? Investigating Course Design in Dynamics

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Lt Col Kent Jensen is a USAF officer who taught in the USAF Academy's Engineering Mechanics Department from 2014 to 2017. He graduated from the USAF Academy in 2000 with his Bachelors of Science Degree and from the University of Utah with his Masters of Engineering Degree in 2001. He then attended USAF pilot training and flew C-130s until 2014. He transported troops and materiel across the US, Europe, Africa and SW Asia until 2009 when he taught young pilots to fly the C-130 in Arkansas. In 2011 he moved to California to perform operational flight testing of mobility aircraft before returning to the USAF Academy to teach. He recently left the USAF Academy to oversee Hill AFB's flight, weapons and occupational safety programs in Utah.

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Abstract

In this study, we investigated whether the reordering of kinetics and kinematics topics in a traditional dynamics course leads to improved student ability to choose and apply appropriate kinetics principles to solve single- and multi-concept dynamics problems. To test this hypothesis, three sections of Dynamics were taught using a traditional ordering of topics and one section was taught with a reordering of the topics with kinetics taught before kinematics. Students' ability to choose and apply appropriate kinetics principles was assessed using common questions on exams, a common final exam, and an in-class questionnaire assignment administered at the beginning and end of the semester. In this study we did not see a statistically significant improvement in performance, and we were therefore not able to duplicate the results from a previous study that showed that the reordering of the topics in the context of an integrated sophomore curriculum resulted in an improvement in students' ability to solve dynamics problems.

Project Description and Background Information: The vast majority of dynamics textbooks (Hibbeler (2016), Boresi and Schmidt (2000), Beer and Johnston (2015), Meriam and Kraige (2015), Shames (1996), Bedford and Fowler (2007), Soutas-Little and Inman (1999), Tongue (2009), and Gray, Costanso, and Plesha (2012)) are organized with an almost identical ordering of topics [1]-[9]. This ordering is generally particle kinematics, particle kinetics, rigid body kinematics, rigid body kinetics, 3-D kinematics and kinetics, and finally vibrations. The current broad use of the kinematics-before-kinetics ordering could be due to historical acceptance and familiarity (current professors learned in this way), but there is no empirical research to support that ordering as preferable.

At Rose-Hulman, kinetics principles are introduced in the larger context of conservation principles, that is, conservation of mass, charge, linear momentum, angular momentum and energy, using only very basic kinematics [10]. Only after students are able to appropriately apply the kinetics principles are additional kinematics topics discussed. This approach is currently part of a sophomore engineering curriculum (SEC) as shown in Figure 1. In this curriculum the concepts of conservation and accounting permeate the sequence of courses [11], [12].

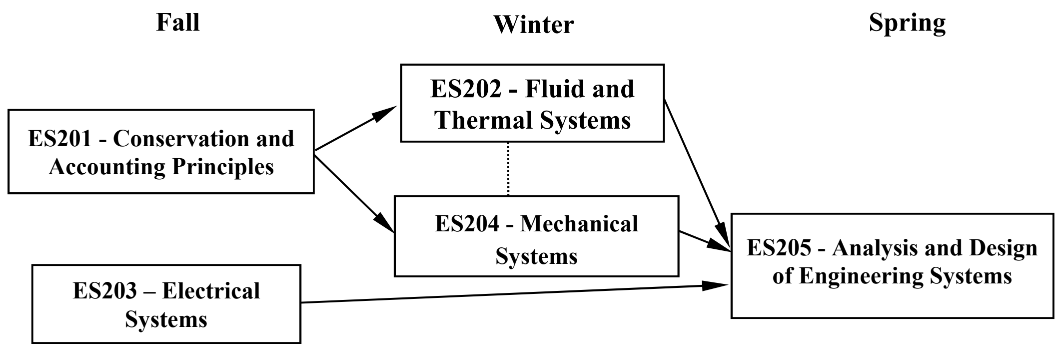

Figure 1 - Summary of the sophomore engineering curriculum (SEC) at Rose-Hulman. A sequence of three courses can be used since Rose-Hulman is on the quarter system.

Reference [10] discusses a previous study where the mechanics portion of the SEC was assessed. In that study, identical finals were given to students in the SEC (where kinetics is introduced before kinematics) and students taking a traditional dynamics course (where the traditional ordering of topics was used). The two courses were taught by the same professor using similar pedagogical methods (concept questions, daily quizzes, simulations, demonstrations, active learning, and a computer algebra system); therefore, the primary difference was the reordering of the topics. Both finals consisted of 20 multiple-choice problems (40% of the total points) and 3 workout problems (60% of the total points). Students' performance on the multiple-choice problems was not statistically different, but students in the new curriculum were found to perform significantly better on the longer, more complicated workout problems as shown in Table 1. Please see [10] for more details on this study. In Table 1, a "correct" answer indicated that the student missed no more than one or two points on the problem. This meant the student identified the correct kinetics principles and was able to apply them correctly. Unfortunately, we no longer have the data, so we are unable to definitively state the statistical significance of these results, but since there were over 100 students in the sample, we are relatively confident that these results are statistically significant.

Table 1 Percentage of students with correct answers for the workout problems (1997-1998 academic year)

Workout problem number	Students in the SEC	Students in traditional Dynamics class	Difference
1	36.8	17.0	19.8
2	70.1	22.0	48.1
3	46.0	6.0	40.0

Project Goals and Methods: In this study, we investigated whether the reordering of kinetics and kinematics topics in a traditional dynamics course, that is, a course that is not part of a larger integrated framework, leads to improved student performance on single- and multi-concept dynamics problems. We hypothesized that the larger conservation and accounting framework that is incorporated at Rose-Hulman is not necessary to see improvements in student performance because Physics Mechanics is a required prerequisite for Dynamics. Therefore, students will already have seen, and have experience using, the three kinetics principles used in dynamics: Newton's 2^{nd} law, work-energy, and impulse-momentum. Almost all dynamics textbooks seem to assume no knowledge of kinetics and, based on the authors' experiences, most dynamics instructors assume no previous knowledge of kinetics. We hypothesized that presenting the kinetics material first would improve students' performance on single- and multi-concept problems because we would be able to (1) build on students' previous learning in Physics, (2) motivate learning of the kinematics material, because we need the velocity and/or acceleration for our kinetics principles, and (3) provide students with multiple opportunities to apply the kinetics principles across a variety of contexts and in an interleaved manner [13]. This would give students more practice at higher levels of Bloom's taxonomy [14] and at spaced intervals, which has been shown to improve student learning [15].

To test this hypothesis, one professor taught two sections of Dynamics, one with a reordering of topics (kinetics taught before kinematics), and one with the traditional ordering (kinematics taught before kinetics). Two other professors taught one section each in the traditional way as additional control sections. Therefore, the test section was taught by one professor who has experience teaching this material with the topics reordered, and three control sections were taught with the topics in the traditional order. We attempted to make the ordering of topics the only difference between the sections. Student performance on single- and multi-concept problems was assessed using common exam questions.

In this study we also wanted to determine if students' demonstrated ability to choose appropriate kinetics principles to solve problems is affected by the reordering of the topics. Based on prior research, we anticipated greater improvement across the semester in ability to choose concepts on multi-concept problems than on single-concept problems for students in the class with kinetics taught before kinematics. This was assessed using a questionnaire at the beginning and end of the course. The questionnaire used is included at the end of this paper.

Results

Figure 2 shows a comparison between the test group's and the control group's performances on the common final exam and on specific questions that required multiple kinetics concepts. The final exam consisted of 15 multiple choice questions and four workout problems, two of which were multi-concept problems. Of the three multi-concept problems shown in Figure 2, two were from the final exam and one was from one of the midterm exams. We chose to only include the results from multi-concept problems in this Figure since our hypothesis was that students would perform better on these types of problems with the topic reordering. From Figure 2, it is clear that there was no statistically significant difference in the performance of students taught using the two different arrangements of the topics.

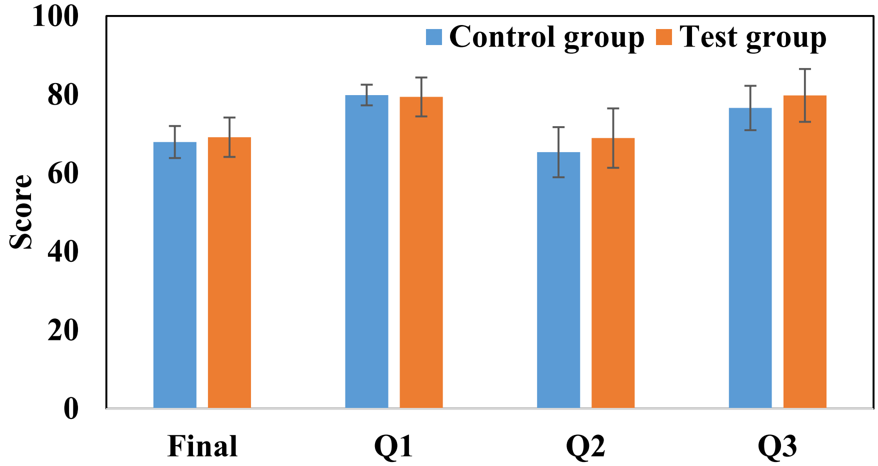

Figure 2. Comparison of student performance on the final exam and on problems involving multiple kinetics concepts. The error bars correspond to a 95% confidence interval.

Figures 3, 4 and 5 show the results from asking students to identify the appropriate kinetics principle or principles to use on eight dynamics problems. The problems used are shown at the end of this paper. Figure 3 shows the pre-class results, Figure 4 shows the post-class results, and Figure 5 shows the gain, that is, the post-class results minus the pre-class results. The problems identified with an "MC" are multi-concept problems.

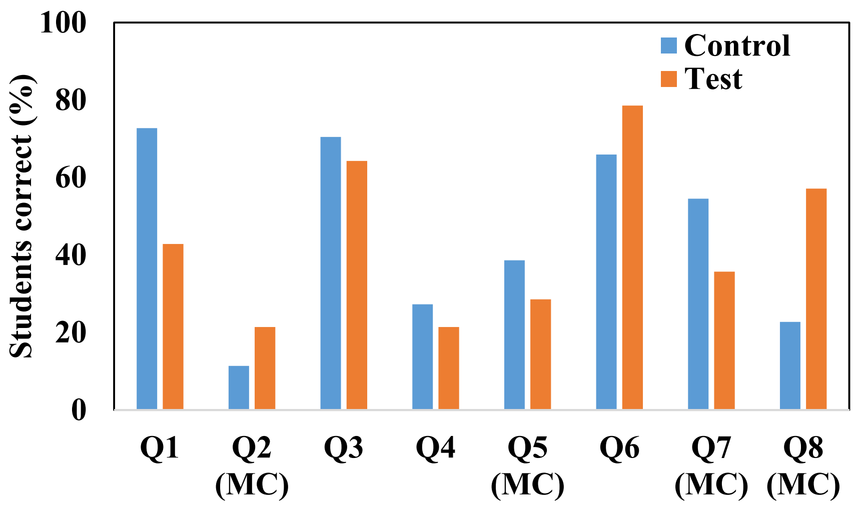

Figure 3. Pre-class assessment of students' ability to identify kinetics principles. Multi-concept problems are designated with "MC."

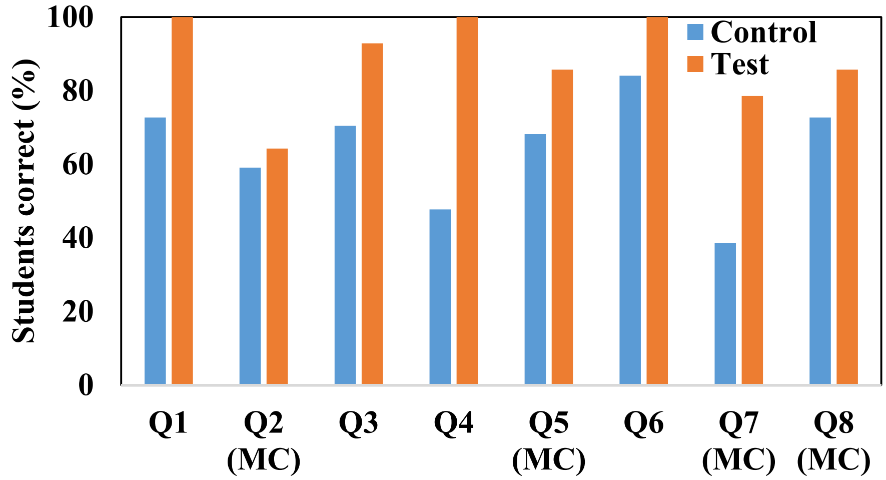

Figure 4. Post-class assessment of students' ability to identify kinetics principles. Multi-concept problems are designated with "MC."

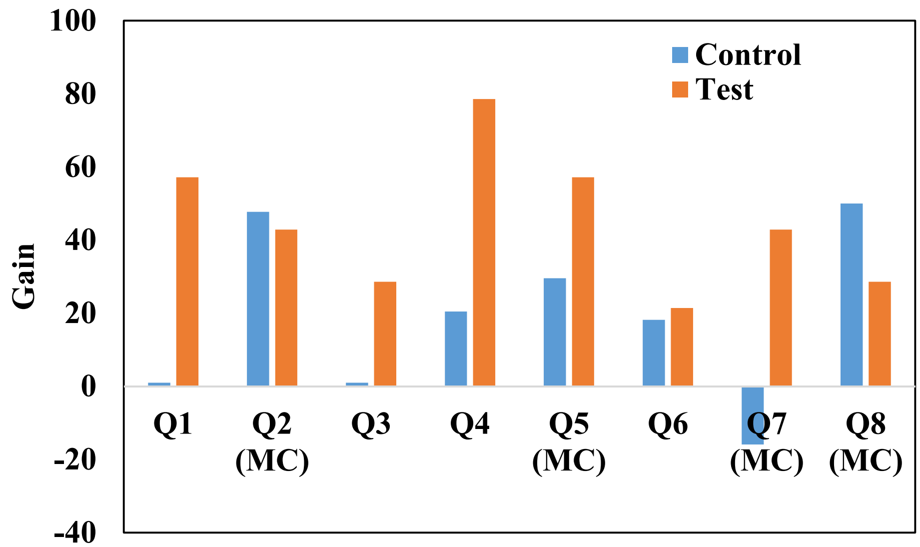

Figure 5. Gain in ability of students to identify kinetics principles to use from the first day of class to the last day. Multi-concept problems are designated with "MC."

For problems requiring two kinetics principles, students needed to identify both of them to get full credit. For problems requiring three principles, we gave credit if they identified two out of the three. Figure 3 shows that the pre-class performance was not bad, and that students were bringing some knowledge from their previous physics classes into this class. The two problems they performed worst on were Q2 and Q3. The main issue was they did not recognize the need to use impulse-momentum for the impact in Q2 and the term "kinematics" may have been new to them, so they did not recognize Q3 as a pure kinematics problem.

Figure 4 shows that the percentage of students correctly identifying the appropriate principles was higher for the test group for every problem, but Figure 5 shows there was only a larger gain on six of the eight questionnaire problems. The reason for the reduction in students' ability in the control group to identify the correct kinetics principles for Question 7 is unknown. The final questionnaire was given the last day of class, and they may not have put forth their best effort. The questions that had the lowest gains were often because the students performed relative well on the pre-class assessment (Q1, Q3, and Q6).

The reason the apparent increase in ability to identify the appropriate principles did not translate into improved performance on the exams requires further investigation. In this data analysis we did not need to account for a difference in average GPA of the students in the two groups because the GPAs for the test group and for the control group were virtually identical (3.34 vs 3.33).

Conclusions and Recommendations

In this study we investigated whether the reordering of kinetics and kinematics topics in a traditional dynamics course leads to improved student ability to choose and apply appropriate kinetics principles to solve single- and multi-concept dynamics problems. We were not able to duplicate the results from a previous study where the reordering was part of a larger integrated curriculum. The sample size was quite small in this study, so there may be benefit in repeating this study with a larger number of students, but based on the lack of obvious improvements on the common exam problems, we do not recommend implementing the reordered syllabus without additional study.

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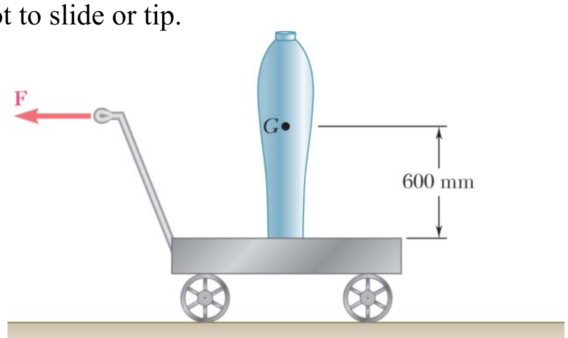
Appendix A – Questionnaire

The purpose of this questionnaire is to assess your ability to choose appropriate kinetics and kinematics concepts to solve dynamics problems. You have 15 minutes to complete the questions. Do not write down any equations, but indicate in words what kinetics principles (underlined below) you would use. If no kinetics principles are applicable, simply indicated kinematics.

Kinetics principles - Basic laws of nature: <u>Newton's 2nd Law</u>, conservation of energy (or <u>work-energy methods</u>), or conservation of momentum (or <u>impulse-momentum methods</u>)

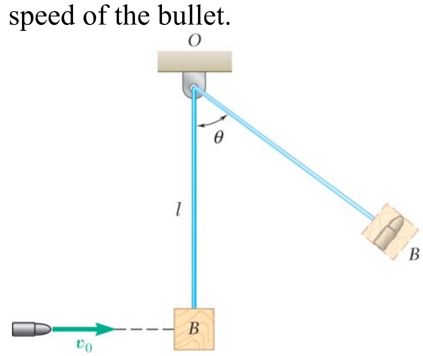
Kinematics – The relationships between quantities such as position, velocity, and acceleration such as projectile motion or the use of normal and tangential coordinates.

1. A 40-kg vase has a 200-mm-diameter base and is being moved using a 100-kg utility cart as shown. The cart moves freely ($\mu = 0$) on the ground. Knowing the coefficient of static friction between the vase and the cart is $\mu_\sigma = 0.4$, determine the maximum force **F** that can be applied if the vase is not to slide or tip.



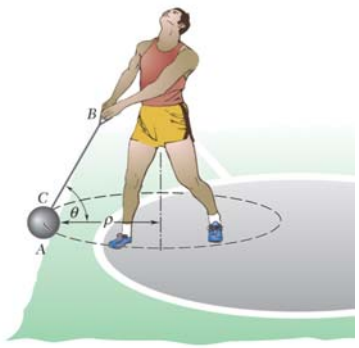
Kinetics principle(s) and/or kinematics you would use:

2. A ballistic pendulum is used to measure the speed of high-speed projectiles. A 6-g bullet *A* is fired into a 1-kg wood block *B* suspended by a cord of length *l* = 2.2 m. The block then swings through a maximum angle of θ= 60º. Determine the initial speed of the bullet.



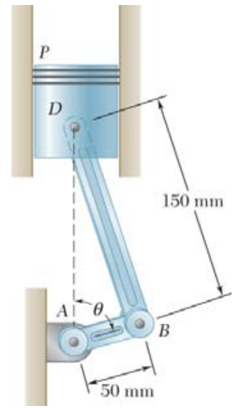
Kinetics principle(s) and/or kinematics you would use:

3. During a hammer thrower's practice swings, the 7.1-kg head *A* of the hammer revolves at a constant speed *v* in a horizontal circle as shown. If ρ = 0.93 m and θ = 60°, determine the tension in wire *BC*.



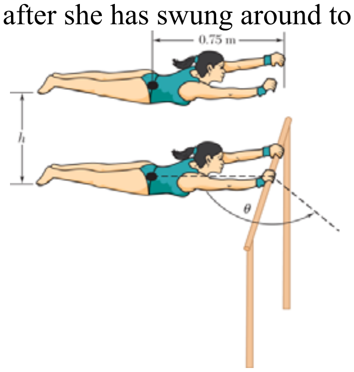
Kinetics principle(s) and/or kinematics you would use:

4. Knowing that crank *AB* rotates about Point *A* with a constant angular velocity of 900 rpm clockwise, determine the acceleration of the piston *P* when θ = 30°.



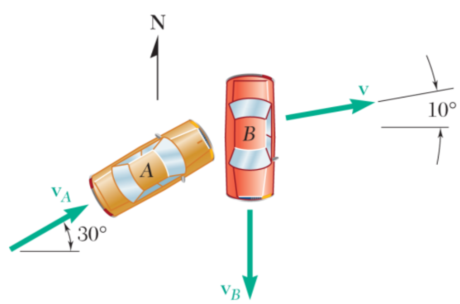
Kinetics principle(s) and/or kinematics you would use:

5. The 40-kg gymnast drops from a known height *h* straight down to the bar as shown. Her hands hit the bar and clasp onto it, and her body remains straight in the position shown. Knowing her mass and mass moment of inertia, and assuming that friction between the bar and her hands is negligible and that she remains in the same position throughout the swing, determine the reaction between her hands and the bar after she has swung around to $\theta = 135°$.

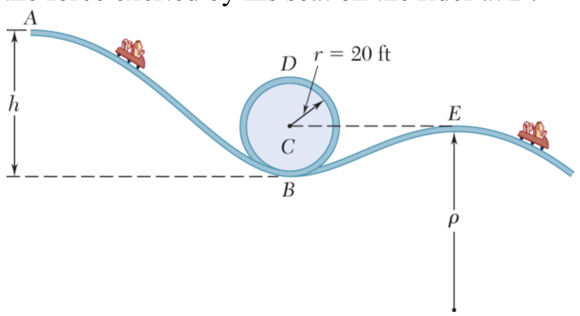
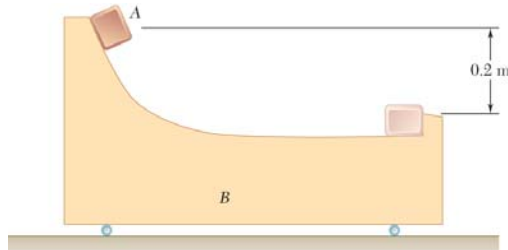


Kinetics principle(s) and/or kinematics you would use:

6. At an intersection car *B* was traveling south and car *A* was traveling 30° north of east when they slammed into each other. Upon investigation it was found that after the crash the two cars got stuck and skidded off at an angle of 10° north of east. Knowing the masses of cars and one of the drivers was going 50 km/h, determine the speed of the faster of the two cars if the slower car was traveling at the speed limit.



Kinetics principle(s) and/or kinematics you would use:

7. A roller coaster starts from rest at *A*, rolls down the track to *B*, and moves up and down past Point *E*. Assuming no energy loss due to friction, determine the force exerted by his seat on the rider at *D*.  **Kinetics principle(s) and/or kinematics you would use:**	8. Block *A* is released from rest and slides down the frictionless surface of *B* until it hits a bumper on the right end of *B*. Block *A* has a mass of 10 kg, object *B* has a mass of 30 kg and *B* can roll freely on the ground. Determine the velocities of *A* and *B* immediately after impact when the coefficient of restitution *e* = 0.7.  **Kinetics principle(s) and/or kinematics you would use:**