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USING REMOTE ACCESS FOR SHARING EXPERIENCES IN A MACHINE DESIGN LABORATORY

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Abstract

A new Machine Design Laboratory at Marquette University has been created to foster student exploration and promote “hands-on” and “minds-on” learning. Laboratory experiments have been developed to give students practical experiences and expose them to physical hardware, actual tools, and design challenges. Students face a range of real-world tasks: identify and select components, measure parameters (dimensions, speed, force), distinguish between normal and used (worn) components and between proper and abnormal behavior, reverse engineer systems, and justify design choices. The experiments serve to motivate the theory, spark interest, and promote discovery learning in the subject of machine design.

This paper presents details of the experiments in the Machine Design Laboratory and then explores the feasibility of sharing some of the experiences with students at other institutions through remote access technologies. The paper proposes steps towards achieving this goal and raises issues to be addressed for a pilot-study offering machine design experiences to students globally who have access to the internet.

Keywords: machine design; laboratory experiments; remote access

Resumen

Un nuevo laboratorio de Diseño de Maquinaria ha sido desarrollado en Marquette University para facilitar la exploración estudiantil y promover el aprendizaje mental y practico. Se desarrollaron diversos experimentos de laboratorio que ofrecen a los estudiantes experiencias prácticas y los exponen tanto a maquinaria real, herramientas y desafíos de diseño de la vida real. Los estudiantes enfrentan un rango de diferentes trabajos de la vida real tales como: identificación de componentes, medición de parámetros (dimensiones, velocidad, fuerza), distinguir entre componentes normales y desgastados y entre comportamiento normal y anormal, ingeniería inversa de los componentes, y justificación de decisiones relativas al diseño. Estos experimentos sirven para motivar la teoría, incitar el interés, y promover el aprendizaje de descubrimiento sobre diseño de maquinaria.

Este ensayo presenta detalles acerca de los experimentos dentro del Laboratorio de Diseño de Maquinaria y explora la posibilidad de compartir algunas de las experiencias con estudiantes de otras instituciones usando tecnología de acceso a distancia. El ensayo propone los pasos a seguir para lograr esta meta, y aborda diversas dificultades que deberán enfrentarse en un estudio piloto para estudiantes, tanto locales como globales.

Palabras clave: *diseño de maquinaria*; *experimentos de laboratorio*; *acceso a distancia*

1. Introduction

The promise of remote access of laboratory equipment is that deserving students around the globe would be able to run experiments and engage in real-world investigations that otherwise would not be possible. The idea of remote access for engineering students has been discussed in previous conferences, including a well-attended session at the 2012 WEEF Conference. Its potential for changing education is as enormous as that of MOOCS.

This paper proposes a pilot-study to assess the feasibility of remote access of experiments in the area of machine design. The project will explore the effectiveness of exploiting internet tools and communication technologies for engineering students to engage in laboratory activities remotely. The experiments were developed in a new Machine Design Laboratory in the College of Engineering at Marquette University. The experiments reflect the spirit of transformational learning that is a theme in a new $50 million Engineering Hall in the College.

<u>Student-Centered Learning Methods</u>

In a traditional college class, time is spent with a professor lecturing and students watching, listening, and writing. Cooperation is generally discouraged. In student-centered pedagogical methods, the focus of activity is shifted from the teacher to the learners. Numerous studies and articles have shown that student-centered learning methods have advantages relative to the classical teacher-centered approach (Prince, 2004; Prince and Felder, 2006; Prince and Felder, 2007; Felder and Brent, 2009; Goldberg and Nagurka, 2012). The advantages are reflected in a range of outcome measures: short-term mastery, long-term retention, depth of understanding, critical thinking, creative problem-solving skills, positive attitudes toward the subject, and level of confidence in knowledge or skills.

The essence of student-centered learning methods is transformational learning. There are several types of student-centered methods, including active, cooperative, collaborative, and inductive learning. Some students thrive more with one style than another. The experiments reported in this paper embrace many of these student-centered learning methods.

2. Student-Centered Learning in the Machine Design Laboratory

A new Machine Design Laboratory has been created in the College of Engineering at Marquette University. The 100m^2 laboratory, which incorporates areas for teaching and training, was designed to foster student exploration with hardware, machines, and physical systems.

To promote "hands-on" and "minds-on" learning, the laboratory is equipped with workbenches, tools, instruments, computers, data acquisition systems, and an assortment of machines and mechanical systems. These include motorcycle engine assemblies (engines and transmissions), bicycles (including a chainless bicycle and a custom front-wheel-drive, rear-wheel-steer bicycle), a go-kart chassis, a Machine Fault Simulator training station, and other systems (industrial gearboxes, gear-motors, automotive transmission and differential, drill presses, etc.)

Discovery Learning Experiments

Experiments encouraging discovery learning were developed to give mechanical engineering students practical experiences and to enhance creative exploration and investigation in machine design. In the experiments, students are exposed to physical hardware, actual tools, and real-world design challenges. The experiments intentionally immerse students in an environment where they are forced to hone a range of machine design skills. These skills include the ability to identify machine components, know proper nomenclature, measure parameters (dimensions, speed, force), select components from catalogs for design challenges (understanding tradeoffs for performance, life, cost, etc.), distinguish between normal and used (worn) components, differentiate and predict proper and abnormal behavior, reverse engineer systems, develop engineering intuition, and communicate effectively in justifying design choices.

To conduct the experiments students pursue active, collaborative, and inductive-based learning. The experiential learning opportunities are similar to those associated with industrial co-op, internship, design and research experiences. Students face directed and open-ended challenges giving them significant potential for learning in solving machine design problems.

3. Experiments in the Machine Design Laboratory

Teams of 2 or 3 students conduct the experiments (described below) in 2-hour sessions each week. Each experiment lasts one to two weeks.

1. Introduction to Machine Systems

This introductory experiment explores a range of topics related to machine components and systems. Students examine and interact with systems including a Machine Fault Simulator training station, a drill press (Figure 1), a motorcycle engine, a chainless bicycle that uses a driveshaft, and a go-kart chassis. Laboratory activities stimulate thought about machine design components and machine assemblies, emphasize the importance of proper nomenclature, and help gauge students' prior knowledge and experience with topics of machine design.

The purpose of the experiment is for students to (1) gain practical experience with various machine design components, (2) become familiar with how machine design components are incorporated into systems, (3) interact with tangible components and mechanical hardware, and (iv) reinforce basic concepts of statics, dynamics, and mechanics of materials.

2. Stress Measurements and Concentrations

This experiment reinforces material from a prerequisite course in "Mechanics of Materials" and supports review lectures on stress and strain. Key aspects of the experiment are measurement of strain using strain gages (single axis and rectangular rosette gages) and photoelastic methods for components exposed to different kinds of loading (pure bending, pure torsion, combined loading) and with stress concentrations (holes, grooves, fillet changes.) Students determine (1) the stress-strain relationship and critical section in a cast iron flat bar that has two geometry changes, (2) the stress in a cantilevered aluminum tube under combined bending and torsional loading, and (3) the stress distributions in steel round bars with various geometry changes, such as holes, grooves, and fillets (Figure 2), and observe the stress-strain patterns of loaded components via photoelastic methods.

The purpose of the experiment is for students to (1) experiment with methods used for measuring strain and determining stress, (2) investigate stress and strain relationships for loading bending, torsion, and combined loading, and (3) explore the effects of static stress concentrations in machine components.

3. Fits and Tolerances

This experiment investigates press fits of shafts and hubs. Students are presented with a precision ground rod and three coupler hubs, each with a slightly different hole diameter (Figure 3). By inserting the rod into the hole of each coupler hub, different press fits are achieved. Students make dimensional measurements and use the Limits and Fits Tables in machine design handbooks and equations to find the maximum tangential and radial stresses that develop between the hub and shaft and the torque carrying capacity of the different fits. Students also press fit an aluminum rod into a hole in a steel plate using an arbor press with a load cell attached to the ram. Students compare the measured force needed for the press-fit with a predicted force from classical pressure vessel theory.

The purpose of the experiment is for students to (1) gain practical experience with press and shrink fits, (2) to become familiar with the use of different classifications for fits, (3) to gain experience in designing and assembling a press fit, and (4) to apply pressure vessel theory to predict stresses in interference fits.

4. Gears

Students examine gears in different machine systems including a commercial gear box, a motorcycle engine transmission, and small geared motors (Figure 4). Students use the torque-speed tradeoff of gears to accomplish desired tasks, giving them experience with the fundamentals of gears and the design of gear assemblies. The experiment has multiple activities, including the determination of transmission ratios, familiarization with different types of gears, and design of gear-train systems. Students identify different types of gears (spur, helical, worm, bevel, etc.) and the applications suited for each type. They investigate gear trains in machines to obtain transmission ratios and comment on design decisions (why a spur gear was chosen and not a helical gear, why different materials were used for the gears, why the sizes chosen were selected, which gear might fail first, etc.)

The purpose of the experiment is for students to (1) become familiar with types of gears used in machine systems, (2) gain experience selecting appropriate gears from catalogs for specific applications, (3) understand the kinematics and kinetics of simple and compound gears, and (4) design and analyze simple transmissions, appreciating space and assembly constraints. Students also design and build a gear-driven clock mechanism. They use CAD software to create their designs, and then manufacture the gears using rapid prototyping 3D printers. Students assemble the gear trains and test the accuracy of their clocks (Figure 5).

5. Flexible Components

This experiment investigates flexible components – roller chains, mechanical belts, and wire rope – used to transmit power and introduce compliance that plays a role in vibration isolation. Students classify different types and sizes of wire rope, belts (V and timing), and roller chain. They study the design of the chain drive connecting the crankshaft and the transmission in a motorcycle engine and of a double banded belt drive system. Students investigate the force carrying ability of a belt on a sheave (Figure 6). They measure the tight and slack side tensions of the belt as a function of angle of belt wrap. Students assemble a chain drive system given a set of sprockets and a desired transmission ratio. They select appropriate sprockets and determine the number of stages and sprocket center distances. They then cut an appropriate chain length, and assemble and test their system.

The purpose of the experiment is for students to (1) become familiar with flexible components in machine systems, (2) gain experience identifying and selecting flexible machine elements from catalogs for specific applications, (3) understand the design process for a flexible component system, and (4) give students an opportunity to interact with chains, belts, wire rope.

6. Bearings

This experiment introduces students to bearings used in mechanical systems and provides experience in calculating the expected life of a bearing. The activities focus primarily on rolling contact bearings, although students identify other types of bearings (ball, needle, etc.) and learn their specific parts. Students spin a flywheel that is mounted on a shaft supported by two bearings secured in housings (Figure 7). They listen and place their hands on the bearing housings to feel any vibrations. They then swap out the bearings and again listen and sense vibrations, noting differences between new and worn bearings. Students also calculate bearing fatigue life using a web-based life calculator and investigate bearings in commercial gearboxes and a motorcycle transmission.

The purpose of the experiment is for students to (1) become familiar with bearings used in machine systems, and (2) gain experience selecting appropriate bearings from manufacturers' catalogs for a given application.

7. Bolts

In this experiment, students explore the use of bolts as fasteners. Students are presented with different bolts, a bolt grade chart, and thread pitch gauges, and are asked to identify and grade the bolts. A test fixture is used to measure the clamping force using a torque wrench (Figure 8). Students clamp bolts using different methods to determine if the proper preload (clamping force) has been achieved. Bolts are also over-clamped to show the importance of properly tightening fasteners. Students intentionally over-torque bolts to observe what happens to the bolt and the parts being clamped.

The purpose of the experiment is for students to (1) gain experience with fasteners and torque wrenches, (2) become familiar with common thread sizes of fasteners, (3) investigate the strength properties of different grades of bolts, (4) measure clamping force and assess proper torquing, and (5) observe the effects of over-torquing.

4. Remote Access Experiments

Two remote access experiments are proposed. The first experiment is a subset of Experiment 4 above; the second experiment is a subset of Experiment 2 above. Based on the assessment of the effectiveness and success of these experiments, other experiments would be adapted for remote access.

Remote Access Experiment #1

In a first remote access experiment, local and remote-access students would collaborate in the design of gear clock mechanisms. Students at both locations would be given specifications including a known input shaft speed, size (and possibly weight) limitations, and a budget. Using CAD tools, students at both locations would collaborate to design geared clock mechanisms that show seconds, minutes, and hours. This would require the students to interact and face real-world challenges in communication to resolve differences and optimize designs. Next, all students would send CAD files to Marquette where two sets of the gears would be fabricated using rapid prototyping 3D printers. One set of gears would be sent to the remote students; one set would remain with the local students. Each group of students would assemble the gears, which requires decisions on how to mount the gears on a frame, and then test their clock designs for accuracy and operational difficulties. Finally, the local and remote-access students would discuss the project lessons and suggest improvements to their designs and assemblies.

Remote Access Experiment #2

In a second experiment, remote-access students would make stress-strain measurements of loaded shafts. The experimental hardware would be located at Marquette, where a teleoperated robotic system would apply loading to shafts in a specialized test-rig. The system would be actively controlled over the internet by remote students, who would observe real-time measurements of strain gage readings on the shafts as a function of the imposed loading. Students would learn about bending, torsion, and combined loading, and be able to compare theoretical predictions with data collected remotely.

The long-term goal is to offer a suite of machine design experiments that can be conducted semi-autonomously via remote access by students anywhere in the globe with access to the internet. To test the feasibility of remote access and understand its challenges, we propose two intermediate steps: (1) developing and testing software tools to ensure successful data communication necessary for remote-access using the design of geared clock mechanisms as the trial case (that is, remote access experiment #1), and (2) designing and developing a system for teleoperation that would be used for active control of machine design experiments, such as in measuring stress-strain due to static loading of shafts with shoulders, holes, etc. (that is, remote access experiment #2). These steps are described below.

Communication Needs for Remote Access.

For successful remote access, several communication-related questions must be addressed. How would data files (CAD and design files, programs, etc.) be shared? What file formats and file sizes would be acceptable? What documentation for users would be needed? What bandwidth would allow for smooth video interaction (and for teleoperation)? How would queues be handled (to avoid people simultaneously working on design files)?

To answer these communication questions, a pilot study would be conducted locally. This activity would lead to guidelines and a software system on a local server to ensure successful communication needed for remote access for the experiments.

Teleoperation Needs for Remote Access

To remotely operate lab equipment and implement the commands of remote students, it would be possible – although not ideal – to rely on humans (in teleoperation terms, with the local students being ‘slaves’ and the remote students being ‘masters’). This would be manually intensive and not fulfill the long-term goal of achieving a semi-autonomous system, with remote commands implemented through active control of hardware locally. Toward this end, a teleoperation system consisting of hardware with integrated software would be created. In a simple design, it may be a one or two degree-of-freedom robotic system with end-effectors that apply loads. In more advanced designs, it may be end-effectors that manipulate and assemble machine components. The software for effective ‘human-machine’ interaction tailored for machine design experiments would also need to be developed.

These two steps, which could be pursued in parallel, would require a budget (estimated to be $50,000) to cover costs for hardware, software, and personnel.

5. Conclusion

This paper describes the details of experiments and pedagogical approaches that foster student learning in a new Machine Design Laboratory at Marquette University. The educational benefits to students include (1) hands-on learning in a laboratory environment with real-world hardware, (2) directed and open-ended machine design challenges that promote active-learning and force out-of-the-box thinking, and (3) experience working in teams. The experiments provide students the opportunity to apply classroom learning in a real, functioning environment. The laboratory activities attempt to teach students the importance of logical thinking as well as develop intuition for the selection of different machine element components. The experiments are predicated on student-centered learning methods that are the cornerstone of modern engineering education practice.

The long-term objective is to enable students globally to participate in the experiments. To achieve this goal, the project would be implemented in stages. First, the experimental protocol would be tested at Marquette to debug issues related to remote access. This step would uncover the pitfalls before engaging global partners. Second, one or two partners who have interest in helping develop the system need to be identified. Third, a feasibility test would be conducted to further debug issues of remote access. Finally, multiple partners would be sought to engage with Marquette students in conducting machine design experiments.

Many educational institutions do not have the resources to support laboratories or purchase equipment integral to the education of next-generation engineers. Marquette University is looking to partner with a few such institutions to offer deserving students meaningful machine design laboratory experiences via remote access.

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Figure 1: Investigating the operation of a drill-press in Experiment 1.

Figure 2: Measuring strain in round stock with stress concentrations in Experiment 2.

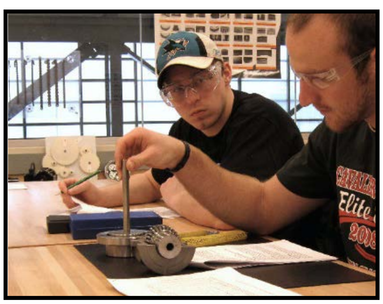

Figure 3: Checking fit of ground rod in Experiment 3.

Figure 4: Counting gear teeth in HVAC baffle drive in Experiment 4.

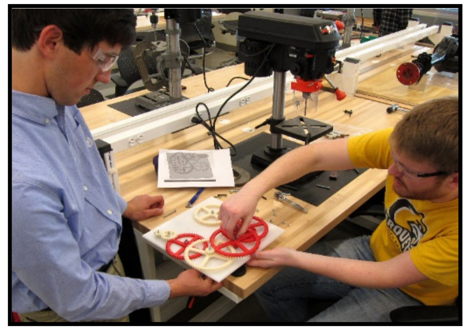

Figure 5: Assembling gear-driven clock mechanisms in Experiment 4.

Figure 6: Investigating belt tension in Experiment 5.

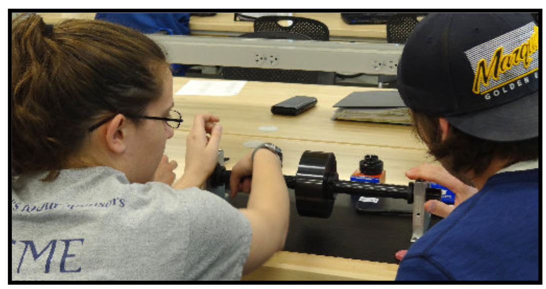

Figure 7: Investigating bearing operation in Experiment 6.

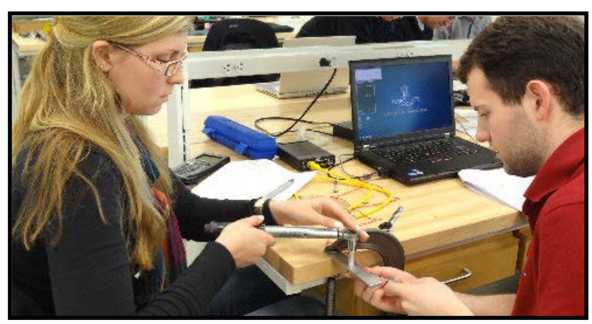

Figure 8: Measuring bolt clamping force in Experiment 7.