Teaching Advanced Vehicle Dynamics Using a Project Based Learning (PBL) Approach

Sangram Redkar
Arizona State University

Abstract

This paper presents an interesting teaching experiment carried out at Arizona State University (ASU). The author offered a new course in computational/analytical vehicle dynamics to senior undergraduate students, graduate students, and practicing engineers. As the author initially explored the possibility of incorporating a PBL approach in this course, the following question arose: Can a PBL approach be successfully implemented in a diverse classroom where the individual students may have different skill sets and academic expectations? This paper reports the efforts to find answers to this important question via a practical experiment. The author designed and offered a PBL course to a diverse class of students and measured the outcomes via qualitative and quantitative assessment and triangulation approach.

The objective of this PBL course was to present vehicle dynamics theory with practical applications using a commercial dynamics simulation software (MSC-ADAMS). The class composition for this course was quite diverse. Some students had more than 20 years of industrial experience and some undergraduate students had little or no industrial experience. In order to help students meet their learning goals, the author (instructor) adopted an integrated PBL approach. The author tuned PBL methodology for a diverse classroom and helped students meet their educational goals.

In the PBL approach used here, the students were presented with theory concepts and along with in-class tutorials, where the instructor discussed each step in detail. Students were then assigned home-works that strengthened the understanding of the concepts, and finally, were asked to work on a real life project that forced them to 'think outside the box'. The emphasis during the initial stages of the learning process was to make students aware of the capabilities and limitations of software used to solve vehicle dynamics problems. This led to the development of an 'engineering-sense,' or an ability to make sense of the results obtained using the software.

In this paper, we review this 'understand-crawl-walk-run' PBL approach adopted for this course and present some of the challenges faced by the author. We evaluate this PBL pedagogy, qualitatively and quantitatively and discuss the results of student survey, assessment, student learning objectives and course evaluations. We also present evidence that the PBL is an effective approach for teaching a diverse class where students have different backgrounds, age, experience, and academic expectations.

Introduction:

In the fall of 2008, the graduate students and practicing engineers requested the author, an Assistant Professor in the Department of Engineering Technology (ET) to offer a new course in computational vehicle dynamics that would allow them to understand vehicle dynamics from a multi-body analytical dynamics point of view and use a commercial dynamics software (MSC-ADAMS) to solve practical vehicle dynamics problems (MSC Website, 2011). It is noted that MSC is the software company that has developed the multi-body dynamics simulation software ADAMS and various modules like ADAMS-View, ADAMS-Car, etc. This course was offered as a graduate/senior undergraduate course and had a unique class composition. Forty percent of the students had 10 years or more of industrial experience, 20 percent of the students had 20 years or more of industrial experience, 30 percent of the graduate students had less than two years of experience, and 10percent of the senior undergraduate students were interested in pursuing careers in automotive engineering.

Even though the project-based teaching is a very popular approach in STEM education, this approach needs to be implemented slightly differently when the student population ranges from senior executives with 20 years or more of experience to senior undergraduate students with little to no practical experience (Ramsden, 2002; Blumenfeld, 1991; DeFillippi, 2001; Hmelo-Silver, 2004). A lot of "short term" Continuing Education Programs (CEP), industry training courses, and certification classes use similar teaching methodology. However, the difference between these "short term" CEPs and one semester university courses is that the "short term" programs use a more focused approach and have very specific learning objectives. On the other hand, a typical university course spans over 16 weeks and has broader learning objectives than the "short term" CEP course. The author feels that the main difference between a "short term" course and semester course is that the "short term" course provides the professional skills while the university course should provide "an ability to develop and enhance professional skill set".

One interesting example would be the "short term" Finite Element Analysis (FEA) courses offered by many FEA commercial software vendors. These courses equip the students with the procedure of carrying out a FEA with the software, but fail to provide the "engineering sense". The author has seen many instances where the students trust the software results blindly, and arrive at erroneous results and designs. Thus, the author wanted to present the material via PBL so that the student can learn the skill set and develop an ability to make sense out of the software results. This is possible if the students have the theoretical understanding of the material, know the advantages and limitations of particular software, work out and validate the test cases, and extend this knowledge to solve the practical problems.

Development of a semester-long PBL course for a diverse student population needed a strong collaboration from the industry, MSC software, and the university. The central idea behind the course was that the analytical vehicle dynamics theory would be covered by the instructor, U-Haul Technical Center would suggest and support suitable 'real life' projects, and the students would work on these projects using MSC ADAMS software suite (specifically, ADAMS View, ADAMS Car, ADAMS Chassis etc) (U-Haul, 2011). The MSC university program supported this idea and provided ASU with an academic network license for 150 seats (MSC Academia, 2011). This academic license allowed the students to work on class projects and homework problems using MSC-ADAMS. The MSC university program manager also provided the instructor MSC-ADAMS study material that is used by MSC software in their commercial "short term" CEP training programs.

1. Instruction Methodology:

The PBL approach has been used in STEM education to enhance understanding of the course material. It has been reported that this approach is effective and widely used in variety of classroom settings (Thomas, 2000). Some of the important characteristics of PBL are project based instruction, community of inquiry, use of technology tools, and multidisciplinary themes. Thomas (1999) and Scardamalia (1991) discuss the various aspects of PBL. However, some interesting questions arise when one tries to understand, implement, and assess PBL. PBL has been defined and implemented with so many variations it is difficult to distinguish between PBL and Non PBL. As an example, should the instructor define a project or should students choose projects? What level of instructor involvement is necessary? Should the projects be real-life projects or academic projects? How is project based learning different than "intentional learning," "design experiments," and "problem based learning" (Scardamalia, 1991; Scardamalia, 1989; Brown, 1992; Brown, 1996; Gallagher, 1995; Gallagher, 1995). Is active learning a subset or superset of PBL? How is an integrated lecture/lab class different from PBL or discovery learning? Many graduate level classes have projects; can they be classified as a PBL? Are there any grades in PBL?

It can be noted that the idea of assigning class projects is not new. So when and why would PBL be different compared to a hands-on, discovery-based learning approach? The five important criteria that separate PBL from other learning methodologies as presented by Thomas (1999) are centrality, driving question, constructive investigations, autonomy, and realism.

Another important part of PBL research is studying student characteristics and their relationship with PBL. There are various student characteristic variables that can affect the effectiveness of PBL. Several PBL practitioners have stated that PBL, because of its unique features, is a more effective means of adapting to students' various learning styles or "multiple intelligences" than the traditional instructional model (Gardner, 1991; Diehl, 1999). In this paper, we would like to present evidence that PBL can be tuned to students' various learning abilities and expectations in a diverse classroom. The past research on PBL and student characteristics has looked at investigating learning styles of students who were characterized by their teachers as "pleasant surprises" (students who perform poorly in conventional classrooms, but who do well in PBL activities) and "disappointing surprises" (students who performed well in conventional classrooms, but who turned in poor projects or no projects at all) (Rosenfeld, 1998).

Researchers have studied the effect of gender and PBL. Boaler et. al (1998) have discussed that PBL can be used to engage "reluctant students" in the course. It is interesting to note that in these studies the students had similar backgrounds and course expectations. In this study, we report the effectiveness of PBL in a diverse classroom where the students have different backgrounds, ages, and expectations.

There is a significant body of PBL research where the challenges in PBL implementation are reported (Krajcik, 1998; Krajcik, 1994). The challenges while implementing PBL when the student population is diverse are slightly different. In this work, we also present the challenges that the instructor faced while presenting the material via PBL.

We propose a simple "understand-crawl-walk-run" approach to PBL with teaching advanced vehicle dynamics as a case study. We try to answer the following fundamental questions.

1. Can PBL be implemented for a classroom when the student population is diverse in terms of background, experience, and age?
2. How do we measure if PBL was successful or not?
3. What are the challenges while implementing PBL for such a diverse classroom? Are these challenges typical?
4. Can we provide some evidence-based guidelines for designing, implementing and assessing PBL effectively and efficiently?

The course we implemented this "understand-crawl-walk-run" PBL approach involved some theoretical material and hands-on projects using the MSC ADAMS software suite. The study material provided by MSC was based on MSC's 'crawl-walk-run' approach. In this approach, students build and analyze models of progressively complex assemblies and systems. The instructor decided to adopt this approach with slight modifications (understand-crawl-walk-run). Initially, the theory material was presented and explained the theoretical concepts outlined in the text ('understand'). Some simple tutorials were presented where the students were guided through the modeling and analysis process ('crawl'). Later, project assignments (home-works) were given to the students so that they could work out the problems on their own ('walk'). Finally, the students were assigned some real-life projects to test and hone their skills ('run'). At the beginning of the course, the students were presented with this teaching approach and suggested to select a project that can be developed in a building block approach throughout the semester. It is noted that this approach is termed as "understand-crawl-walk-run" to indicate its relationship to MSC's "crawl-walk-run" approach. The relative relationship between these phases is shown in Table 1. Table 1 was developed by mapping the material covered, assignments, and projects during the semester and teaching material to course progression. It is interesting to note that these phases overlap each other. However, as the course advances, the overlaps between these phases reduce. Initially, the students have to go back and forth between "understand" and "crawl" and need to spend a lot of time correlating the theory material to software applications. As the students become familiar with the software and understand the strengths and weaknesses of the software, the transition from "crawl" to "walk" and from "walk" to "run" is much smoother and faster, which is analogues to the natural process of an infant learning locomotion.

The Multi-body Systems Approach to Vehicle Dynamics by M. Blundell and D. Harty (2007) was selected as a text for the course because it discussed the computational multibody dynamics with software applications. Prof. Blundell from Coventry University provided his teaching material and assignments to the instructor (Coventry Website, 2011). The instructor was able to offer this course in fall of 2008 because of generous support from MSC Software, U-Haul Technical Center, and Coventry University. This was a very unique endeavor, where a team from the industry and universities from the US and abroad came together so that the students can have a very good 'cutting edge and hands-on' learning experience.

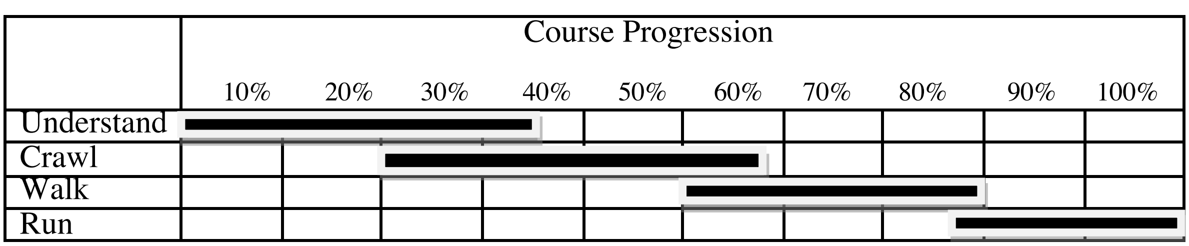

Table 1: Various phases of the approach

Topic No	Topic Name	Weeks	Focus Area
1	Introduction	1	Course Outline, Projects discussion and project assignments.
2	Kinematics and Dynamics of Rigid Bodies	2,3	Review of concepts in Dynamics of Multi-body systems
3	Multi-body Systems Simulation Software	4,5	Introduction to ADAMS-View, ADAMS-Car
4	Modeling and Analysis of Suspension Systems	6,7	Types of suspensions, suspension modeling and analysis using ADAMS-Car
5	Tire Characteristics and Modeling	8, 9	Introduction to tire models, applications of tire models, modeling tire in ADAMS-car
6	Modeling and the Assembly of the Full Vehicle	10, 11, 12	Modeling and assembling subsystems to create full vehicle
7	Simulation Output and Interpretation	13, 14	Virtual testing using ADAMS-Car
8	Project presentations	15,16	

Table 2: Course Outline and Schedule

2. Course Learning Objectives and Syllabus Structure:

This PBL course had two primary course learning objectives. After successful completion of the course:

1. The students should be able to understand multi-body system approach to vehicle dynamics.
2. The students should be able to use multi-body computational software (MSC-ADAMS) to solve vehicle dynamics problems.

It is to be noted that vehicle dynamics is a complex subject that involves concept from design, system analysis, vehicle handling, and safety. In order to understand multi-body system approach to vehicles, one has to consider various subsystems such as steering, suspension, tires, chassis, etc. The second objective focuses on understanding and modeling the subsystems and assemblies in MSC-ADAMS, parameter specifications, studying performance, simulations, and interpretation of the test results. Thus, the lecture schedule was comprised of topics (shown in Table 2) like vehicle dynamics, introduction to simulation, and testing. MSC training material was incorporated as appropriate.

3. Class Composition and Academic Expectations:

This class had a unique class composition. Twenty percent of the students had 20 years or more of industrial experience ('Group A'), 40 percent of the students had 10 years or more of industrial experience ('Group B'), 30 percent of the graduate students had less than 2 years of experience ('Group C'), and 10 percent of the senior undergraduate students ('Group D') were interested in pursuing careers in automotive engineering. At the beginning of the course, the instructor conducted a brief student survey to understand following:

a) Student comfort level in analytical/theoretical dynamics
b) Student comfort level in mathematical concepts like matrices, vectors transformation, and calculus.
c) Student comfort level in modeling and drafting.
d) Student understanding of practical vehicle dynamics problems.
e) Student ability to correlate simulation results to actual experiments.
f) Student experience with actual vehicle handling/dynamic testing.
g) Student expectations (self-learning objectives).

The basic purpose of the survey was to tailor the course content to students' backgrounds, expectations and experience and to offer a project based learning experience. The students were asked to self-evaluate on the

Question	Group A	Group B	Group C	Group D
(a) comfort level in analytical/theoretical dynamics	Low	Medium	High	Medium
(b) comfort level in math	Medium	Medium	Medium	Medium
(c) comfort level in modeling and drafting	Low	High	Medium	High
(d) understanding of practical problems	High	High	Medium	Low
(e)ability to correlate simulation results to actual experiments	High	High	Medium	Low
(f) experience with actual vehicle handing/dynamic testing	High	High	Low	Low

Table 3: Student Survey Results

scale of 1-10, where 1 is the lowest and 10 corresponds to the highest. The scale 'High' refers to score of 8 and above, 'Medium' refers to the score of 4 to 7 and 'Low' refers to scores 3 and below. The outcome of survey questions (a-f) is presented in Table 3.

Students from 'Group A' expected more understanding and correlation of software simulation and experimental testing. Students from 'Group B' wanted to focus on developing software as well as analytical skills. Students from 'Group C' expected to get more understanding of the software and detailed modeling and analysis procedure. The students from 'Group D' were keen on learning the software and simulation approaches.

It can be noted that the class population had a lot of expectations for this course. At the beginning of the course, the students were presented with PBL approach and asked to select a project that can be developed via a building block approach. Interestingly, the students in 'Group A' proposed to work on a practical subassembly problem instead of a full vehicle. The students in 'Group B' proposed to model and analyze a vehicle dynamics problem for which the experimental test data was available. The students in 'Group C' proposed to work on a vehicle subassembly-integration problem and students in 'Group D' wanted to work on the modeling and analysis of 'SAE-Mini Baja' subsystem and vehicle assembly problem. The students were asked to prepare project proposals that were reviewed by the instructor. It is noted that simulations, when used in conjunction with theory, could be very useful in learning and teaching (Barron, 1998; Shtub, 2009; Babich, 2009). However, for this class, some of the simulation project proposals were either too broad or too specific. Some proposals needed resources and background beyond the scope of the course. Another important factor emphasized by the instructor was that the projects should have a building block (subsystem-assembly-analysis-simulation-validation) approach that would fit the 'understand-crawl-walk-run' teaching philosophy as shown in Figure 1.

Some of the sample projects students worked on were:

a) Trailer analysis: In this project, students proposed to study the dynamic performance of larger trailers with a load compensating linkage between the front and rear spring systems.

b) Modeling and dynamic simulation of SUV-trailer combination: In this project, the students proposed to analyze a SUV-Trailer combination and study pulse steer, yaw mode oscillatory stability, and under-steer testing.

c) Dynamic analysis and testing of surge brake: In this project, a student proposed to model, analyze, and simulate surge brake assembly. The results from the simulations would be compared to experimental results. Figure 2 shows the surge brake assembly and braking mechanism, Figure 3 shows the MSC-ADAMS model, and Figure 4 shows the compression spring deformation and driving torque requirement per stroke. This analysis helped to design the surge brake durability testing machine shown in Figure 5. Shah (2008) discusses more details about this project.

d) Dynamic analysis of a torsion bar system: In this project, a student proposed to model, simulate and analyze a torsion bar system (shown in Figure 7) for trailers. The simulation results (forces on torsion bar) for a typical vehicle-trailer maneuver are shown in Figure 8. More details about the project are discussed by Shah (2008) in 'Leading arm and trailing arm suspension design.'

e) Steering-Suspension system analysis: In this project, the students proposed to model and analyze simple steering-suspension geometry and create a template. This assembly would be similar to SAE-Mini Baja car suspension-steering system.

As the students started working on the projects, they encountered several problems. To assist them further, the ET Department and ATIC organized a MSC Software hands-on workshop (Arizona State, 2011). The university program managers of MSC software enthusiastically expressed their support and helped to organize this event (shown in Figure 9). The objectives of this workshop were to introduce faculty, students, and practicing engineers to MSC software products, discuss the MSC university program, and address the problems

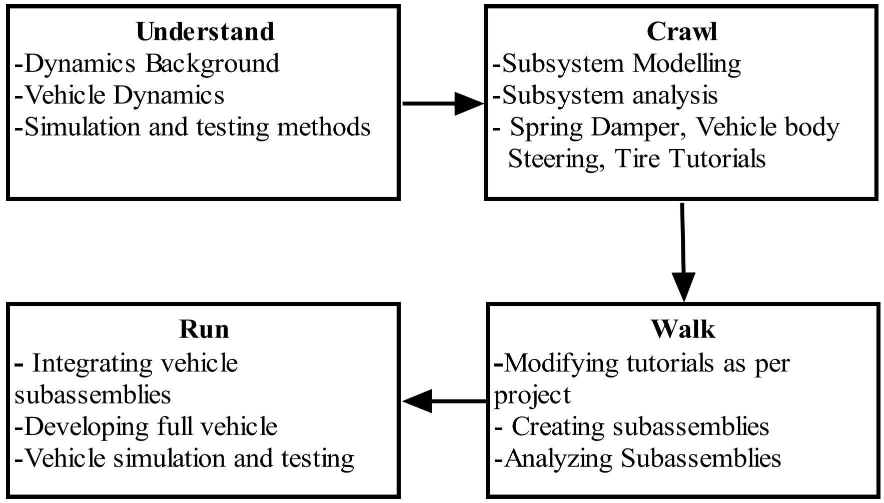

Figure 1: Teaching Methodology

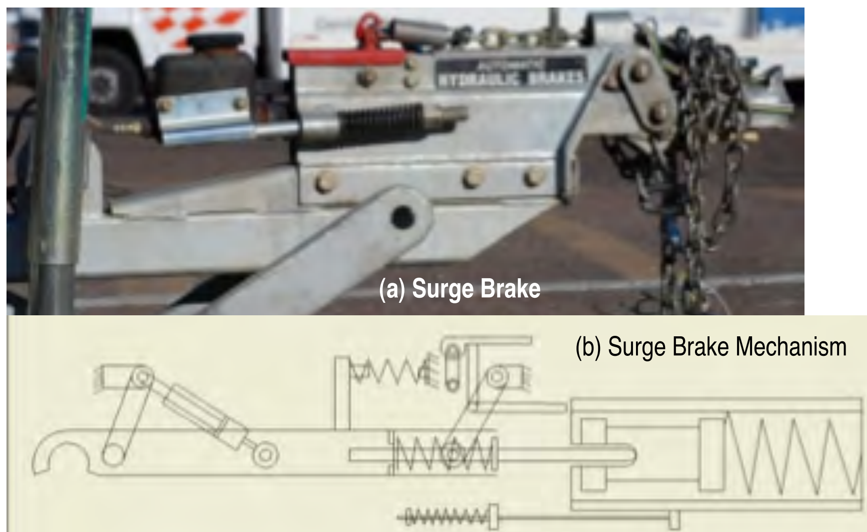

Figure 2: Surge Brake Assembly (Shah, 2008).

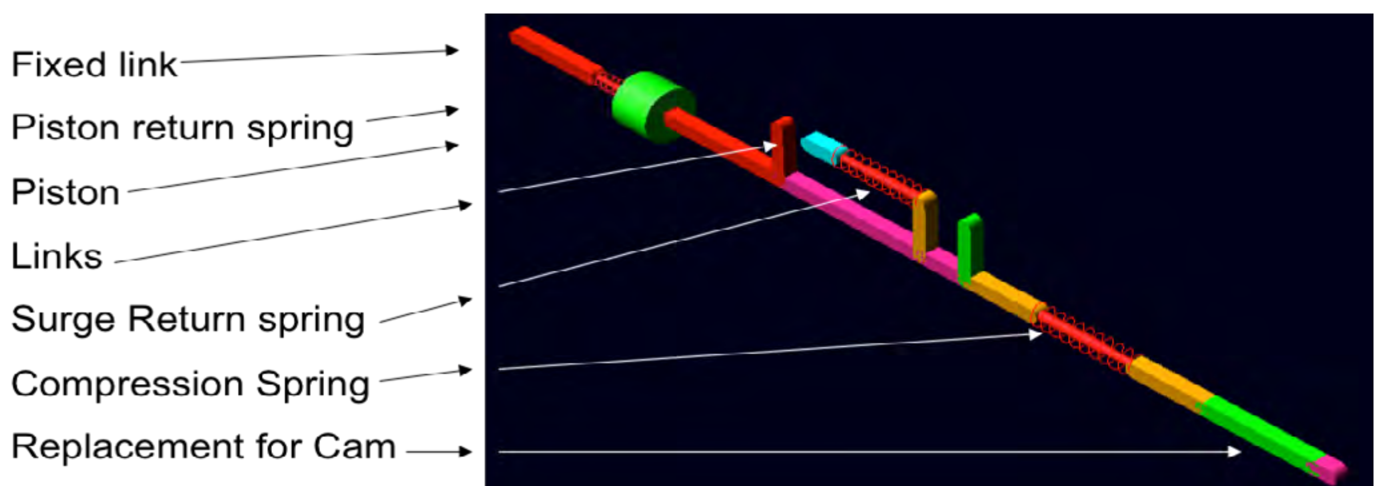

Figure 3: Surge Brake ADAMS-Model (Shah, 2008).

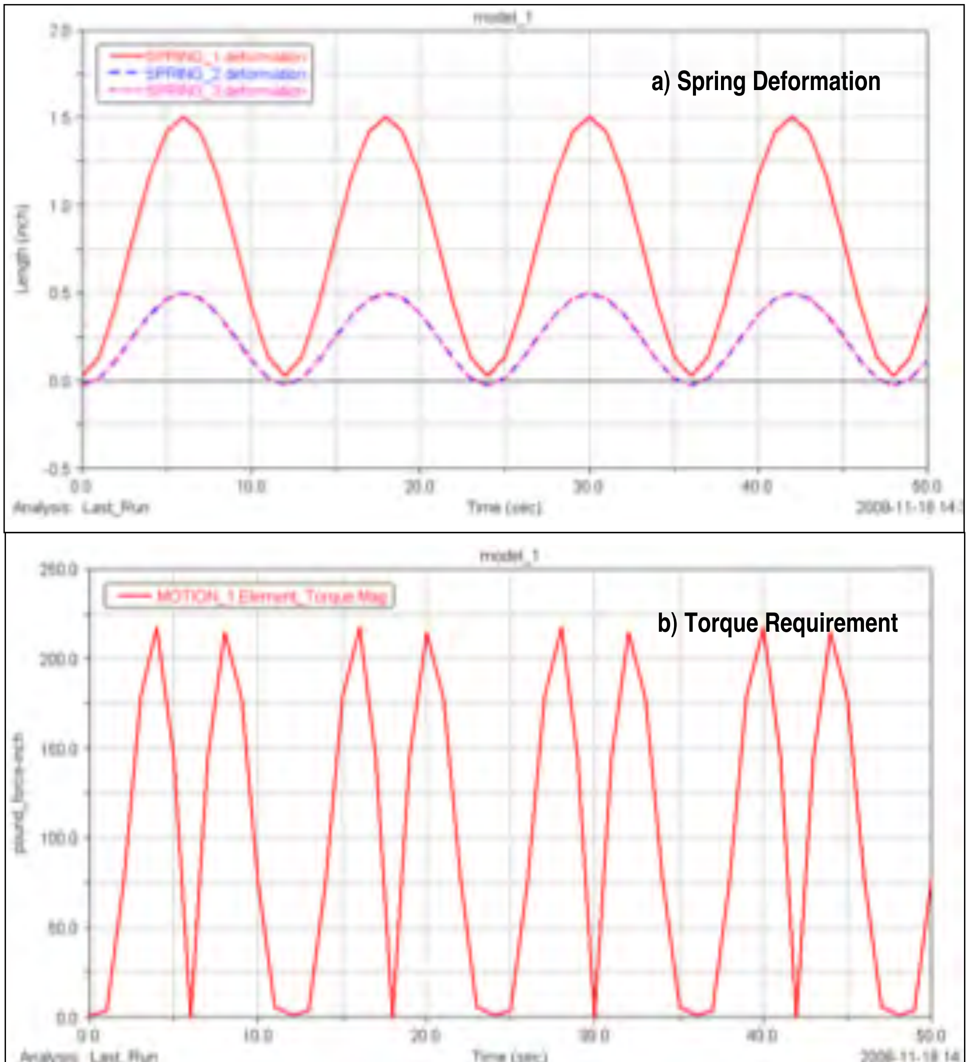

Figure 4: Simulation Results (Shah, 2008).

students faced while working on their projects. Two hands=on sessions (discussed below) were also organized to familiarize participants with Virtual Product Development (VPD) technology.

Session I: MSC.ADAMS-Mechanical System Simulation

In this session, the speaker discussed MSC-ADAMS. Often called a multi-body dynamics program, ADAMS is MSC's tool for studying systems with large motions, with both rigid and flexible bodies without any assumptions about linearity. It automatically includes both geometric and inertial nonlinear effects. Typical applications from orbital dynamics and full-vehicle handling down to disc drive head response and nano-fabricator controls were also presented.

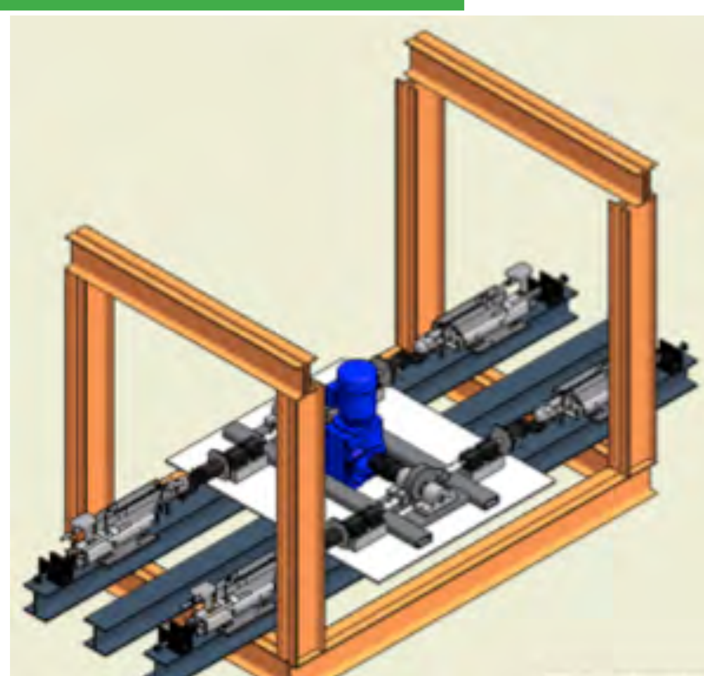

Figure 6: Surge Brakes Durability testing Machine (Shah, 2008).

Session-II: MSC. Nastran-Finite Element Analysis

In this session, applications of MSC's analytical simulation software to support effective design and assessment of product designs were presented. The speaker demonstrated the finite element modeling process by presenting a linear static problem and a more complex transient dynamic impact problem.

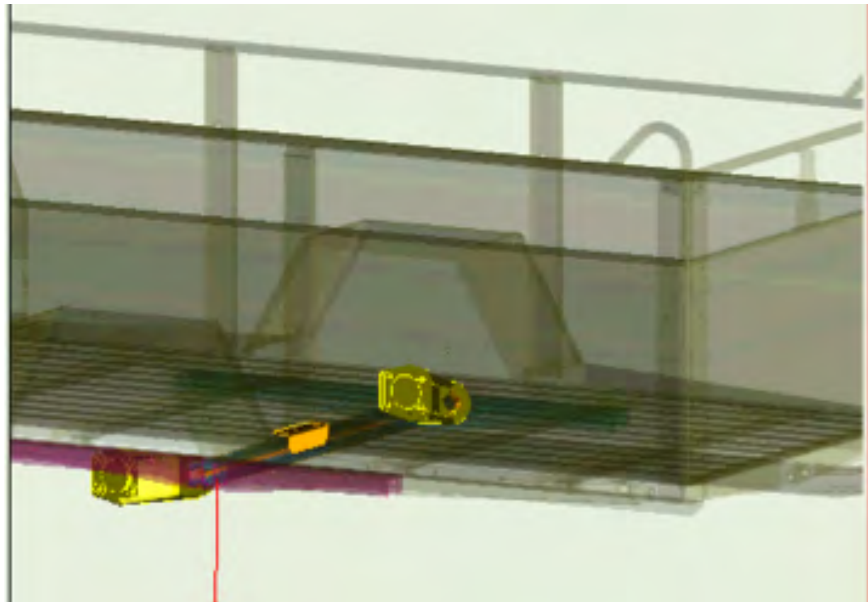

Figure 7: Torsion bar for trailer

4. Student Course Evaluations:

At the end of the course, course evaluations were conducted. The students evaluated the course (exclusive of instructor) based on following seven questions.

EVALUATION OF THE COURSE (exclusive of the instructor)

1. Textbook/supplementary material in support of the course
2. Value of assigned homework in support of the course topics.
3. Value of laboratory assignments/projects in support of the course topics.
4. Reasonableness of exams and quizzes in covering course material.
5. Weight given to labs or projects, relative to exams and quizzes.
6. Weight given to homework assignments, relative to exams and quizzes.
7. Definition and application of criteria for grading.

Students graded the course and instructor on a scale of A to E. This survey was compiled and assigned a numeric score between 2 and 5 (where 5-Very Good, 4-Good, 3-Fair, 2-Poor). Teaching is considered very important in the Engineering Technology department at ASU and departmental teaching evaluation averages are typically very high. The instructor did not have access to the evaluation data before the grades were posted.

The teaching evaluations are very useful to assess the effectiveness of the course and instructor, and provide valuable information so that the course can be improved. In Figure 10, the course evaluations for MET 591: Advanced Vehicle Dynamics are presented and compared with the departmental course evaluation averages.

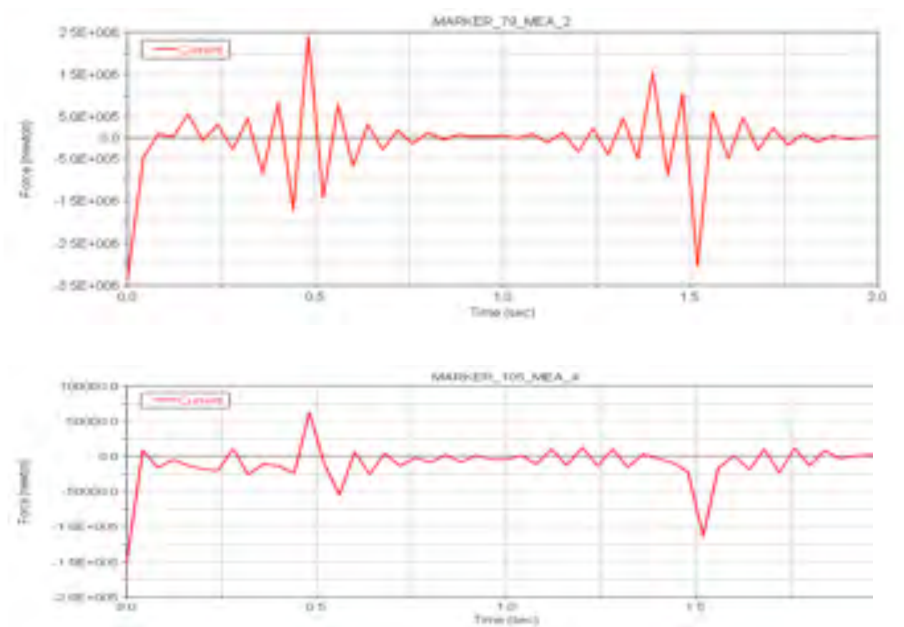

Figure 8: Simulation results

5. Teaching Effectiveness:

It can be observed from Figure 10 that in most criterions the student evaluations exceeded the department average. In this section, we analyze each criterion, the author's efforts to address that criterion, and the student response in detail.

EVALUATION OF THE COURSE (exclusive of the instructor)

1. **Textbook/supplementary material in support of the course:**
   In the summer of 2008, the author reviewed multiple textbooks to use for this course. The author noticed that the conventional analytical vehicle dynamics books did not introduce the computational software tools (like MSC-ADAMS) in sufficient details. On the other hand, the books that presented the applications and use of software in detail did not have sufficient theory. Thus, author used the text by Blundell and Harty (2007) and supplemented the text by the commercial "short term" training material provided by MSC Software Corporation (MSC Software, 2011). To make sure that the transition from theory to software application is smooth, the author also wrote and presented some 'bridge tutorials and problems.'
2. **Value of assigned homework in support of the course topics.**
   As the course was based on a PBL approach, the home-works had practical applications associated with them. For example, one home-work was a simplified vehicle-trailer configuration and students

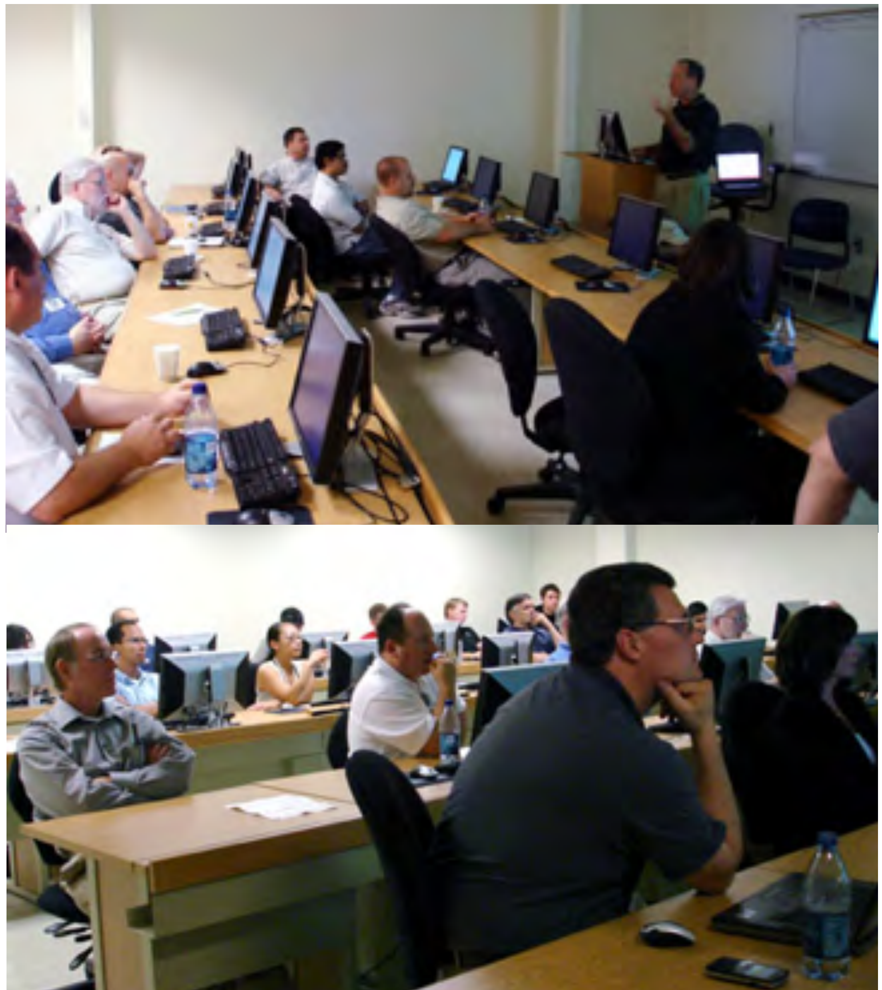

Figure 9: MSC Software Hands on Workshop

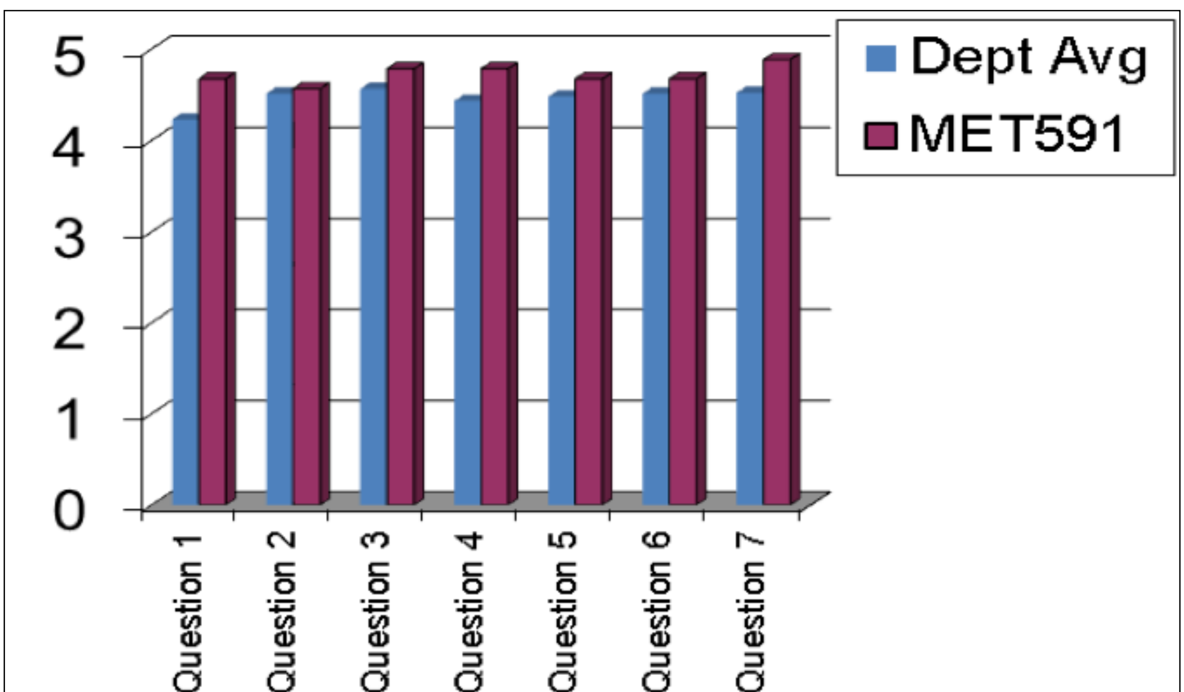

Figure 10: Teaching Evaluations for MET 591: Advanced Vehicle Dynamics

No.	Course Objective	Average Score	Comments/Observations
1	Develop an ability to understand multi-body system approach to vehicle dynamics.	2.7	1. The discussion of multi-body dynamics helped students 2. The projects and overall objectives of the course-industry and school collaboration were appreciated by students.
2	Develop an ability to use multi-body computational software (MSC-ADAMS) to solve vehicle dynamics problems	2.6	1. Introductory class on MSC-software was helpful. 2. Students feel comfortable with the software and are confident that they can build on that foundation.

Table 4: Student Exit Survey

were asked to model it and compare analytical and MSC-ADAMS solutions. In other home-works students were asked to analyze a simple spring mass damper system using MSC-ADAMS and then use it further for the suspension analysis.

3. **Value of laboratory assignments/projects in support of the course topics.**
   The lab assignment for this course included solving tutorials, computer simulations, and examples using the MSC-ADAMS software. Depending upon the type of project students selected, examples were discussed and worked out in the lab. The final course projects were real-life projects and students were asked to solve them, write course reports, and present the work in front of the class and instructor.
4. **Reasonableness of exams and quizzes in covering course material.**
   All the exams for this course were take-home projects where student worked on the problems and instructor assistance was available in case students had any questions. The mid-term and final projects were associated with text material and course notes.
5. **Weight given to labs or projects, relative to exams and quizzes.**
   For this course the following weights were used for grading
   Projects (Mid-term and Final): 30%,
   Research Paper/Report : 30%,
   Assignments (Lab and Homework): 20%,
   Class Participation: 20%.
   Thus, the lab assignments and projects constituted a significant amount of the grade in tune with the PBL philosophy.
6. **Weight given to homework assignments, relative to exams and quizzes.**
   The homework assignments and project reports constituted about 25 percent of the grade. The students were encouraged to log on to ASU's network and use the software for homework via remote log on. Instructor assistance was available for the students who had difficulties while doing the homework via WebEx.
7. **Definition and application of criteria for grading.**
   The following scale was used for grading:
   A: >85%
   B: 85-76
   C:75-66
   D: 65-55
   E<55.
   Students were informed about the current grades and statuses in a timely manner.

In the context of student evaluation, the first course objective related to the following evaluation questions

1. Textbook/supplementary material in support of the course
2. Value of assigned homework in support of the course topics
3. Reasonableness of exams and quizzes in covering course material.

The second course objective related to:

1. Value of laboratory assignments/projects in support of the course topics.
2. Weight given to labs or projects, relative to exams and quizzes.

It can be observed from Figure 10 that this course met or exceeded the departmental course evaluation average when the evaluation questions are mapped to the course objectives. Hence, we can conclude that the course objectives were successfully met.

It can also be noted that at the end of the course, an exit survey was conducted that asked students to evaluate if the course objectives were met on the scale of 0-3 where 0- course objectives were not met at all, 1- course objectives were partially met, 2- course objectives were completely met, and 3- course objective were exceeded. The students were also asked to provide reasons for their numeric score. The results of this survey are presented in table 5. It is noted that since this was an anonymous survey the student scores and comments cannot be mapped against the student profile (or groups) similar to the survey presented in Table 4.
Based on the student evaluation of the course and exit survey, it can be seen that this course met the course objectives successfully. It is also noted that the students suggested some improvements like:

1. Incorporating more tutorials
2. Offering this course as a two-semester course
3. Offering a follow-up course

6. Conclusion:

The 'Advanced Vehicle Dynamics' course presented a case where ASU, local industries, and MSC software came together to offer students an excellent educational experience. The instructor adopted the 'understand-crawl-walk-run' type of teaching philosophy mixing theory and practice. Because of the diverse class composition and varied student expectation, the instructor used a PBL approach, where the students could concentrate and achieve their individual learning goals. The routine class discussions helped students to understand the material. A hands-on workshop was organized for the problems and questions that needed 'expert help'. Specific efforts to encourage active learning included blending theory with practical industrial applications, case studies, well defined yet flexible curriculum, and periodic assessments that resulted in high teaching evaluations and meeting the course objectives. Thus, we can observe that well-designed PBL can be a very effective approach to instruct a diverse class of students.

Acknowledgement:

The author would like to thank Mr. Paul Grabill of U-Haul Technical Center, Mr. Dan Abir, Mr. Lindley Bark, Dr. Andrew Elliot and Mr. Jim Ryan of MSC Software. Special words of thanks go to Ms. Casey Radigan, University Program Manager at MSC software, for her help and support. The author is also thankful to Dr. Mike Blundell for sharing his course material. The author is also thankful to Dr. Anshuman Razdan and Ms. Jane Laux for their help and support in organizing MSC software workshop through ATIC.

References:

Arizona State University College of Technology and Innovation Website. (Retrieved 2011, Feb. 22). http:/atic.asu.edu/

Babich, A., & Mavrommatis, K. (2009). Teaching of complex technological processes using simulations. *International Journal of Engineering Education, 25*(2), 209-220.

Barron, B. J. S., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., Bransford, J. D., & The Cognition and Technology Group at Vanderbilt. (1998).Doing with understanding: Lessons from research on problem- and project-based learning. *The Journal of the Learning Sciences, 7*, 271-311.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991).Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3 & 4), 369-398.

Blundell, M., & Harty, D. (2007). T*he multibody systems approach to vehicle dynamics*. Elsevier Publishing.

Boaler, J. (1998). Open and closed mathematics: Student experiences and understandings. *Journal for Research in Mathematics Education, 29*, 41-62.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning Sciences, 2*, 141-178

Brown, A. L., & Campione, J. C. (1996). Psychological theory and the design of innovative learning environments. On procedures, principles, and systems. In L. Schauble & R. Glaser (Eds.). Innovation in learning: New environments for education (pp. 289-325). Hillsdale, NJ: Lawrence Erlbaum Associates.

Coventry University Website. (Retrieved 2011, Feb. 10). http://www.coventry.ac.uk

DeFillippi, Robert J. (2001). Introduction: Project-based learning, reflective practices and learning. *Management Learning*, 32; 5.

Diehl, W., Grobe, T., Lopez, H., & Cabral, C. (1999). Project-based learning: A strategy for teaching and learning. Boston, MA: Center for Youth Development and Education, Corporation for Business, Work, and Learning.

Gallagher, S. A., Stepien, W. J., & Rosenthal, H. (1995). The effects of problem-based learning on problem solving. *Gifted Child Quarterly, 36*, 195-200.

Gallagher, S. A., Stepien, W. J., Sher, B. J., & Workman, D. (1995). Implementing problem based learning in science classrooms. *School Science and Mathematics, 95*,136-146.

Gardner, H. (1991). *The unschooled mind*. New York: Basic Books.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? 16(3), 235-266.

Jones, B. F., Rasmussen, C. M., & Moffitt, M. C. (1997). *Real-life problem solving.: A collaborative approach to interdisciplinary learning*. Washington, DC: American Psychological Association.

Krajcik, J. S., Blumenfeld, P. C., Marx, R. W., Bass, K. M., Fredricks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. *The Journal of the Learning Sciences, 7*, 313-350.

Krajcik, J. S., Blumenfeld, P. C., Marx, R. W., & Soloway, E. (1994). A collaborative modefor helping middle-grade science teachers learn project-based instruction. *The Elementary School Journal, 94*, 483-497.

Meyer, D. K., Turner, J. C., & Spencer, C. A. (1997). Challenge in a mathematics classroom: Students' motivation and strategies in project-based learning. *The Elementary School Journal, 97*(5), 501-521.

MSC Software Website. (Retrieved 2011, Feb. 22). http://www.mscsoftware.com

MSC Software Academia Webpage. (Retrieved 2011, Jan. 2). http ://www.mscsoftware.com/university/

Ramsden, P. (2002). *Learning to teach in higher education*. Routledge, N Y.

Rosenfeld, M., & Rosenfeld, S. (1998). Understanding the "surprises" in PBL: An exploration into the learning styles of teachers and their students. *Paper presented at the European Association for Research in Learning and Instruction (EARLI)*, Sweden.

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *Journal of the Learning Sciences, 1*, 37-68.

Scardamalia, M., Bereiter, C., McLearn, R. S., Swallow, J., & Woodruff, E. (1989). Computer supported intentional learning environments. *Journal of Educational Computing Research, 5*, 51-68.

Shah, B. (2008). Design and construction of surge brake durability testing machine. *MS Project report/MET 591 class project report*, Arizona State University.

Shah, M. (2008). Leading arm and trailing arm suspension design. *MET 591 Class project report*, Arizona State University.

Shtub, A., Parush, A., &Hewett, T. (2009). Guest editorial: The use of simulation in learning and teaching. *International Journal of Engineering Education, 25*(2), 206-208.

Thomas, J. W., & Mergendoller, J. R. (2000). Managing project-based learning: Principles from the field. *Presented at the Annual Meeting of the American Educational Research Association*, New Orleans, LA.

Thomas, J. W., Mergendoller, J. R., & Michaelson, A. (1999). *Project-based learning: A handbook for middle and high school teachers*. Novato, CA: The Buck Institute for Education.

U-Haul Website. (Retrieved 2011, Feb. 12). http://www.uhaul.com

Sangram Redkar received his PhD from Auburn University in 2005. He joined Arizona State University in the fall of 2007 as a tenure track assistant professor. Dr. Redkar has a keen interest in engineering education. Dr. Redkar's research interests are a) Nonlinear Dynamics and Control b) Inertial navigation and GPS c) Design, Dynamics and control of Micro-Electro Mechanical Systems (MEMS). He has graduated 10 MS students and one PhD student. His research work at ASU (since fall of 2007) has resulted in 18 journal publications, nine peer reviewed conference papers and one research monograph.