Provost’s Learning Innovations Grant for Faculty
Special Request for Proposal
Course Development
2009-2010

Please hand-deliver your completed grant proposal (cover page, 4 pages, plus attachments), the original plus 15 copies, to:
Susan DeWoody, 1530 Wallace (Bldg 5)
by 4:30 p.m.
Friday, May 1, 2009.
No hand written proposals will be accepted.
Notification of awards will be made by Friday, May 29, 2009.

Project Title:
A Classroom Experimentation Module Set in Engineering Dynamics for Increased Student Comprehension by Connecting Theory with Experiment in an Interactive Setting.

Applicant(s):

<table>
<thead>
<tr>
<th>Name</th>
<th>Jason R. Kolodziej</th>
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<th>475-4313</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dept.</td>
<td>Mechanical Engineering</td>
<td>College</td>
<td>Kate Gleason College of Engineering</td>
</tr>
</tbody>
</table>
A Classroom Experimentation Module Set in Engineering Dynamics for Increased Student Comprehension by Connecting Theory with Experiment in an Interactive Setting.

SUMMARY:
Engineering Dynamics is hard, and is possibly the most challenging course a Mechanical Engineering (ME) student will take during the critical first 2 years of college. The subject matter can be abstract, involving complex concepts such as rotating coordinate systems, centripetal acceleration, and angular momentum, to name a few. For a 19 year old undergraduate student with little “hands-on” experience beyond high school physics to understand, let alone achieve the mastery needed to be a successful mechanical engineer, a strong understanding of Dynamics is critical. Moreover, Dynamics is a key contributor to many lower-division ME students ending Year 2 on academic probation.

The proposed project seeks to develop a sequence of 10 in-class experimentation modules tying the current week’s lessons into a more comprehensive learning package by combining theory with practice. Having a full laboratory component of the class is not readily achievable due to lab space, equipment, and student scheduling. However, Dynamics is a 5 credit hour course (rather than 4 credits for the other four Core courses resulting in 25% more in-class time) indicating the extensive amount of material, effort, and instruction, required to successfully understand the course subject material. These modules will be delivered by the faculty instructor with full class participation, because the concepts involved in the experiment would be directly from the current week's lecture. It is expected that discrepancies will arise between theory and experiment. These unexpected (or believed to be not important) differences are a very welcome byproduct of these modules since engineering intuition and problem solving are frequently required in the student’s future workplace.

Table 1 is a week-by-week breakdown of all the topics covered in the Dynamics course. Roughly, the concepts can be broken into two sections: (1) Particle Dynamics and (2) Rigid Body Dynamics. In the Appendix of the proposal are two suggested modules for Weeks #2 and #6 from the weekly schedule in Table 1. While these are preliminary suggested experiments to illustrate the theory, they are directly taken from the student's end-of-chapter homework problems, and would provide an excellent theory versus experiment connection. A similar experiment would be developed for each of the ten weeks.

There are two primary hardware components expected as part of this proposal. One is a data acquisition system (DAQ) and the other is a digital video camera. Engineering dynamic’s experiments are, by definition, not static. The motion of a system subject to external forces versus time is a critical component of the study of dynamics. Therefore, a necessary requirement is “real-time” data capture. One means to accomplish this goal is PC-based data collection (using an inexpensive, external USB-based DAQ device connect to the instructor's laptop) and the other is digital imaging.

While computer DAQ systems are common in undergraduate engineering labs, and will be a large component of this project as well, concepts such as projectile motion and motion on a non-uniform path cannot easily (if at all) be measured by electro-mechanical sensors. The proposal is to include a tripod mounted high-speed digital camera with a known timestamp to capture the motion of the object. With an appropriately graduated background it is possible to “plot” the motion of the object versus time. From this a theoretical comparison can be made.

<table>
<thead>
<tr>
<th>WEEK</th>
<th>TOPICS COVERED</th>
<th>SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cartesian Coordinates (x-y), Projectile Motion</td>
<td>Particle</td>
</tr>
<tr>
<td>2</td>
<td>Normal-Tangential Coordinates (n-t), Polar Coordinates (r-θ)</td>
<td>Particle</td>
</tr>
<tr>
<td>3</td>
<td>Work &amp; Energy Principles, Conservation of Energy</td>
<td>Particle</td>
</tr>
<tr>
<td>4</td>
<td>Impulse &amp; Momentum, Conservation of Momentum</td>
<td>Particle</td>
</tr>
<tr>
<td>5</td>
<td>Impact, Angular Impulse &amp; Momentum</td>
<td>Particle</td>
</tr>
<tr>
<td>6</td>
<td>Rigid Body Kinematics, Relative Motion Analysis - Velocity</td>
<td>Rigid Body</td>
</tr>
<tr>
<td>7</td>
<td>Relative Motion Analysis - Acceleration, Mass Moment of Inertia</td>
<td>Rigid Body</td>
</tr>
<tr>
<td>8</td>
<td>Translation &amp; Rotation, General Plane Motion</td>
<td>Rigid Body</td>
</tr>
<tr>
<td>9</td>
<td>Work &amp; Energy, Conservation of Energy</td>
<td>Rigid Body</td>
</tr>
<tr>
<td>10</td>
<td>Work &amp; Energy, Synthesis of All Topics</td>
<td>Rigid Body</td>
</tr>
</tbody>
</table>

Table 1 - Topics Covered in Dynamics (0304-359)
**TARGETED LEARNERS**

The proposed course improvement is directed at 2nd year Mechanical Engineering students completing the final class in the Statics / Mechanics of Materials / Dynamics sequence in the Engineering Sciences Core Curriculum (ESCC) and is typically offered during the Spring Quarter. Upwards of 120 students per year, over 4 faculty taught sections, take Dynamics. It is one of five core courses that define what it is to be a mechanical engineer with all subsequent courses based on these fundamentals. The course improvement will increase understanding and comprehension, thus enabling a stronger engineering foundation for future coursework and eventual graduate research or employment.

The roll-out of this in-class, interactive, demonstration will be ready for Spring 2010’s standard Dynamics course offering. It is planned that the PI will be instructing one of the four sections of the course at which time a pilot offering of the weekly demonstration can be interjected. Given the previous teaching experience of the PI in Dynamics (offered 5 days a week) a Friday offering of this type of interactive learning would be a welcome conclusion to the week, while connecting the current week’s theory with experiment.

**RATIONALE**

Having instructed undergraduate engineers in Dynamics, a common student complaint is that that the material is not “touchable”. Many of these students select mechanical engineering as a possible career because they like to build and design things. Dynamics introduces them to the other side of engineering, namely, analysis. However, without the ability to work in a “hands-on” capacity the connection of theory with practice is often lost, and thus retention is poor.

While the main idea of the project is to reproduce with experiment the results from theory. A key secondary benefit is if discrepancies from theory exist, and they probably will, it is important to address why? This type of analysis in theorizing the error is not typically addressed in lower-division engineering courses since the systems under analysis are idealized textbook problems. Making this connection is extremely valuable to an engineer-in-training. Since many students have not had co-op or internship opportunities yet, comparing experimental result versus theoretical expectation is minimal.

The Engineering Sciences Core Curriculum is a sequence of five lower division (1st and 2nd year) courses that define what it is to be a Mechanical Engineer (ME). These courses are Statics, Mechanics of Materials, Dynamics, Thermodynamics, and Fluid Mechanics (0304-336,347,359,413,415). All mechanical engineering future coursework are derivatives of these five fundamental classes. Every ME student is required to complete Dynamics to be eligible for mandatory co-op in Years 3-5. Dynamics is typically offered in the Spring Quarter with their first co-op opportunity in the following Summer Quarter. It is imperative that a strong Dynamics fundamental background be established.

Experiential learning is included in a variety of courses in the first 3 years of undergrad such as Materials Processing, Measurement Instrumentation & Control, Mechanics of Materials, Thermo-Fluids Lab I & II, and some out-of-department Physics workshops. Noticeably absent from this list is an experimental Dynamics component which does not occur until Year 4 in System Dynamics. The proposed course inclusion is to address this need in Year 2. While a full Dynamics lab course is not currently feasible (for a course already 5 credit hours) adding an in-class experimentation component is not. In the Statics-Mechanics-Dynamics 2nd-year sequence Statics and Mechanics are 4 credit hour classes versus 5 credit hours for Dynamics illustrating the important need for additional weekly student/faculty interaction. The proposed goal is to make this additional hour per week as interactive and “hands-on” as possible giving the Dynamics course a much needed experimental component.

**IMPACT**

The anticipated impact on teaching and learning is expected to be significant. To date nothing like this has been attempted in the ME department. There would be a sequence of in-class, interactive, experiments performed weekly. If this method of instruction proves to be a success it is likely that other courses will adopt the concept. It is noteworthy that this in-class experimentation is not intended to replace the personal experience of a laboratory setting. It is meant to enhance learning in classes not
traditionally taught with a lab component. It is expected that the learning experience of the students will be greatly enhanced by live experimentation in proving the connection of a very theoretical subject and practice.

Above all the primary goal of this project is to increase the student retention of course material in Dynamics, a well-known challenging course in undergraduate mechanical engineering. It is well accepted that visualizing a problem (or system) can greatly enhance comprehension of a new and advanced topic. The PI's experience in industry has found that there is little substitute for physical experimentation in engineering. The plan is to incorporate experimentation in a traditionally very theoretical class with the expectation that long-term knowledge retention will be realized.

Outcome assessment is always a question when introducing a new methodology in teaching. As mentioned, Dynamics is part of the Engineering Sciences Core Curriculum. In 2008, a major initiative within the ME department was to establish uniformity in the core undergraduate classes. Thus, in the Spring Quarter of each academic year Dynamics is offered in multiple sections by a team of several different faculty. In addition to using a common syllabus in policy, grading, and homework problems the team meets weekly to ensure a cohesive delivery of course material. Moreover, three times throughout the quarter all sections meet for common mid-term and final exams. All of this is in an effort to maintain a uniform teaching/learning environment for the student regardless of the instructor. However, day-to-day lectures are still up to the experience and creativity of the section instructor. Therefore, a possible first attempt at assessing the outcome of the project would be to introduce the in-class experimentation modules in one of the sections. Since grading evaluation is done uniformly across all sections student success can be easily benchmarked between classes. If a marked improvement in student scores is seen in the section with in-class experimentation then the modules can be rolled-out to the other sections in subsequent years. It is expected that the PI's section of Dynamics in the Spring of 2010 will be the class to experience the in-class experimentation first. (Since all modules should be completed by Spring 2010 each section is eligible to use the modules as per instructor acceptance. Outcome assessment would then be versus previous offerings of Dynamics under the ESCC mandate.)

Finally, it is highly expected that the undergraduate student researcher and the PI will disseminate the development, impact, and assessment, of the In-class Dynamics Experimentation Module experience locally within the department, as well as, RIT wide. In addition, publication in a peer reviewed journal and/or conference such as the American Society of Engineering Education Annual Conference & Exposition is included as part of the deliverable of the project.

STUDENT INVOLVEMENT

An undergraduate student researcher and PI collaboration is expected to be engaged in developing the 10 experimentation modules. The student will have taken the Dynamics course within the previous 2 years and will be intimately familiar with the class content. In addition, this student will be able to obtain peer feedback on suggested concepts, visual aids, and experiments that will be beneficial to improve knowledge retention of course theory.

BUDGET

1. **Salaries:**
   a. No faculty compensation ($0) is requested as part of this proposal.
   b. The undergraduate student is expected to research and develop these modules for credit as part of a technical elective, thus no student compensation ($0) is expected. If the research is not performed for technical elective credit compensation will only then be used at the standard rate.

2. **Supplies:**
   a. It is expected that the full award ($5,000) will be used for hardware. Table 2 outlines the expected purchases
**Table 2 - Proposed Budget**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>COST</th>
<th>PRELIMINARY SELECTION</th>
<th>RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Acquisition (DAQ)</td>
<td>$849</td>
<td>National Instruments - NI USB-6211</td>
<td>$200-$1300</td>
</tr>
<tr>
<td>DAQ Software</td>
<td>$0</td>
<td>NI LabVIEW Professional (RIT site license)</td>
<td>$625-$1100</td>
</tr>
<tr>
<td>Digital Video Camera</td>
<td>$1,583</td>
<td>Sony XCD-SX90</td>
<td>$900-$2500</td>
</tr>
<tr>
<td>Tripod</td>
<td>$100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensors</td>
<td>$1,500</td>
<td>linear &amp; rotational potentiometers</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>force transducers</td>
<td></td>
</tr>
<tr>
<td>Supplies</td>
<td>$500</td>
<td>springs, cables, fixtures, tracks</td>
<td></td>
</tr>
<tr>
<td>Misc.</td>
<td>$468</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$5,000</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TIMELINE**

- **Spring 2009:**
  - Identify undergraduate student researcher to assist in developing the experimentation modules.

- **Summer 2009:**
  - Outline the weekly goals of the Dynamics course and determine 10 demonstration projects.
  - Select and purchase data acquisition and digital video camera and determine necessary hardware and sensors required for each experiment overlapping equipment as much as possible.
  - Begin the design, test, and documentation of each individual experiment.

- **Fall 2009-Winter 2010:**
  - Complete design, test, and documentation of each individual experiment.

- **Spring 2010:**
  - Rollout modules in traditional offering of Dynamics. Probable test case in PI’s section with possible inclusion in other sections as per instructor’s acceptance.
  - Review results and assess improvement in curriculum understanding and grade performance.
  - Publish results in an engineering peer-reviewed journal or conference such as American Society of Engineering Education.
APPENDIX I

SUGGESTED MODULE #2 –

Problem:

The 2-kg spool S fits loosely on the inclined rod for which the coefficient of static friction is $\mu_s=0.2$. If the spool is located 0.25m from A, determine the minimum constant speed the spool can have so that it does not slip down the rod.

Theoretical Solution:

Using n-t coordinates to solve this problem since the path of motion is defined by the rotation of the rod.

- Solving first for the radius of curvature ($\rho$)
  $$\rho = 0.25 \left( \frac{1}{2} \right) = 0.2m$$

- Defining the positive normal direction to the left and the positive bi-normal direction vertical. The spool will stay in one position on the rod if the forces in the bi-normal direction are in equilibrium ($a_n=0$)
  $$\sum F_n = ma_n: \quad N_s \left( \frac{4}{3} \right) - 0.2N_s \left( \frac{4}{3} \right) = 2 \left( \frac{v^2}{0.2} \right)$$
  $$\sum F_b = ma_b: \quad N_s \left( \frac{4}{3} \right) + 0.2N_s \left( \frac{4}{3} \right) - 2(9.81) = 0$$

- Solving for the normal force on the spool and the velocity
  $$N_s = 21.3N$$
  $$v = 0.969m/s$$

Experimentation:

For this module the idea is to design the physical system as close to the problem statement as possible. This would include fabricating an inclined rod and a spool to fit. The friction coefficient would have to be analyzed independently by the PI because friction modeling is not part of this Dynamics course. Since this is a kinetic problem both forces and accelerations are included in the analysis. There would be a stepper or servo motor attached to the base to provide controlled angular motion with a tachometer to measure angular velocity $\omega$. The inclined portion of the rod would be labeled with a linear measurement scale to determine the position of the spool on the rod.

<table>
<thead>
<tr>
<th>HARDWARE</th>
<th>VARIABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuator</td>
<td>Stepper Motor</td>
</tr>
<tr>
<td>Sensor</td>
<td>Tachometer</td>
</tr>
<tr>
<td>Sensor</td>
<td>Digital Video Camera</td>
</tr>
</tbody>
</table>

Table 3 - DAQ Requirements for Module #2

This experiment would validate the theoretical results above. However, an interesting addition to the experiment would be the motion of the spool as it starts from rest at the bottom of the incline. To perform this study a high frame rate digital video camera could be positioned above facing downward. When the motor is started the position of the spool could be video captured with a time-stamp. When the spool reaches its final position the camera data could be analyzed over a series of frames. The students could then plot the position of the spool versus time.
APPENDIX II

SUGGESTED MODULE #6 –

**Problem:**

If bar AB has an angular velocity \( \omega_{AB} = 6 \text{ rad/s} \), determine the velocity of the slider block C at the instant \( \theta = 45^\circ \) and \( \phi = 30^\circ \). Also sketch the location of bar BC when \( \theta = 30^\circ, 45^\circ, \) and \( 60^\circ \) to show its general plane motion.

**Theoretical Solution:**

- Applying the relative velocity equation for the motion of slider C
  \[
  v_C = v_B + \omega_{AB} \times r_{B/A}
  \]
- Requires the motion of joint B which is simply the angular rate of the link AB times the length
  \[
  v_B = \omega_{AB} \times r_{B/A}
  \]
- Yields,
  \[
  v_C i = (6k) \times (0.2 \cos 45^\circ i + 0.2 \sin 45^\circ j) + (\omega k) \times (0.5 \cos 30^\circ i - 0.5 \sin 30^\circ j)
  \]
- Combining like coordinates \((i, j)\)
  \[
  i: v_C = -0.8485 + \omega (0.25) \\
  j: 0 = 0.8485 + 0.433\omega
  \]
- Thus
  \[
  \omega = -1.96 \text{ rad/s} \\
  v_C = 1.34 \text{ m/s} \text{ to the left.}
  \]

**Experimentation:**

For this module the physical system requires linkages, pins, a slider, track, etc. Since this is a kinematic problem frictional effects are not required as part of the solution and can be omitted. There would be a stepper or servo motor attached to point A to provide controlled angular motion with a rotational potentiometer (POT) to measure angle \( \theta \), which then could be differentiated to determine the angular velocity, \( \omega_{AB} \). A linear potentiometer would be connected to slider C to determine linear position which also could be differentiated to determine velocity \( v_C \). Assuming signal noise is kept to a minimum this differentiation would not significantly corrupt the velocity measurement. A rotational potentiometer could also be included at point C to ensure angle \( \phi \) is correct for the instant under consideration.

<table>
<thead>
<tr>
<th>HARDWARE</th>
<th>VARIABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuator Stepper Motor</td>
<td>( \omega_{AB} )</td>
</tr>
<tr>
<td>Sensor Rotational POT</td>
<td>( \theta, \omega_{AB} )</td>
</tr>
<tr>
<td>Sensor Linear POT</td>
<td>( v_C )</td>
</tr>
<tr>
<td>Sensor Rotational POT</td>
<td>( \phi, \omega_{BC} )</td>
</tr>
</tbody>
</table>

Figure 2 - System Diagram for Module #6

Table 4 - DAQ Requirements for Module #6