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NUMERICAL SIMULATION AS IN INTEGRAL COMPONENT OF DYNAMICS PROBLEM SOLVING

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Numerical Simulation and Group Homework in a Second-Year Dynamics Course

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Abstract

Roger Williams University engineering faculty believe that properly preparing students to use modern engineering tools is best accomplished through integration into coursework throughout the four-year curriculum. But this is challenging in practice, as engineering courses are already packed with essential technical content and any encumbrance to delivering this material is unwelcome. The author's engineering mechanics course (*Dynamics*) is an effort to satisfy the conflicting goals of building technical skills while delivering complex content. This paper describes a multi-year effort to integrate solid modeling into the course by requiring numerical validation of symbolic solutions to homework problems. Working in homework groups, a student will hand-solve problems using traditional methods, but then must demonstrate that their solution is correct by comparison to a partner's numeric results from a Motion Analysis of a SolidWorks© model duplicating the geometric and inertial properties of the problem. As a direct result, student groups independently validate their symbolic and numerical solutions, providing immediate feedback and significant gratification as reported by the students. This paper will provide a detailed description of the use of SolidWorks© in the course over a twelve-year period, 2013-2024 inclusive. Anonymous surveys conducted each year (>550 responses over the study period), provide a statistically significant basis for evaluating the pedagogical effectiveness of this approach. This paper will present summative statistical results plus an analysis of changes over time concurrent with evolving course policies and material. Although student response is shown to be overwhelmingly positive, this paper will also discuss areas where student feedback is decidedly mixed, indicating potential for improvement.

Keywords

Dynamics, Simulation, SolidWorks, Group Homework.

Introduction

Roger Williams University engineering faculty believe that properly preparing students to use modern engineering tools is best accomplished by reinforcing skills throughout the four-year curriculum. But this is challenging in practice, as engineering courses are already packed with essential technical material and any encumbrance to delivering this material is unwelcome. The classical mechanics course (*Dynamics*) described in this paper is an effort to satisfy the conflicting goals of building technical skills using engineering tools while maintaining theoretical content.

The use of numerical simulation is not unique to the course described here. Quoting from [1] "Computational tools are necessary to prevent unnecessary mistakes when solving problems in classical mechanics”. In a dynamics course offered by Kurt M DeGoede of Elizabethtown College, students may demonstrate computational skills when they “Construct a model and perform analysis of an assigned 2D system with SimMechanics” [2]. In a course by William E. Howard of East Carolina University, SolidWorks is used to produce videos offered to students as supplemental materials [3]. Mark David Bedillion of the South Dakota School of Mines and Technology includes four extra-credit SolidWorks assignments students may complete [4].

Other authors [5], [6],[12] have cataloged the challenges of developing technical skills while maintaining a commitment to theoretical content. The literature shows that many instructors use some form of computer-aided simulation of problems [7] and some further employ problem solving software and interactive computing [8], [9], [10], [11], [12]. Despite the abundance of similar approaches, the author can find no references in the literature to courses employing SolidWorks in the manner described here.

Dynamics is a required course for all students in the fourth semester of our eight-semester BS in engineering program. This course has been offered annually in the format described here to the entire sophomore class (50-60 students) from 2013 to 2024 inclusive. A total of five-hundred-fifty-four (554) students over this period voluntarily completed year-end, anonymous surveys soliciting feedback on their experiences. Students indicated their level of agreement or disagreement on a Likert scale to twelve prompts. The author has compiled and analyzed these data to support overall conclusions on the suitability of SolidWorks to the course objectives. This paper will present the objectives, describe the use of SolidWorks and homework teams and evaluate the results.

Objectives

The author acknowledges that this paper presents an ambitious and unconventional approach to teaching a conventional course. This departure from time-tested practices is motivated by the following objectives.

1. **Kinematic Visualization –** Dynamics is most effective when students visualize the objects under study moving. This is a challenge when only static, two-dimensional figures are employed.

2. **Quantitative Insight –** Educate students on the interdependence of kinematic and kinetic parameters of moving bodies.

3. **ABET Objective 7 –** Student preparation in “an ability to acquire and apply new knowledge as needed”.

4. **Develop Skills –** Train students to effectively use SolidWorks as modeling and analysis tool.

5. **Combat Plagiarism –** Develop a climate in which each student develops mastery of complex material.

Course Structure

Dynamics employs a traditional lecture format in which the instructor derives relevant formulas and works example problems on a chalkboard. Students complete graded weekly problem sets in groups, with each group assigned four problems. Each student in the homework group is responsible for completing one “symbolic” solution and one “numeric check”. The “symbolic” solutions are traditional paper-and-pencil solutions using equations of motion, algebra and the student’s hand-held calculator. There is little novelty in the symbolic solutions; student work resembles that of twenty years ago and even resembles work the instructor submitted as an undergraduate student - quite a few years before that.

The novelty of this course is the “numeric checks”, where students must construct SolidWorks models duplicating the kinematic and kinetic conditions of the problem. Students must then employ this model to check the work of a groupmate by producing a single page that convincingly demonstrates the validity their groupmate’s solution. Figure 1 shows a typical student-submitted validation page. Note that the upper part shows the SolidWorks implementation of the given homework problem (shown in the lower left). Also note that motion analysis graphs and exported data show the initial angular velocity and acceleration of the subject link while the insert demonstrates that driving motor parameters were implemented as

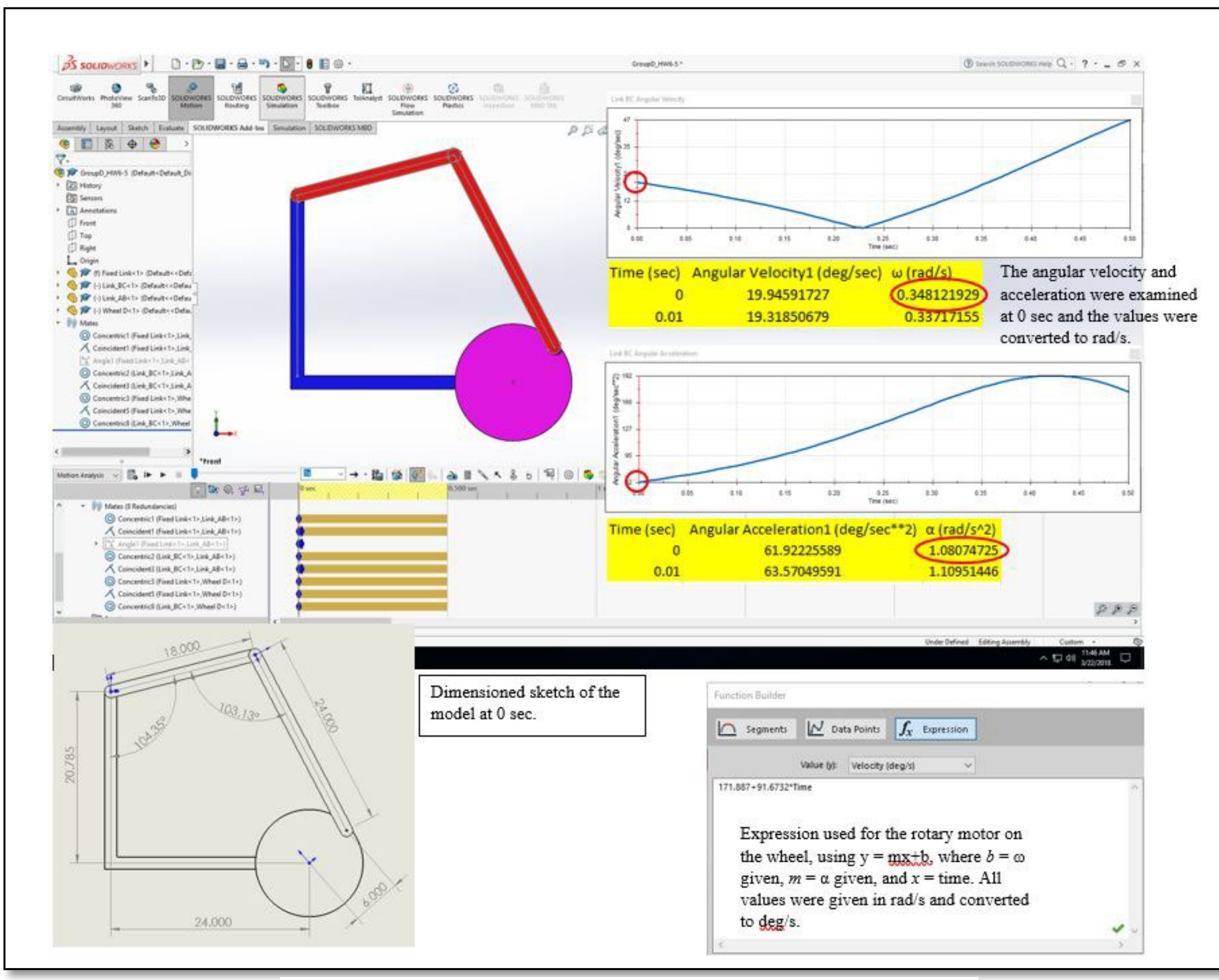


Figure 1 Example Numeric Validation

specified. The student has circled values in the figure matching their groupmate's hand-computed results.

At this point in the student's career the simulations are black-box. Students are trained in model construction techniques and the correct buttons to push to produce results, but no explanation in the underlying numerical solution algorithms is attempted. The author teaches a course titled *Finite Element Analysis* solely devoted to the underlying mathematics to upper-level mechanical engineers, but the *Dynamics* course described here serves sophomores of all specializations.

Challenges

The primary challenge is building student competency in SolidWorks. There is scarcely enough time for engineering mechanics content, leaving no class time for SolidWorks training. Our program incorporates an Engineering Graphics and Design course in the first semester that provides some prerequisite skills in SolidWorks. *Dynamics*, offered in the fourth semester, must overcome gaps in preparation and must accommodate transfer students without prior experience in SolidWorks. The responses to prompt one in the Results section indicate that students only feel marginally prepared to begin using SolidWorks at the start of this course.

To provide instructional support without sacrificing class time, the instructor created a library of narrated video demonstrations guiding the student, keystroke-by-keystroke, towards creating a SolidWorks simulation for each of the forty-three in-class example problems. Each video demonstrates how to extract numerical results from the simulation and compares these to hand-calculated results, in all cases with remarkable agreement. Students repeatedly play the video while simultaneously constructing a "similar" simulation. "Similar" here means, for example, that both are projectile motion problems, but the figures, parameters and unknowns are dissimilar. Responses to prompts ten and eleven in the Results section strongly indicate that the students utilize this resource. Extra-credit is awarded to students who make a sufficient quality tutorial video of their validation, thus producing a library of student-made tutorials. Surveys since 2019 have included the prompt "Student made videos are better than instructor made videos." - responses to date are neutral.

The labor demands of weekly homework often create an irresistible temptation to plagiarize. Clandestine observation of students at work has convinced the author that self-motivated students tend to work in small close-knit groups. Members of these groups will either submit identical homework or make efforts to disguise this. Once the leading students complete the assignment, other students will then attempt to plagiarize - with or without the consent of the original group.

We seek to permit and encourage the close-knit collaboration while preventing the plagiarism. The author's solution is to assign a unique problem set to each student group. Admittedly an ambitious undertaking, the author has developed eighteen sets of sixty-problems, or roughly 600 original homework problems. As each problem appears in two sets, students may seek out the other person on campus working on the same problem. This will be a different person each week, so there is little opportunity for systematic plagiarism, but rather this is another form of encouraged collaboration. Developing these distinct sets was less onerous than it might sound. Figure 2 demonstrates that problem variety is only superficial. The nine problems shown are all gear trains, but the difference between the figures and parameters appears to eliminate inter-group plagiarism. The author does not provide approved solutions to these problems.

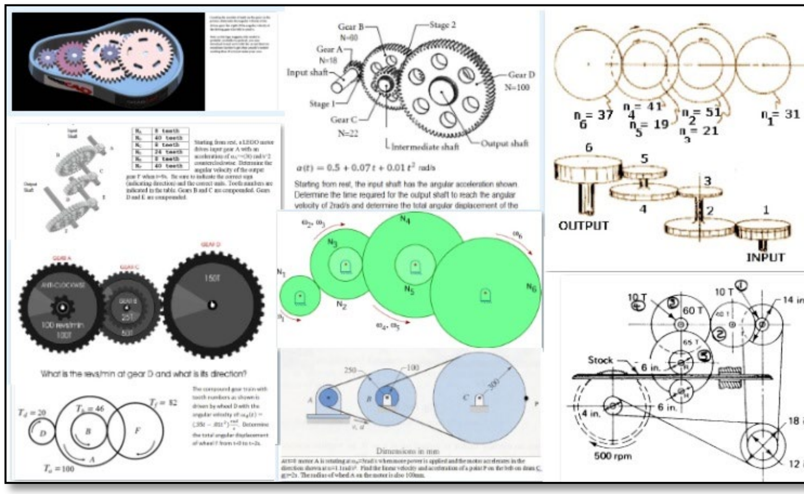


Figure 2 Superficial Variety in Homework Problems

This structure discourages but does not completely eliminate social loafing. Because group submissions must be mutually self-validating; a loafing group member will be a burden to the group. A group may expel a non-contributing member by simple majority vote, forcing that member to work solo. If the group does not take this step, the instructor will occasionally step in and disband dysfunctional groups.

Results

Does this novel homework structure achieve its stated objectives? Anonymous surveys conducted each year (554 responses over the study period) provide a statistically significant basis for evaluating the pedagogical effectiveness of this approach. The survey consisted of twelve Likert scale questions. Adhering to the format suggested by Robbins et al.[13], Likert scale

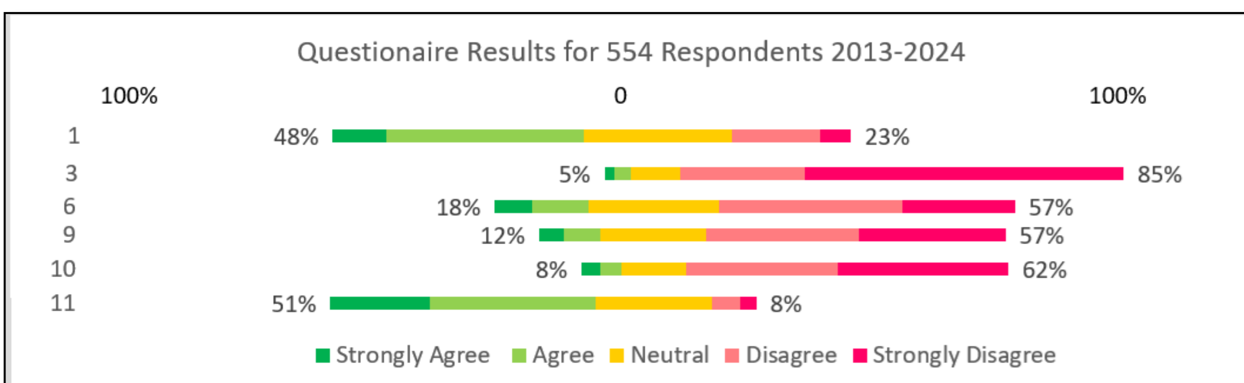
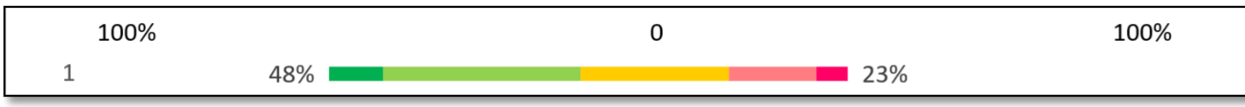


Figure 3 Aggregate General Acceptance Responses

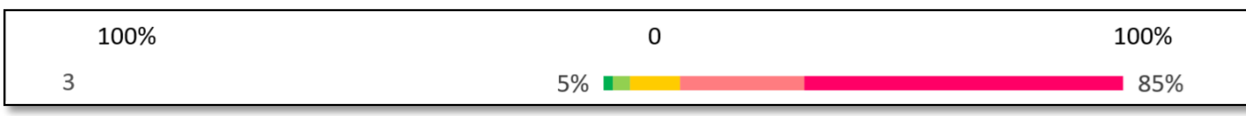
results are presented as a percentage of respondents centered at “neutral”, with agreement on the left in green and disagreement on the right in red, as shown in Figure 3. The total percentage of responses to the left and to the right of “neutral”, i.e., the sum of “strongly agree” and “agree” is shown as a label on each side. To limit acquiescence bias, topic order was scrambled and a portion of prompts are keyed in the negative direction - meaning a student enthusiastic about this approach would need to *disagree* with the prompt. The question number (out of twelve questions) appears to the left.

The prompts were designed either to measure general student acceptance to the use of SolidWorks or to measure specific course objectives. The general student acceptance results are presented first, followed by a discussion of specific course objectives.

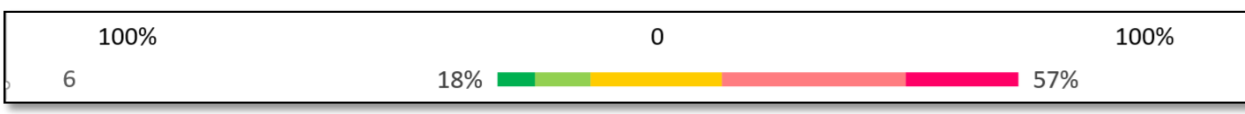
Prompts Measuring General Student Acceptance



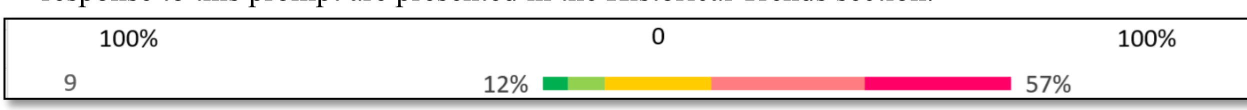
1. *My prior coursework prepared me to use SolidWorks in this course.* For most respondents, prior coursework is a one semester *Engineering Graphics and Design* course and one SolidWorks project in *Statics*. Students indicated agreement by a margin of approximately two-to-one, at best marginal satisfaction with plenty of room for improvement.



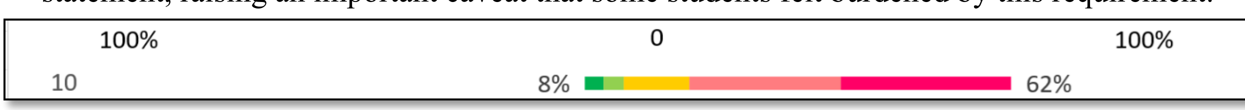
3. *SolidWorks should be removed from the course.* This question is intended to resonate with student opinion that SolidWorks is either too hard, not central to course objectives or not worth the effort. Overwhelming disagreement (85%) suggests that SolidWorks is perceived as a reinforcement and not a distraction to the course material.



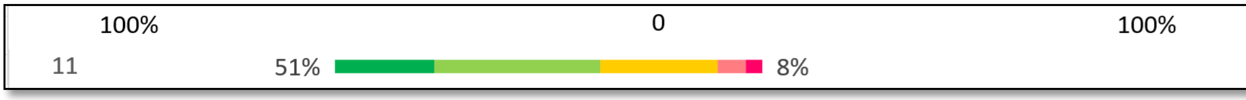
6. *The time invested in SolidWorks is not proportional to the benefit.* Over the study period, students self-reported 3-6 hours per week using SolidWorks. By an approximately three-to-one ratio student perceive the benefit to be worth this time investment. Historic trends in the response to this prompt are presented in the Historical Trends section.



9. *I hated building the SolidWorks models.* Twelve percent of respondents agreed with this statement, raising an important caveat that some students felt burdened by this requirement.



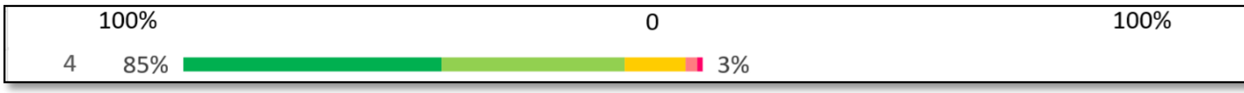
10. *The tutorials videos were of no value to me.* A disagreement ratio near eight-to-one suggests that tutorial videos are a valuable resource.



11. I played and replayed the videos following the actions while completing my own simulation. Roughly half of students agreed with this prompt indicating use of the videos as the author described above.

Prompts Measuring Specific Course Objectives

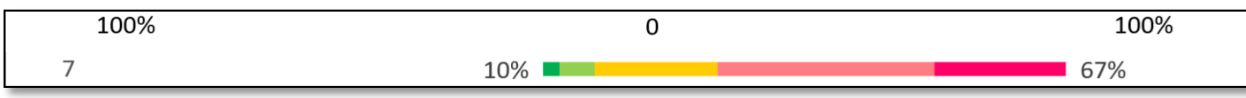
Objective 1. Kinematic Visualization



4. *SolidWorks helped me envision the problems better.* Eighty-five percent agreement suggests that the use of SolidWorks effectively achieves the objective. Visualization is enhanced as a two-dimensional pictorial description is brought to life by the student's own hand. By dragging the mouse, the student observes gears spin, links move, bodies come into contact and range of motion limits reached.

Objective 2. Quantitative Insight

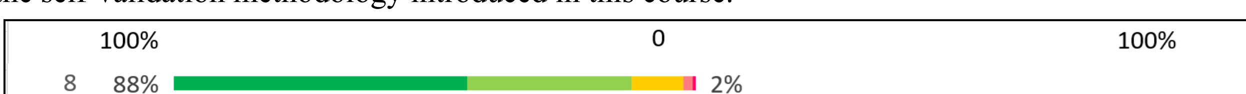
Once the problem kinematics are established, students move to the *Motion Analysis*, a rich set of SolidWorks features allowing students to control motion and analyze the results. A student may not intuitively recognize that a body with a positive initial velocity but increasingly negative acceleration will eventually stop, but the motion analysis shows it convincingly.



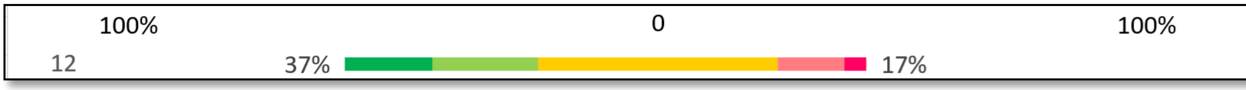
7. *I didn't really trust SolidWorks, I could always fudge a number to get the answer the others got.* Six-to-one disagreement suggests that this phenomenon does exist, but is not dominant. Students find that they cannot force SolidWorks to produce arbitrary numeric results to create the appearance of validation. This response demonstrates that students have gained appreciation that theoretical and numerical results must mutually validate.

Objective 3. ABET Objective 7

Engineering faculty would likely agree that "back-of-book" answers are rarely available in engineering practice. Rather, successful engineers have developed the skill set necessary to validate their own work. We claim a portion of this class satisfies ABET objective *7. "An ability to acquire and apply new knowledge as needed, using appropriate learning strategies."* due to the self-validation methodology introduced in this course.



8. The ability to verify my own solutions was rewarding to me. Strong agreement (eighty-eight percent) suggests the intended benefit is achieved.



12. I started to trust the SolidWorks result more than my hand calculations. The author interprets the mixed response as an indication that healthy skepticism is retained.

Training engineers to teach themselves is critical to an ABET accredited program, yet it is not clear that traditional homework assignments produce this outcome. The numeric simulation is an alternative means of producing a result, and neither the symbolic solution nor the numerical solution in isolation are as convincing as when the two methods produce compatible results. Student's responses suggest they recognize the potential of the simulation to produce erroneous results and often initially produce wildly divergent results. There is a teachable moment here when students can find nothing else wrong with their numeric simulation and start searching for the mistakes in their symbolic solution.

Objective 4. Develop Skills

We expect our seniors to use SolidWorks extensively in our capstone senior design, but our students formally learn SolidWorks only in their first semester. By the fourth semester *Dynamics* course they have already become a little rusty. If we do not require students to use SolidWorks as an integral part of intermediate coursework; we should show little surprise when seniors proclaim that they have forgotten it all. Figure 4 shows two responses measuring this objective.

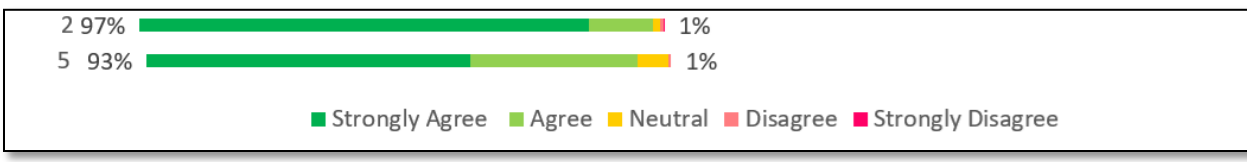


Figure 4 Aggregate Skills Responses

2. *My use of SolidWorks improved as a result of this course.* Ninety-seven percent agreement indicates that the straightforward objective of improving skills in SolidWorks is achieved.
5. *I feel confident I will be able to use SolidWorks in future courses because of the use in this class.* One percent disagreement suggests students appreciate that SolidWorks is a general tool with wider applications than this course.

Objective 5. Combat Plagiarism

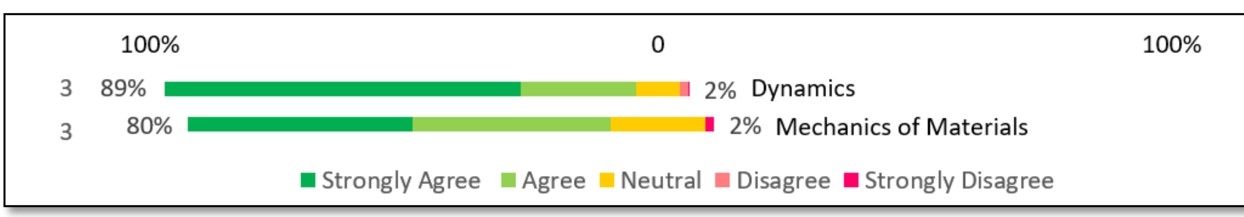


Figure 5 Aggregate Benefit Responses Compared to Mechanics of Materials

3. *My fellow students contributed to my learning.*

Although this appears to be large agreement with the prompt, students in our relatively small engineering program typically agree, even in courses with no structural incentive to collaborate. As a convenient basis of comparison, the author simultaneously teaches *Mechanics of Materials* to the same population. As shown in Figure 5, students report only marginally more benefit from collaboration in *Dynamics* (a shift from *agreement* to *strong agreement*) as compared to a representative response from S'14 of *Mechanics of Materials*. The author interprets these data to suggest that pre-established cooperation habits of students are not significantly modified by course structure.

Students expelled from groups supply some anecdotal evidence that this homework structure is successful in creating a climate of individual effort. The author has repeatedly witnessed that these students, initially the worst-case plagiarizers, have no place to turn within this structure and start doing their own work. These students begin to regularly appear at office hours and submit improving solo sets for the remainder of the semester. Once heading for disaster, these students often improve their homework scores, perform better on the final exam and pass the course.

Historical Trends

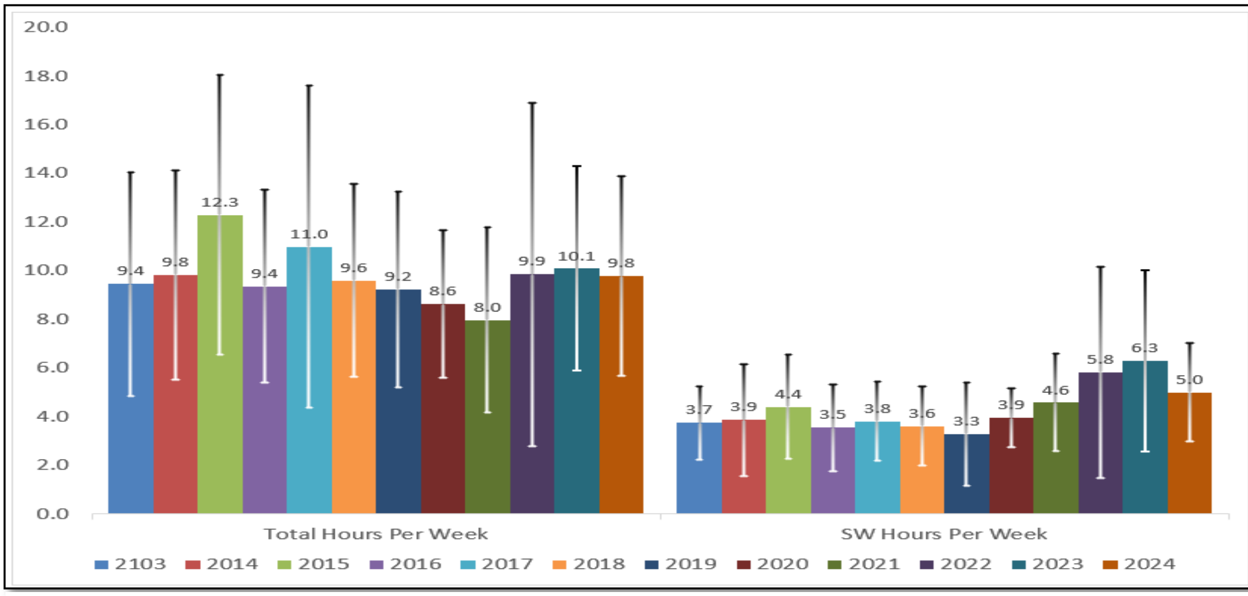


Figure 6 Historic Trends in Student-Reported Hours per Week

The twelve-year span of this study invites an investigation into historical trends in student response. Figure 6 shows student-reported hours per week outside class, (error bars ± one population standard deviation). The data appear to trend towards an increasing percentage of time spent using SolidWorks with no decrease in total hours.

Relative to federal standards for three credit hours [14], the workload is too heavy for this three-credit course. The 35 hours of class meeting time and student-reported ~120 hours out-of-class time exceeds the 126-hour standard. It is tempting as an engineering faculty to dismiss this with a wry smile, but in reality, this a course defect. Efforts to address this defect included removing particularly abstruse or complex problems, simplifying figures, providing redundant dimensions and adding tutorial videos. The flat trend in total hours per week in Figure 6 suggests the instructor's efforts have failed to reduce the workload.

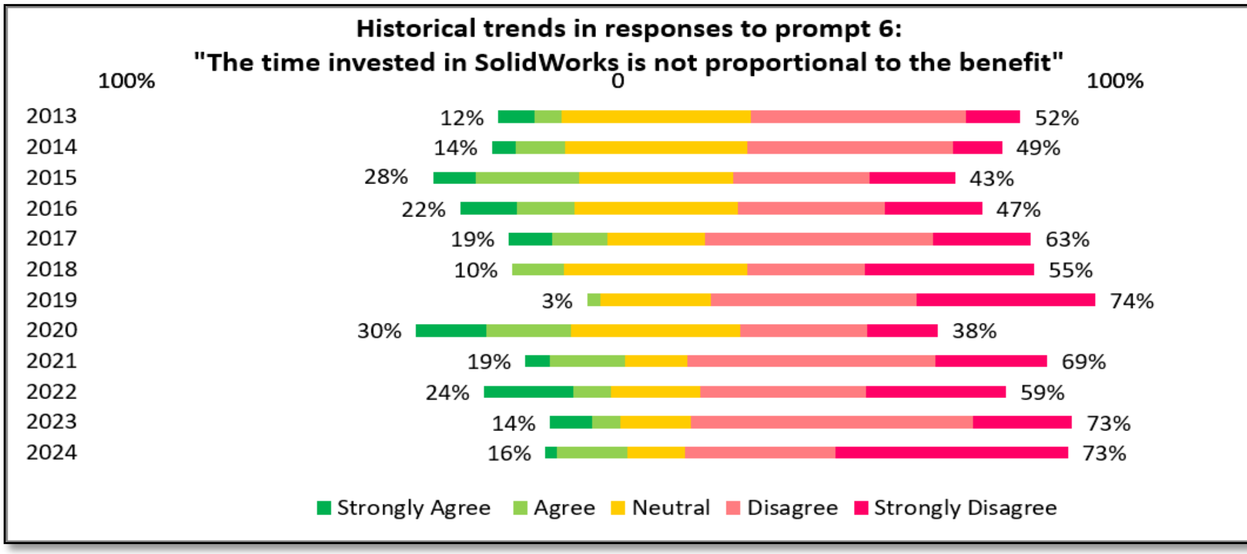


Figure 7 Historical Trends in Responses to Prompt 6.

Figure 7 shows a history to responses to prompt 6: "The time invested in SolidWorks is not proportional to the benefit."; with decidedly mixed opinions in 2013 and also in 2020 under COVID mandated remote instruction. The trend is towards decreasing neutrality in favor of disagreement. The author attributes this trend to incremental improvements in the homework assignments, clarified instructions, and more proactive intervention in dysfunctional groups. There were also technology improvements over the period of the study, both in new releases of SolidWorks and in school computational infrastructure. Figure 7 also shows that there remains a smaller but significant portion of the class unconvinced that this approach is worthwhile.

Conclusions

Despite the time investment reported by the participants, a strong majority believe SolidWorks should be retained as a requirement in the course. The ability to check one's own work is both a novel and important skill that can benefit students significantly when introduced in the sophomore year. The author concludes that this approach strengthens the entire engineering program by equipping students with the tools for lifelong learning early in their career.

There are caveats and room for improvement in this course. Simulations are black-box with no explanation of the underlying algorithms (a course titled *Finite Element Analysis* is later in the mechanical program). Plagiarism is combatted with this homework structure but is not defeated, i.e., it is still possible to fake it. Creating a climate where individual effort is the norm appears to be more effective than policy restrictions and/or punishments for plagiarism. The course continues to require more student time than is consistent with three-credit hours despite the instructor's efforts to curtail this. The author will need to reduce out-of-class time by about twenty hours to be consistent with the federal definition of three credits.

Each of the five objectives are achieved as measured by direct survey over a twelve-year period. However, a weakness of the analysis presented in this paper is the absence of conclusive proof that student's mastery of *Dynamics* is enhanced by this approach. A parallel study of student performance on theoretical examinations or other methods to measure concept mastery would strengthen the support for this methodology. The author hopes to present results of this analysis in future publications.

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