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Interconnected Laboratory Modules in Metrology, Quality Control and Prototyping area Courses: Lessons Learned and Laboratory Modules Assessment

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(Overview of the Project Outcomes)

Introduction

As manufacturing industry faces new challenges related to redefining its role and scope in US and western civilizations, manufacturing education in moreover confronted with adapting to the new face of manufacturing and with improving teaching and learning effectiveness in both online and in-class courses and training. The major objectives of our project are to design and use hardware and software based CNC machine control simulator systems to enhance the cognitive learning of online laboratories and design and use of simulator interfaces for metrology and quality control systems to enhance the cognitive learning of online labs. The major outcomes of the project are: 1) Facilitate student exposure to potential careers in the area of manufacturing technology and CN, while improving the precision metrology skills shortages by incorporating current advances in CNC technology and engineering metrology into the undergraduate/adult learning environment. The emphasis is placed on the laboratory activities and projects to simulate innovative design, analysis, process simulation, and prototyping and improvement cycle. 2) Using Project Centered Learning (PCL) pedagogy in the learning modules, students are developing skills to confront ambiguity and uncertainty that are expected and are integral part of the solving engineering problems.

We briefly discuss the implementation and integration of our laboratory activities (learning modules and tutorials) that provide students with a realistic interaction with CNC machine in the area of prototyping, metrology, quality control and quality assurance, both at undergraduate and graduate level in our Drexel University Engineering Technology curricula. Through the developed and implemented experimental settings during this project, we are engaging students in both on-site and online/remote laboratory experiments. Although the latter is still a desiderate of this project, the onsite modules have been fully developed, tested and implemented, all of the modules being an integrant part of our current curricula for several courses that were impacted by this project.

Virtual, remote or hands-on laboratories by themselves cannot guarantee successful student learning outcomes; each has its advantages and disadvantages. Virtual labs offer cost savings and active learning, but they are not real and present limited opportunities for trial and error. Remote labs provide real experiments with real equipment at lower cost but lack the “feel” of handling real equipment and can be less engaging. Onsite labs offer hands-on experience and problem-solving opportunities but are costly, less flexible and fail to provide access and ease of use for the disabled and distance learners. The literature review cited here suggests that a "mixture of elements might be superior to any single technology." A key aspect of our project, therefore, is to use and improve the our onsite laboratory with the High Speed CNC components, to enhance student lab experiences by allowing them to perform real laboratory experiments and tasks that both reinforce and assess what they've learned in their virtual lab studies in less time and with less risk than would normally be present. Our strategy based on virtual-labs-to-onsite-labs approach is focused on increasing the students' efficiency while performing physical laboratory activities by shifting the center of attention towards the learning objectives of the laboratory rather than on "how to do the laboratory."

This paper presents the overall integrative approach of advancement, development and implementation of our state-of-the-art offline and online learning environment to support and enhance students' learning and training as they use simulated systems to design and conduct virtual and real-time machining experiments and calibration of precision machine tools.

In the sections to follow, we present a comprehensive assessment and evaluation plan and its outcomes, guided by five foundational evaluation questions, designed to focus data collection and analysis on a) the project's stated objectives and outcomes, b) broader issues such as dissemination of project information and activities, and c) sustainability of project components beyond the life of the grant.

Also we have an overview of the interdisciplinary aspects of our project and how this was used to enhance student learning and perspective over their educational journey. This paper is centered on assessment of the student learning outcomes as main end-goal of our project, during the 3-year project life. Sustainability of the project will be correspondingly presented here, including the life beyond the grant of the project. The accomplishments of the long term objectives of our project are and will continue to be included in the project web page for the re-developed courses carrying the course modules and lectures in a PDF format and Lecture PowerPoint presentations for students and other users to browse and download from any location using remote desktop and virtual lab server. The interactive components, simulations and laboratory experiments are available for other universities and Drexel University-affiliated colleges. Online learning will be a channel for use of the developed materials and also their dissemination.

Curricular developments and integrative approach

Senior Design Project Course Sequence

One of the most impacted courses by this project is Drexel University Engineering Technology MET 421/422/423 (Senior Project Design) - a sequence of three-quarter capstone project design courses required for all the BSET concentrations. The goal of these courses is to demonstrate the ability to manage a major project involving the design and implementation of products with a mixture of electrical and mechanical elements as a member of a product development team. Several projects that were conducted by our ET students were employing the capabilities of the above equipment and tools acquired or developed with the help of this project. One of the examples of such projects is a 2014 SME Senior design competition award winning that aimed at developing a 3D printer that will bring a new twist to the field of 3D printing - conductivity. This project was sponsored by our grant up to $1000 and has the following goals:

- The ability to print with a low-resistivity polymer such that we could 3D print a simple flashlight with integrated wires and resistors.
- To be able to print quality 3D objects in a large build envelope of 500 mm x 500 mm x 500 mm without warping.
- To reduce the cost of 3D filament so that large objects could be printed for a reasonable cost.
- Target cost is less expensive than professional machines.

(a) (b) (c)

Figure 1. Various components of the 3D printer. (a) Filament extruder (b) Printer frame (c) Extruder head design patent (US Patent No. 61/904,868, 2013 - Patent Pending)

Other capstone or term projects have been impacted by the outcomes of this project, directly or indirectly during the past three academic years, such as remote operated latch system or micro-piezo-electric mixing pump. Overall the courses related to prototyping and manufacturing were mostly impacted and therefore creating the experiential framework for students to be able to undertake more challenging topics. However, the experiential and knowledge scaffolding was created by the lower level core curriculum courses in the area of measurement, instrumentation and quality control. Since our curricula is primarily based on integrated experiential learning presented in a hybrid format – seamless combination of lecture and laboratory activity, where the theoretical preparation is supported and enhanced by experimental components, interdisciplinary approach is an integrant part of all our courses. Moreover, our program is hosting one major – Engineering Technology - with four concentrations: mechanical, electrical, bio-engineering and industrial engineering technology. Our core curriculum is created to sustain all these concentrations, therefore our emphasis on interdisciplinary approach.

Measurement and Instrumentation Techniques course incorporated about five laboratory experiments as a part of the project, based on Coordinate Measuring Machine and using the HAAS CNC Mill and Renishaw QC20-W (Wireless) Ballbar System and Renishaw XL-80 Laser Interferometer System (angular pitch and yaw, and linear momentum). The educational modules encompass five lab manuals that will walk the students through the procedures as well as guide them on how to interpret the data they recorded. A partial tutorial example is presented below.

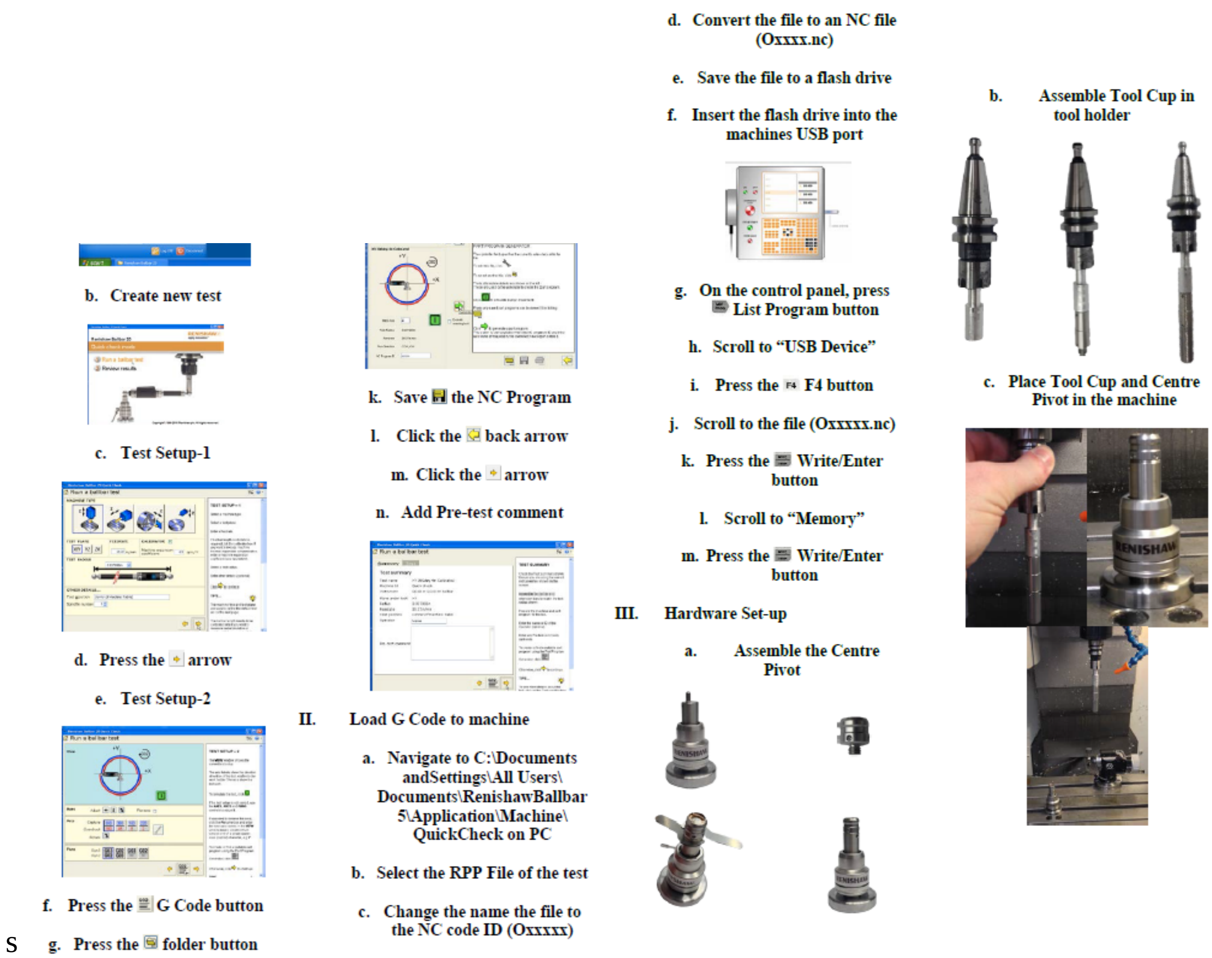

Figure 2: Tutorial example for lab manuals

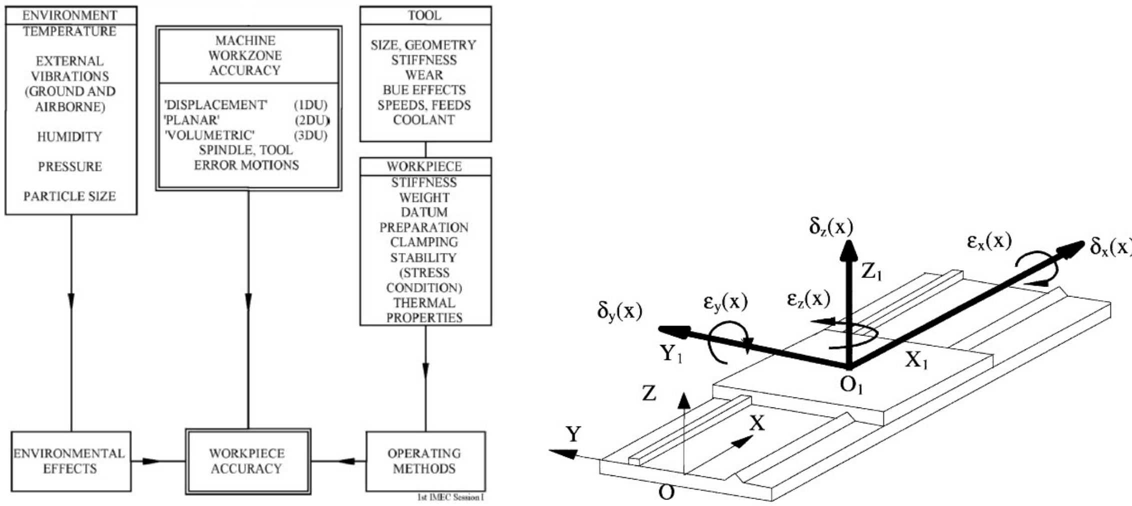

Figure 3: Overall machine total errors

Students were administered questionnaires regarding these five laboratory activities. The survey is summarized in the questions below. Answers were presented on a Likert type scale

5 = Strongly Agree , 4 = Agree; 3= Disagree; 2 = Strongly disagree 1 = N/A.

1. How much did this course contribute to your understanding of how Precision and Accuracy of Machine tools are assessed?
2. How much did this course contribute to your understanding of how Renishaw Ballbar system work?
3. How much did this course contribute to your understanding of how Renishaw Laser system work?
4. How much did this course contribute to your understanding of CMM system?
5. How much did the term project contribute to your ability to work in teams?

1. How much did you enjoy term project part of the course?
2. I want more hands on use of CNC machine calibration tool Renishaw Ballbar in this course
3. I want more hands on use of CNC machine calibration tool Renishaw Laser systems in this course
4. I want more hands on use of CMM system in this course
5. If we had video instructions on use of Renishaw Ballbar, Laser and CMM systems, this will improve your learning in this course
6. If your answer 5 or 4 to question 1and 2, what will be ideal ratio of use of Renishaw Ballbar to Renishaw Laser? (circle one)

50-50% 70-30% 80-20% 50-50% 30-70% 20-80%

This type of surveys was administered for three Measurement and Instrumentation course during AY 2012-2013 and AY 2013-2014. Students on average scored the lab activities in the range of 4.1 to 4.3 out of max 5.0 possible based on this survey. The students 'comments were very important for assessing our project as they pointed towards the strengths and the weaknesses of these experiments. While the strengths pointed towards the real-life industrial grade scenarios presented and the valuable skills acquired by students, the weakest part was the need of having more working stations so more students can have this experience at the same time. These experiments tend to be lengthy and since we have one station, the lab might appear to some students as more demonstrative than hands-on. We are in process of addressing this issue by combining these activities with other at the same time so we may be able to rotate students in smaller groups. In this way more students can get the hands-on part.

Measurement and Instrumentation course uses a variety of sensors and measurement techniques to monitor machining processes (sensors including vibration, acoustic emission, cutting dynamometers). Data acquisition and processing for tool breakage and quality control of machined parts has been added to the course curriculum. This course is a core curriculum course for all concentration for BSET. Similarly Quality Control course is a core curriculum one. Both of them include laboratory experiments based on the equipment and instrumentation provided by the funding of this project. The manufacturing and prototyping related courses reflect the competitive trend in the evolution of manufacturing towards increased flexibility, high speed machining, remote quality control, sensors, and Internet-based information and communication technologies using CNC systems and simulators. Students study parametric programming techniques to run in-process gauging and tool setting probes. The students will convert a CNC machine tool into a coordinate measuring machine, which will eliminate post-process part inspection. This technology is becoming a common practice in discrete part manufacturing industries. Students will measure the effects of the thermal status of the machine tool on the machining accuracy of the machine tool. Student teams conduct experiments to check calibration of the machine tools using ballbar & laser calibration equipment purchased through the NSF grant.

Based on these modules and lecture based educational components we were able to expand the competencies included in about seven undergraduate and graduate courses offered at our ET program. That had a ripple effect towards courses that were not directly linked to the main goals of this project. Students undertook projects that integrated the valuable knowledge of these new and improved courses and implemented them in areas of microcontrollers, fuel cells, micro-fluidics.

Assessment for Online/Offline Laboratory Learning

A comprehensive assessment and evaluation plan was incorporated throughout the entire project. Such plan contemplated several quantitative and qualitative measurements to be used as feeders for necessary calibration and adjustment of the different components of the project. The results of the assessment and evaluation may also, ultimately provide important baseline data to be used in investigating curricular reforms by identifying the strengths and weaknesses of those students enrolling in the ET courses. The assessment and evaluation plan is an iterative process to assure continuous quality improvement for ultimately accomplishing the project's goals. Formative assessment was performed through tests and questionnaires and by systematically collecting feedback from students and faculty. Improving learning through formative assessment depends basically on three key factors: (1) effective feedback to students; (2) active involvement of students in their own learning; and (3) adjusting teaching to take into account the results of assessment. The ultimate user of assessment information that is elicited in order to improve learning is the student. The assessment for this project incorporates these principles and will be made explicit so that it may be replicated for online/offline virtual laboratory experiences beyond this initiative.

Formative assessment to be incorporated in this research offers three advantages: (1) students are immediately aware of whether or not they answered a question correctly because the correct response is immediately communicated. Therefore, they know right away, what they do and do not know; (2) instructors can look at results and immediately make instructional corrections for individual students or groups of students; and (3) instructors also know what individual students do not know, so essential communication can take place immediately regarding closing learning gaps. The beauty of online protocols is that it makes the administration of frequent tests easy. Information is available instantaneously to both student and teacher for correcting instruction and enhancing learning. Summative Assessment in the form of final exams, projects and student portfolios will be used as exit competency tests or end-of-course assessments. The questionnaires along with randomly selected interviews will ask students to evaluate their overall experience about the experiments, adequacy of laboratory setups, and their suggestions for improvement. Faculty will assess this new pedagogy in terms of their effort, attitude, motivation, and opportunity to use their creativity to identify and solve problems arising from the project.

Cognitive assessment was made through the exams, projects and laboratory reports. Pre-testing was administered during the first lecture for all courses involved to measure what students are expected to know prior to taking the course. The final exam reflects content objectives and expected student knowledge acquisition from the course. The pre-test will include the most missed items on the previous final exams, and the final exams assess the content objectives and expected student knowledge acquisition from the courses. A Likert type scale questionnaire will measure how students feel about aspects of the project. At this stage we concluded that courses improved over the course of the last 2-3 academic years, mainly due to increased industry relevant hands-on activities. The improved courses offered gave students the opportunity to enhance their competencies. Analyzing also the feedback received from our co-op employers regarding our students, we noticed that our students were receiving better evaluations from their respective employers due to their enhanced skills and overall preparation.

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