Comprehensive approach to teaching dynamics of planar mechanisms based on modern learning theories

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Abstract

It is well known that students have different learning styles and for teaching to be effective a non-traditional approaches that can address the different styles should be attempted. Also, according to Kolb, learning is most effective if done in a cycle involving experiencing, reflection, thinking and planning. In this paper, we present an attempt at a comprehensive approach to teaching the course Theory of Machines, a standard course in the majority of mechanical engineering curricula. At the beginning of the semester, students are asked to conceptualize and realize a feasible system for building four bar linkages. The system has to be functional and versatile, allowing mechanisms of different Grashof conditions to be built later on during the semester. As students study and analyze different types of mechanisms using the analytical theory presented in class and its solution using spreadsheets, they actually assemble such mechanisms in parallel in order to verify and validate their solutions and to draw the correspondence between the physical performance and mathematical solution. Finally, general purpose visualization software is used to animate the spreadsheet results. In this multifaceted approach, the different learning styles and the different Kolb stages are attended to. Preliminary formative assessment based on students' opinion survey indicates that the approach was highly motivating and that self-confidence was positively impacted upon the completion of the exercise, starting from theory and ending in the creation of animations.

Introduction

It is well known that the traditional lecture style approach to teaching is not an effective model for teaching and learning. Modern learning theories indicate that different people have different learning styles[1] and that the learner should be actively engaged in the learning process for effective learning[2]. On the contrary, lecture style learning is passive and at the best satisfies the thinker/introvert learning style. The well-accepted Kolb experiential learning model goes even further by suggesting that learning is maximized when performed in a cycle involving a sequence of experiences: concrete, reflective, abstraction/conceptualization, and active experimenting[3]. Lecturing address only one of these essential stages, the abstraction/conceptualization stage, and therefore is not expected to lead to ideal learning. Improved student engagement and learning outcomes from courses can be expected if the Kolb model is used to guide the content and activities of the course[4].

In this work, we report on first attempt to develop and implement a non-traditional approach to teaching the dynamics of planar mechanisms, which is inspired by the Kolb learning model. The

approach combines several learning venues, including physical modeling and virtual modeling, and is hence expected to address a number of the drawbacks of traditional lecture-style teaching. Dynamics of planar mechanism is an important subject in the study of mechanical engineering and at least one standard course, typical titled Theory of Machines, is dedicated to teaching it in the majority of mechanical engineering curricula. The course builds on the fundamentals of engineering mechanics, particularly those covered in the course Dynamics of Rigid Bodies, to teach students the analysis and synthesis of linkages and mechanisms and the theory of cams and gears, among other topics. This makes Theory of Machines one of the early application-oriented courses which require higher levels of learning, which makes it a good target for testing innovations in teaching and learning. One of standard topics covered in this course, kinematics of four bar linkages, is the focus of this paper and has been the subject of several innovations in teaching aimed at enhancing students' learning outcomes. In an honors cross-disciplinary course combining technical and arts students, Animatronics, Sirinterlikci used an approach combining study of theory, observation of commercially available working mechanisms (Automata mechanized sculpture kits), as well as reverse engineering of the toys. The practical aspect of the course received 90% positive feedback from the students regarding engagement[5]. Brookings and Smith used Matlab computation and simulation capabilities to the determination of the motion (including velocity and acceleration) of mechanisms starting from the governing ordinary differential equations. It was noted that the animations were effective in supporting the learning of visual learners[6]. Yin devised a 2-semester long computationally intensive project to design two specific mechanisms one for de-watering of moored boat and the other a piston crank mechanism for small internal combustion engine[7]. Excel computation and graphic capabilities were central to the project. The spreadsheet computations mainly consisted of inverting the coefficient matrix of the systems of simultaneous equations describing the mechanism motion. Liu and Boyle used a pseudgraphical method and TK solver software to present the students with an alternative analysis approach to that based on the vector loop representation on both Grashof and non-Grashof four bar mechanisms[8, 9]. The method received positive feedback from the students. Mohammadzadeh designed a rigorous project for the analytical synthesis of mechanisms using Matlab and Simulink[10]. The author received positive feedback from the students regarding the project and the assertion that the project helped students understand the abstract concepts in machines dynamics, which was also reflected in the results of a follow up exam.

Compared to the efforts cited above, the approach presented here is directly informed by Kolb's experiential learning theory and is comprehensive in the sense that it combines, in one coherent approach, multiple learning experiences which are self-reinforcing. These include a hands-on component, where physical models of mechanism are design and assembled before using them as learning aids, computational and computer animations component, as well as a testing and validation component. The approach gives the student a multifaceted learning experience of planar mechanisms and is expected to result in enhanced motivation and engagement for students of different learning styles and overall learning outcomes. To our knowledge, no similar attempts

combining all the previously listed learning components have been reported in literature. The paper is organized as follows: first the objectives are laid out and then the methods used are described and their linkages to learning theories is made, followed by the presentation and discussion of results, which includes a preliminary assessment. Finally, conclusions and directions for future work are made

Research Objectives

The overarching goal of this research is to develop and evaluate a model for teaching dynamics of planar mechanisms which enhances student learning outcomes through stimulating higher cognitive levels [11, 12] and attending to different learning styles. In this paper, we describe the first version of the developed model and its implementation. We also present a preliminary evaluation of the method using student attitude and engagement as the performance indicator. More specifically, the research question to be answered is whether the proposed experiential model as designed improves student engagement and attitude about engineering education and the profession. In spite of the positive correlation between students' engagement and learning outcome, a direct assessment of the student learning outcomes from this alternative teaching and learning model must be performed and this will be the subject of future work.

Description of the Method

The approach presented in this work was introduced for the first time in fall 2012 semester offering of the course Theory of Machines at the Mechanical Engineering department at Tuskegee University. A precursor which inspired the development of this approach was the positive feedback from students on the introduction of a simple hands-on component in the previous offering of the course in fall 2011 (the course is offered only once a year in the fall semesters at the site of the study). It consisted of the use of physical models of four bar mechanisms as learning aids to help students better understand the concepts presented in class but not necessarily motivated or guided by modern learning theories. The objective was to study the rotatability of different mechanisms based on the Grashof condition and the inversion as well as the limiting conditions. Students were provided with wooden links and asked to assemble different four bar mechanisms using bolts and nuts in a simple and fast manner without consideration to other functionality aspects.

The participants in this study were 11 students taking the course Theory of Machines in fall 2012. The new approach was packaged in the form of a term-long class project which started early on in the semester and was completed in stages as the semester progressed and necessary background covered. Each group consisted on 2-3 members. The project statement is as follows:

Part 1: Design and test a system for constructing four bar mechanisms for the purpose of studying their kinematics. To the extent possible, the design should be cost effective, versatile

and simple. Particularly important is avoiding any artificial constrains on the rotatability of the mechanism, beyond the inherent kinematical constraints. With the understanding that this type of design process is open-ended, make a list of the advantages and drawback of your design.

Part 2: Using Excel and the vector loop method[13], create a general computational framework to perform position analysis of four bar mechanisms. Use the computation results to produce animations of the mechanism using TecPlot (TecPlot is a general purpose commercial software for postprocessing and visualization of scientific data)

Part 3: Perform a case study. Choose a particular mechanism (i.e. define the length of the four links and the inversion). Construct the corresponding mechanism, perform the computation and animation. Validate the virtual model results with the corresponding ones from the physical model. At least three positions

All groups were required to submit a report at the end of the semester detailing their methods and products and discussing the results, and making final remarks and conclusions.

Finally, a preliminary assessment of this pilot implementation of the approach proposed in this study was performed. The assessment used a survey to measure the student opinion and level of engagement induced by the experimental approach. The survey and its results are presented in the Results and Discussion section below.

Links between the method and learning theory

The proposed approach is informed by the current understanding of learning theories in several ways and as such is expected to lead to higher level of engagement and improved student learning outcome. From the view point of Kolb's experiential learning model, our non-traditional approach provides all the elements of experience suggested by the model. The ability of the students to hold and manipulate physical models of four bar mechanisms allows them to concretely experience their motion and to reflect on related kinematical concepts like the Grashof condition, different mechanism inversions, and limiting conditions (toggle and stationary positions). The traditional class lectures, which remain in place in this approach, builds on the previous experiences to give students a more meaningful abstraction and conceptualization experience. The whole experience is further strengthened by engaging the student, through the project, in the process of designing a system to construct and test the mechanisms they use. The iterative and open-ended nature of this process allows students to naturally explore practical considerations of mechanism performance and solidify their understanding of the kinematical concepts involved in such mechanism. Specific examples are provided in the Results and Discussion section. Obviously this design exercise leads to higher cognitive levels of learning on the Bloom's taxonomy including evaluation and synthesis[11, 12]. The above diversity of experiences provided our approach is also expected to enhance the engagement of all students because it attend to more learning styles[1, 3]. Also, the fact that the devised approach integrates hands-on physical modeling, mathematical modeling and simulation,

and testing and validation reinforces the learning experience by making the connections between mathematical models as simplified representation of real life complexity. For example, the correspondence between existence of two solutions for the equation representing the angular position of the mechanism and the possibility of having two valid configurations for the mechanism (open and crossed) is easily seen through this comprehensive approach. Finally, the having students go through the experience of conceiving and realizing a conceptual design for building their own "learning aid" rather than merely using ready-made ones can help boost their confidence and their appreciation of the engineering profession. The same applies to the part of the approach where students generate simple animations of four bar linkages based on their data as opposed to just watching animations as virtual learning aids.

Results and Discussion

Figures 1 and 2 show pictures of two of the systems developed by the students participating in the experiment following two different paths. The system in Figure 1 was conceived and developed from scratch while Figure 2 shows a different approach where the students adopted existing parts from the Lego Mindstorm set and used them to construct the mechanisms. In the first approach, wooden strip were used as links while the joints relied on the shank of cotter pins for both the pivoting and assembly functions. To avoid collisions between the links which artificially restrict the range of motion on the mechanism, spacers of different thickness made of rubber and Teflon were used, Figure 1. A fixed grip was attached to the ground link while a handle was attached to the crank to allow continuous rotation. All components used to construct the mechanism were basic component which can be cheaply and readily obtained from standard hardware stores. For the Lego-based design, the links' length is constrained to specific discrete values while different adoptions to grounding and driving were made. In the words of the students, Table 1 lists the advantages and drawbacks of their design shown in Figure 1, while Table 2 lists those for the approach followed by the other group as shown in Figure 2.

Figure 1, a system for constructing four bar pin jointed mechanism develop from scratch by one of the groups of students.

Figure 2, a system for constructing four bar pin jointed mechanism adopted by another group of students from Lego Mindstorm parts.

Advantages	Disadvantages
Can be used for Grashof, non - Grashof, and special Grashof mechanisms	assembly and disassembly requires a drill, a screw driver, and a wrench
Can be driven through the whole range of motion without interruption	After many assemblies and disassemblies, the cotter pins must be replaced
Can demonstrate the change of point phenomenon in special Grashof mechanisms	assembly is compliant and can be wobbly.
Economical and readily available	Because of the above disadvantage, the mechanism can snap out of toggle positions distorting the theory-predicted kinematic performance
arrangement is lightweight and easily held with one hand	Links of different lengths require drilling more holes in the links and/or replacing the links.
Parts can be reused for different arrangements	

Table 1, advantage and drawbacks of the mechanism construction system shown in Figure 1, as listed by the student developers

Advantages	Disadvantages
Reusable parts	Investment has to be made in Lego kit
Quick modifications	No room for modifications to link length
Easy to ground and drive	New parts that are not currently part of Lego kits has to be developed
Low friction at joints	
More rigid structure (more robust mechanism)	
Precise link dimensions	

Table 2, advantage and drawbacks of the mechanism construction system shown in Figure 2, as listed by the student developers

After the mechanism design and construction stage, the students used Excel to perform the position analysis using the vector loop method as described in their textbook[13]. The use of Excel was the route chosen because it is readily available to students and because a spreadsheet approach can give the student a basic insight into the computational aspects of the solution without the need of higher level experience with programming or use of other software packages like Matlab or Mathematica. The results is summarized by a graph showing the angular position θ_3 and θ_4 of the coupler and output link, respectively, as a function of the input link angular position, θ_2, Figure 3.

coupler

Output link

Input link

θ_3

θ_2

θ_4

Ground link
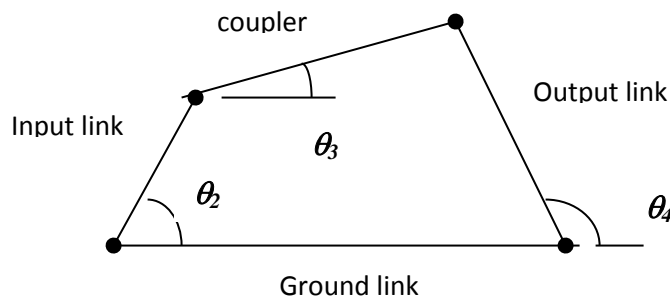
Figure 3, definitions of input and output for four bar pin-jointed mechanism

In the section *Links between the method and learning theory*, it was mentioned that our approach allows students to explore practical consideration in mechanism design that cannot otherwise be experienced. One instant of that occurred during the testing and validation of the specific case studied. When operated, the physical model worked as a Grashof condition with the input link acting as a crank. Nevertheless, when the Grashof condition is applied to the actual lengths of the links, the condition predicts that the mechanism should be classified as RRR1 (non Grashof or triple rocker type). The mathematical model confirmed that as shown in Figure 4 which indicates a small range in the input for which a real solution was not possible. After deeper investigation, it turned out that the mechanism was able to bridge over its limiting positions due to the compliance of the mechanism and hence is strictly an artifact. This is just one example of the higher level learning associated with comprehensive coherent learning experiences.
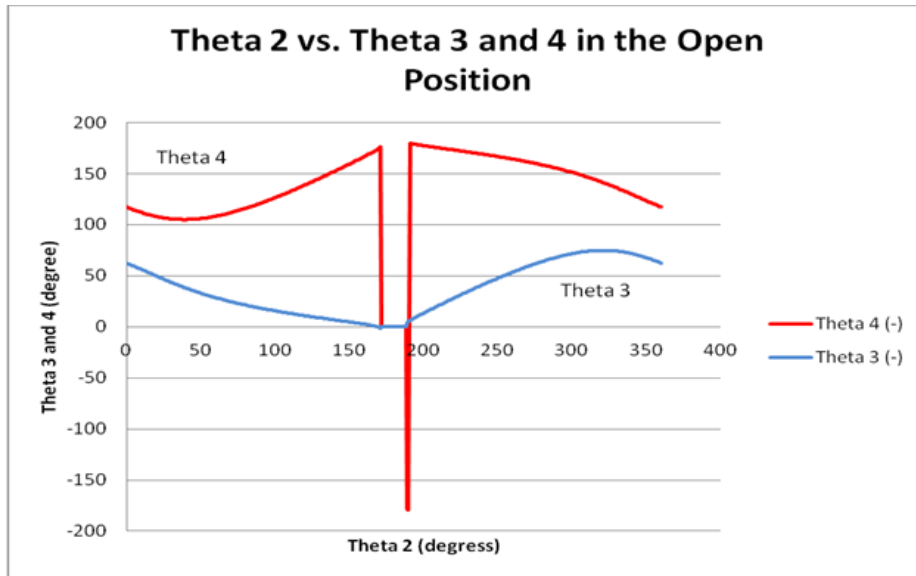
Theta 2 vs. Theta 3 and 4 in the Open Position

Figure 4, spread sheet calculations of angular position of output link and coupler as a function of the input link angular position (see Figure 3 for definitions of angles)

The final part of our approach is giving the students a feeling of what it takes to produces "fancy looking" animations based on their own computation results. This exercise gives the student a better appreciation of the value of what he/she learns in class and also a feeling of what stands between theory and computation on side and advanced visualization methods. Using TecPlot, the exercise demonstrated to the students that their basic task needed in creating animations of their mechanisms in motion is to postprocess their spreadsheet results so that they are compatible with the format of the input files required by TecPlot. This experience is another component of our approach which helps boost students' confidence and motivation while giving them clear understanding of the different stages in developed engineering products.

The final discussion item is assessment. Performing a full scale assessment of the ultimately desired student learning outcome is a large task. Since this is not possible at this stage of our research, we performed a simple assessment using a survey of different student attitudes towards the proposed approach. Figure 5 shows the instrument used to survey the students. The results of the assessment for three questions, those surveying engagement, learning of course concepts and appreciation of the engineering career, are presented in Figure 6. In the figure it is evident that our experimental approach did result in positive impact of those three aspects (in fact all the other aspects surveyed and not included for brevity)

MENG 0315- Hands-on Component-Learning Outcome and Student Opinion Survey

The objective of this anonymous survey is obtain your feedback on the hands-on component of the course which has been newly added. Your feedback is extremely important for continuous improvement.

To which extent do you agree with the following statements?

|	agree	somewhat agree	neutral	somewhat disagree	disagree
The hands-on component of the course was interesing to me	○	○	○	○	○
The hands-on component enhanced my engagement in the course	○	○	○	○	○
The hands-on component helped me better understand the concepts of the course	○	○	○	○	○
the hands-on component helped me better appreciate the engineering profession	○	○	○	○	○
I would like to see a similar approach in my other engineering courses	○	○	○	○	○

If you were to give ONE sugesstion to make enhance your experience and learning outcome from the hands-on component of the course, what would that be

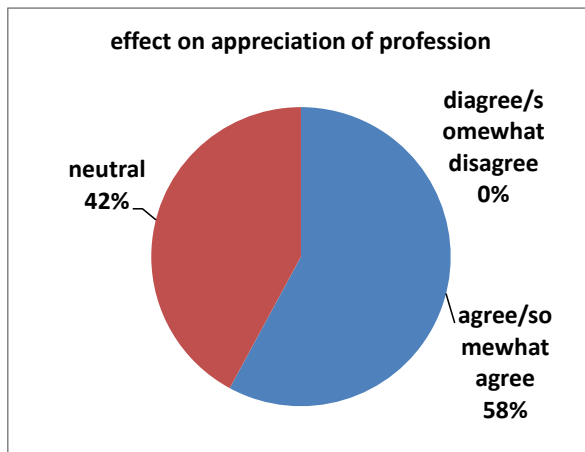Any other feedback and/or suggestions

Figure 5, survey of student attitude used in to assess the impact of the experimental approach
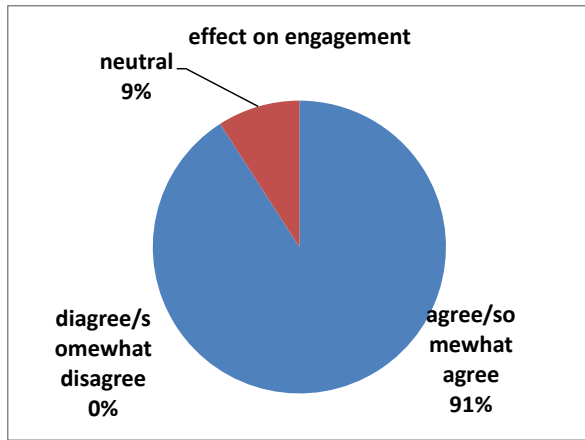
(a)
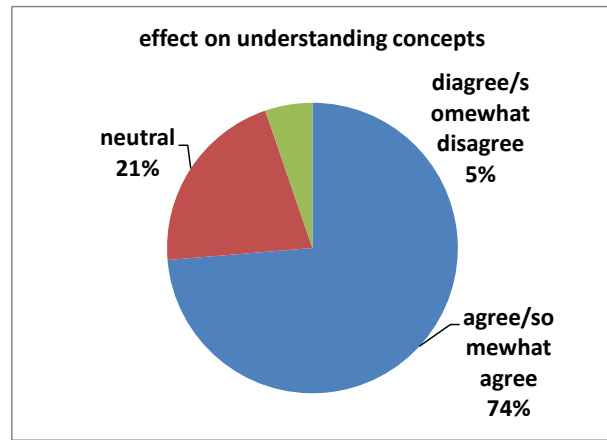
(b)

(c)

Figure 6, results from the student attitude survey regarding the effect of the experimental approach on their a) engagement, b) learning of course concepts and c) appreciation of the engineering profession

Conclusions and Future Work

We presented a non-traditional approach to teaching dynamics of planar mechanisms within the context of the standard mechanical engineering course, Theory of Machines. The approach is rooted in Kolb's experiential learning theory and consisted of several learning venues all coherently integrated in a term long project. The venue includes the development of a system for physical modeling of four bar pin-jointed mechanism and then using the models as learning aids and to test and validate spreadsheet based computational model for position analysis and TecPlot generated animation based on the computed results. Preliminary assessment showed that the students' engagement and appreciation of engineering was enhanced by proposed approach. Based on students' self-evaluation, the approach also lead to better understanding of the concepts

presented in class. The first need for future work is to devices ways to perform broader assessment which focuses on the direct evaluation of the student learning outcomes independent of their own opinion.

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