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Simulations and Manipulatives used to Better Understand Graphics, Statics & Dynamics Concepts

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Abstract

This paper is intended to investigate the merits of adding manipulative devices and solid model simulations to accompany traditional lecture and demonstration materials to a Dynamics course. Based on the successes of Graphics courses using manipulative devices and simulation software to enhance spatial visualization skills in engineering students, a pilot study in a Dynamics course adding a 4-bar linkage mechanism and a NX software simulation was used. A pre-test was administered prior to using the intervention and post test results were collected after. Analysis of the pre- and post- quiz scores showed sufficient improvement in learning to encourage the continued development of more manipulatives and simulations for Dynamics. Recommendations are made to study whether similar methods will impact student learning in Statics courses.

Introduction

Engineering programs often focus on theory and conceptual design, while Engineering Technology (ET) programs typically have an increased focus on application and implementation. Accordingly, Engineering programs require higher-level mathematics, including multiple semesters of calculus and calculus-based theoretical science courses. ET programs, on the other hand, focus on algebra, trigonometry, and basic applied calculus, which are more practical in nature. Most Engineering and ET programs during the freshman year include a Graphics course to familiarize students with the essential spatial visualization skills as well as methods of interpreting engineering drawings and diagrams. In the mechanical field of study, Statics and Dynamics are sophomore-level courses covering a broad spectrum of foundational concepts such as; forces, free body diagrams, equilibrium, friction, moments, displacement, velocity, acceleration, force, work, energy, impulse, momentum, and vibrations. It is well-recognized that graphic interpretation of engineering drawings and diagrams, as well as static and dynamic analysis are fundamental building blocks for many subsequent courses such as Machine Design I and II, Applied Fluid Mechanics, Thermodynamics and Heat Transfer.

Background

In the traditional lecture-based course design, the students take notes on theory and example problems presented by the instructor. The class is usually structured so that the students do assigned homework problems, take exams and quizzes each semester. By teaching the course in this manner, students do not significantly participate in problem solving activities representing real-world applications occurring in the modern engineering/industrial workplace. On the other hand, students are placed in an environment in which they appear to be very comfortable, but not actively participating.

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According to Metz et.al. (2011), approaches used at The Ohio State University to teach spatial visualization skills to engineering students utilized manipulative devices such as a set of interlocking building blocks to allow students to depict objects in 3D, and the use of CAD software to rotate 3D objects. The spatial visualization course provided the opportunity for students to improve their performance on the standardized Purdue Spatial Visualization Test – Rotations (PSVT:R) yielding a gain in both semesters administered. This illustrates the point that topics difficult to master such as spatial visualization can result from a lack of experience rather than lack of ability. In practice, Applied Science Education graduate students participating in a 4 credit course, “The Engineering Process” intended for current and future K-12 science and mathematics teachers, yielded very positive results while utilizing these techniques. Students in 2013 (n=20) and 2016 (n=12), using the textbook by Sorby, Manner, Bartmans. “3-D Visualization for Engineering Graphics. Edition: 4th”, and Sorby, C., “Developing Spatial Thinking. Edition: 1st” respectively, were administered the PSVT:R assessment as a pre and post-test. They were assigned problems from the textbook chapters to complete while utilizing “Snap Cubes” as manipulatives and were exposed to the solid modeling software “Tinkercad” to help visualize objects in 3D space. Although the sample size was very small, the results in 2013 yielded an increase of 5% from pre (66%) to post (71%), and in 2016 there was an increase of 12% from pre (63%) to post (75%).

The concepts in statics, particularly the creation of free body diagrams, rely heavily on understanding spatial relationships of objects. Ha and Fang (2015) make the argument that since engineering mechanics requires spatial abilities, which seem to be overlooked by instructors, that they should seek proper instructional and spatial training strategies to help students be successful. The direction that most universities have implemented are to include a prerequisite Graphics course to develop students’ spatial visualization skills. Given that visualization skills are best learned when manipulative devices and solid modeling multimedia software is implemented in conjunction with lecture, demonstration and textbook sketching exercises (Sorby, 2009 & Ardebili, 2006), it suggests that utilizing manipulatives and solid modeling software may help students better visualize application problems in statics and dynamics courses.

Magill (1997) suggests that Dynamics is “one of the more difficult courses engineering students encounter during their undergraduate study.” One reason for this is that Dynamics material has traditionally been taught without discussing the concepts in a meaningful context. It is a complex course requiring both a solid understanding of basic physics and an intuition regarding solution strategies. In other words, dynamics problems are such that a well-defined solution protocol applicable in all cases cannot be provided. An additional difficulty in the context of teaching the course to ET students is that, due to the learning style of the students, the mathematical content of the course is typically simplified, and the emphasis put on practice of application problems.

While some faculty have responded to the inherent difficulties of teaching and learning dynamics by adopting procedural problem-solving methods (Magill, 2011 & Everett,

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1997) , others have applied a variety of active learning approaches in Dynamics and Statics courses (Asokanthan, 1997; Howell, 1996; Jones & Brickner, 1996; and Holzer, & Andruet, 1998). Asokanthan (1997) for example, reports on the use of simulations, physical models, and videos to involve students in the learning process.

Dynamics course Pilot Study

As a result of the successes in Graphics and Statics courses, a pilot study was implemented to test the implementation of both manipulatives and interactive software in a Dynamics course. The Dynamics course meets for 50 minutes thrice a week, on Mondays, Wednesdays and Fridays. The pilot study intent was to assess the effectiveness of using manipulative models and simulations as an integral part of the course conducted in the spring 2015 semester. The in- and out-of-class activities associated with the pilot study lasted approximately two weeks. Details of the pilot study have been reported in Mehendale et al. (2015), and have been summarized in the following paragraphs and the timeline is shown in Table 1.

Table 1
4-bar linkage modeling homework and pre- and post-assessment.

Day-week number	In-class activities	Out-of-class activities
(M-1, W-1, F-1)	Chapter 16: Planar (2-D) Kinematics of a Rigid Body 16.1 Rigid-Body Motion,16.2 Translation, 16.3 Fixed Axis Rotation, 16.4 Absolute Motion Analysis, 16.5 Relative-Motion Analysis : Velocity, 16.6 Instantaneous Center of Zero Velocity	HW 8 16-3,5,7,11,13,23 (sections 16.1,16.2,16.3) 16-41,49 (section 16.4) 16-61,81,88,101 (sections 16.5, 16.6)
(M-2, W-2)	Chapter 16 Q & A Chapter 17 lecture	
(F-2)	First Quiz (pre-assessment) See Appendix A: First Quiz, and Appendix C: First Quiz Solution	4-bar linkage model hw assigned, due (M-3)
(M-3)	Second Quiz given (post-assessment) **See Appendix B: Second Quiz, and Appendix D: Second Quiz Solution**	

The students also had additional time in class to work hands-on with the 4-bar linkage model (See Figure 1) on Friday of week 2. The NX 4-bar linkage model (See Figures 2 & 3) was made available to the students after quiz 1, and the students were surveyed at the time they took quiz 2 to ask (1) whether they used the NX model, and (2) whether they thought it helped them understand the material better. A total of 20 students took quiz 2. The distribution of the answers to the above questions can be seen in Table 2.

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Table 2
Student responses to NX model survey.

Question	Responses		Distribution
	Question #1	Question #2	
#1) Did you use the NX model simulation? #2) Did the NX model simulation help you understand the material better?	YES	no response	5
	NO	no response	4
	YES	YES	1
	YES	NO	3
	no response	no response	7

Figure 1. Adjustable 4-bar mechanism used in pilot study.

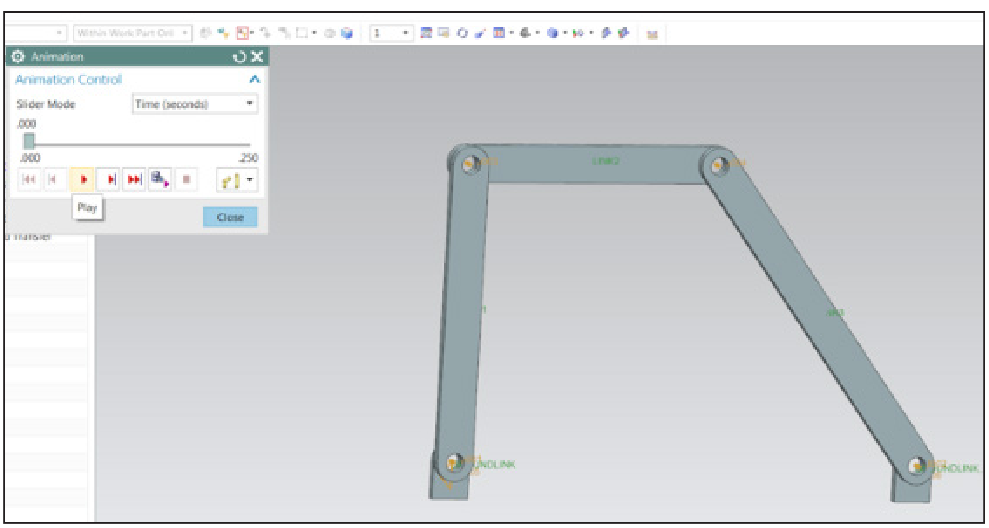

Figure 2. NX 4-bar motion simulation used in pilot study.

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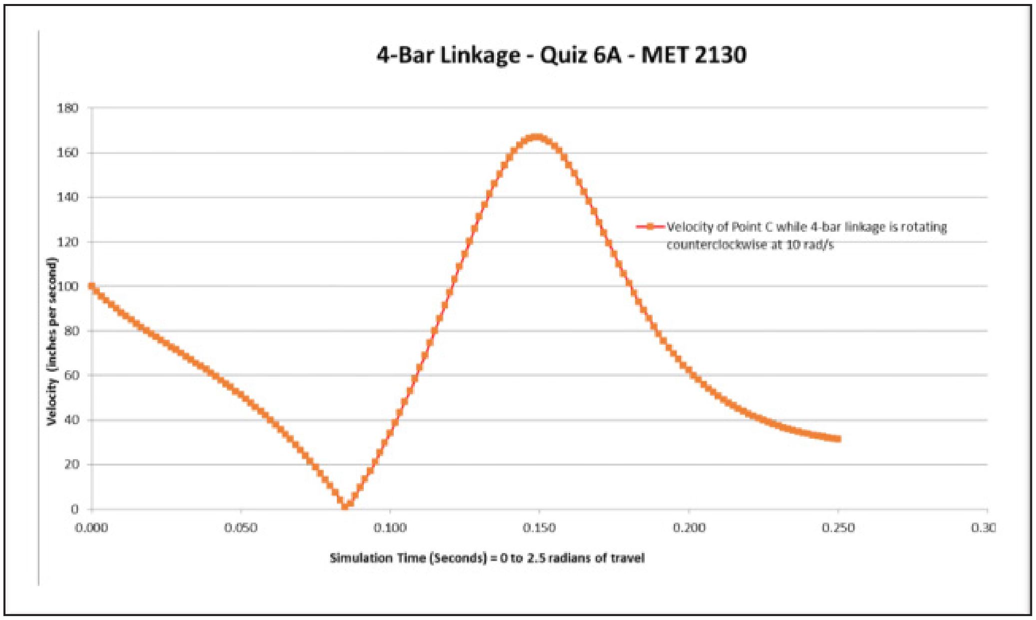

Figure 3. NX 4-bar motion simulation results in Excel graph.

The homework exercise required students to rotate the input linkage of a 4-bar linkage model through a prescribed angle, and then measure the angle of rotation at the output linkage. Specific link lengths L_1, L_2, L_3, and L_4 and angular displacements $\Delta\theta_{in}$ were assigned to each group of students so that the acceleration would be negligible, and thus the angular velocity would be roughly proportional to the angular displacement. It should be noted that the manipulative devices the students worked with were not equipped with instrumentation for measuring the angular velocities ω_{in} and ω_{out} of the input and output links, respectively. For this reason, the students used the angular displacement $\Delta\theta$ as a proxy for the angular velocity ω, which is a reasonably accurate approximation for small angular displacements of the order of about 10–20°. Using this approach, the students were able to calculate the angular velocity of the output link using the approximation: $\omega_{out} \approx \Delta\theta_{out}(\omega_{in}/ \Delta\theta_{in})$. The students were then required to separately verify the measured angular displacements using analysis (using their choice of the instantaneous centers or relative velocity methods).

The second quiz was announced in the previous class, so that any additional studying by the students would be minimal. The first quiz was not returned or discussed until after the second quiz was complete. The second quiz was very similar to the first quiz, with slightly different geometry, and velocities. Again, the students had the option of using either the relative velocity or the instantaneous centers of velocity methods (See Appendices A-D for quizzes and solutions).

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Pilot Study Results

Figures 4 and 5 show the corresponding data for the scores of 20 students who participated in the pilot study in spring 2015.

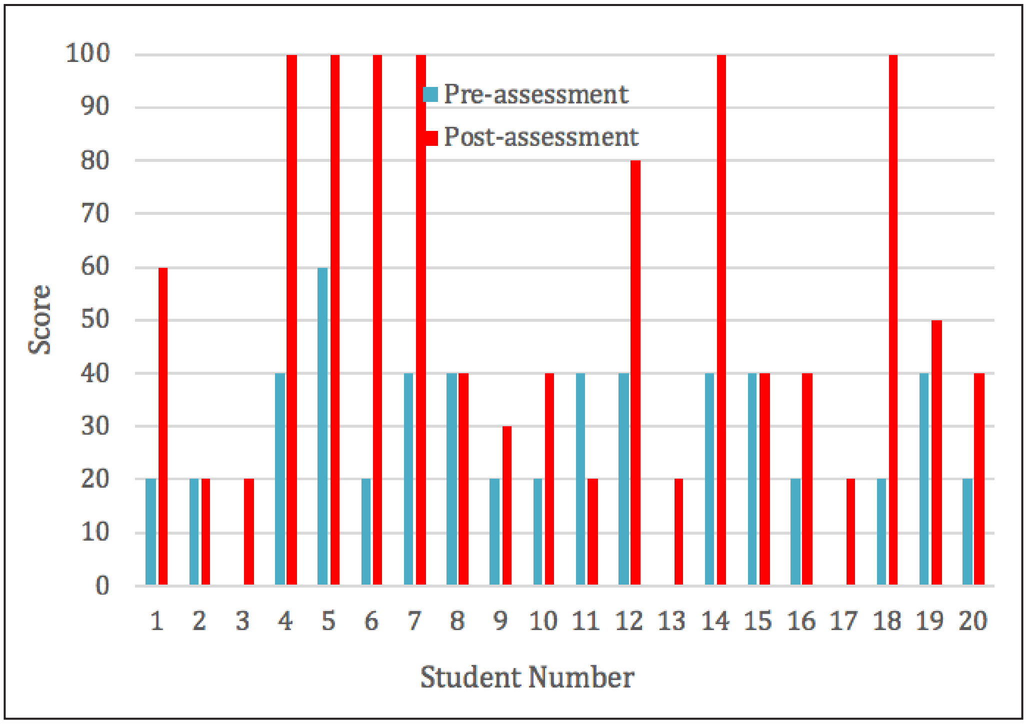

Figure 4. Pre- and post-assessment scores for students in the pilot study.

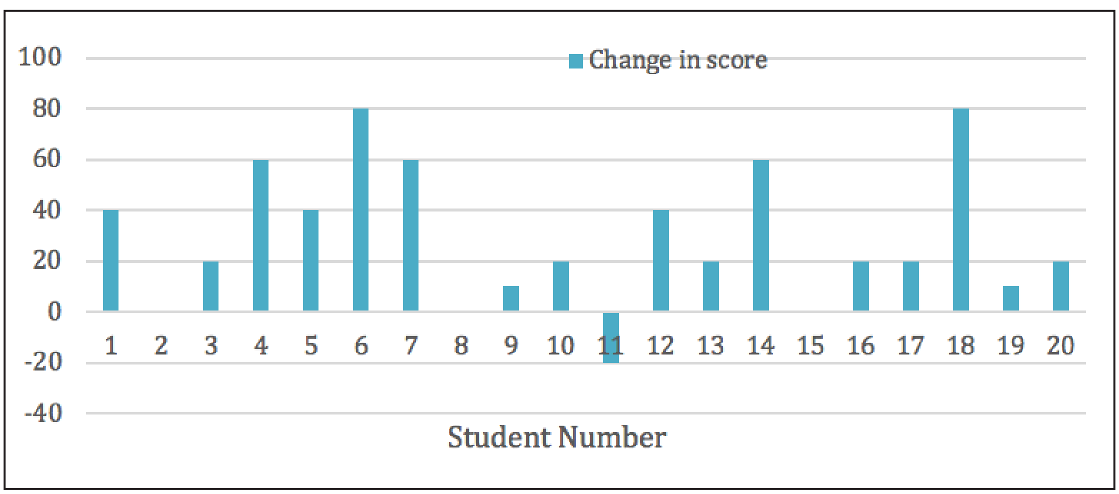

Figure 5. Student score changes resulting from pilot study.

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Overall, the assessment data revealed that as a result of being exposed to the exercise with the manipulative models, 80% of the students obtained improved scores, 15% showed no change in score, while the scores of 5% of the students scored poorer.

Pilot Study Conclusions

Given that no additional instruction was provided, other than the 4-bar linkage model homework and NX simulation, the scores on the post-assessment quiz show a fair improvement over the pre-assessment quiz. Attempts were made to avoid any grade improvement solely due to specific studying immediately before the quiz, but improvement in score could still be attributed to the manipulative model experience, and associated analysis homework.

Although the data obtained in the pilot study was limited, analysis of the pre- and post-quiz scores showed sufficient improvement in learning to encourage the continued development of more manipulatives and simulations for Dynamics. Recommendations are to continue the use of manipulatives and solid modeling software activities in Graphics courses. In addition, Statics and Dynamics courses should implement utilization of manipulatives and solid modeling software to help students visualize industry-based application problems. Future research in the Statics course will investigate the impact of using the Pasco “Comprehensive Materials Testing System”, an integrated system for tensile testing that measures both force and position, as well as solid modeling NX software to illustrate textbook problems using Finite Element Analysis static loading solutions.

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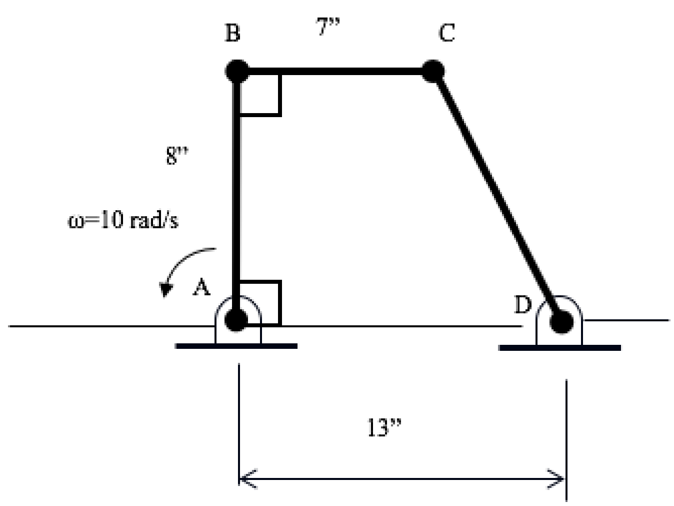
Appendix A: Pilot Study First Quiz

MET 2130 **Quiz 6A** **Name:________________________**

At the instant shown, link AB of the 4-bar mechanism shown is rotating counterclockwise at 10 rad/s, with member lengths as shown. At the instant shown, link BC is horizontal and link AB is vertical.

What is the velocity of joint C (v_c) at the instant of time shown?



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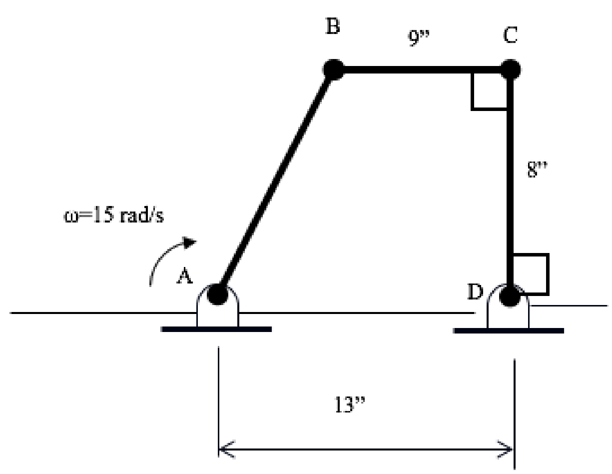
Appendix B: Pilot Study Second Quiz

MET 2130 **Quiz 5B** **Name:__________________________**

At the instant shown, link AB of the 4-bar mechanism shown is rotating clockwise at 15 rad/s, with member lengths as shown. At the instant shown, link BC is horizontal and link CD is vertical.

What is the velocity of joint C (v_c) at the instant in time shown?



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Appendix C: Pilot Study First Quiz Solution

MET 2130 Quiz 6A Name:________________________

At the instant shown, link AB of the 4-bar mechanism shown is rotating counterclockwise at 10 rad/s, with member lengths as shown. At the instant shown, link BC is horizontal and link AB is vertical.

What is the velocity of joint C (v_c) at the instant of time shown?

Method of ICs

$V_B = AB \cdot \omega_{AB}$

$= (8)(10)$

$= 80$ inch/s

$\tan\theta = \frac{8^4}{6_3} = \frac{(x+8)}{13}$

$52 = 3x + 24$

$x = 9.33$ in.

$V_c = 10\,\omega_{CD}$ — (1)

$= y\,\omega_{BC}$ — (2)

$y = \sqrt{x^2 + 7^2}$

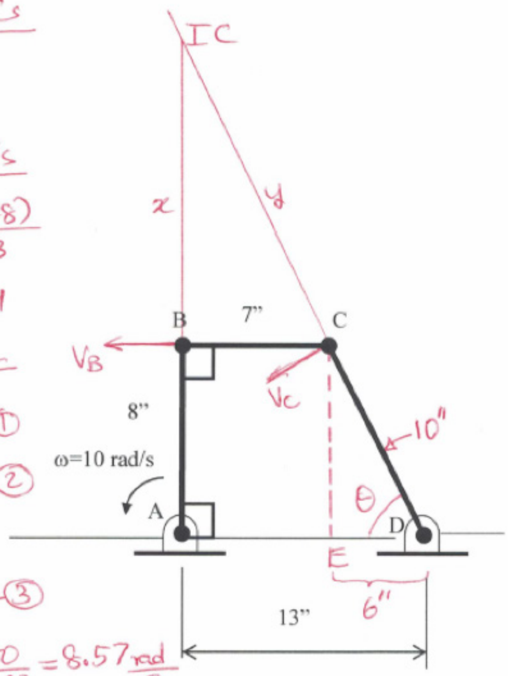
$= 11.67$ in. — (3)

$\omega_{BC} = \frac{V_B}{x} = \frac{80}{9.33} = 8.57\ \frac{rad}{s}$

From (2) and (3):

$V_c = (11.67)(8.57)$

$= \boxed{100 \text{ inch/s}}$



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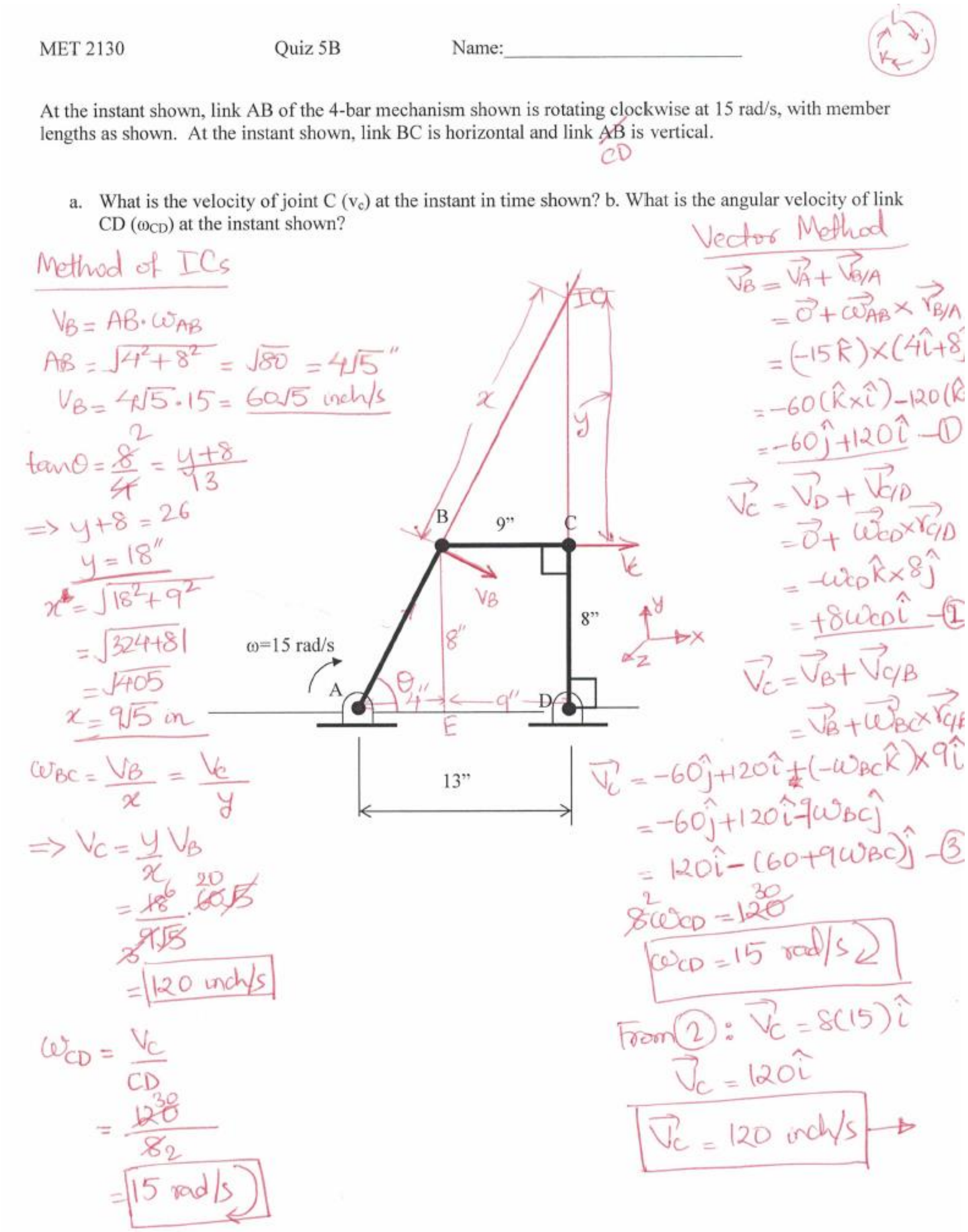
Appendix D: Pilot Study Second Quiz Solution



MET 2130 Quiz 5B Name:________________________

At the instant shown, link AB of the 4-bar mechanism shown is rotating clockwise at 15 rad/s, with member lengths as shown. At the instant shown, link BC is horizontal and link ~~AB~~ CD is vertical.

a. What is the velocity of joint C (v_c) at the instant in time shown? b. What is the angular velocity of link CD (ω_{CD}) at the instant shown?

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