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Integration of an Experiential Assembly System Engineering Laboratory Module*

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Curriculum integration and multidisciplinary studies have become key issues in improving engineering education. This paper presents the design and implementation of laboratory material, based on active and collaborative learning, which integrates three traditionally independent courses in the industrial engineering curriculum: Manufacturing Engineering, Ergonomics, and Simulation, utilizing an experiential assembly system. This collaborative project incorporates a team-based learn-by-doing approach to the theoretical knowledge in these subject areas. These components are implemented in a dynamic and reconfigurable environment in which the students are given the opportunity to contrast their design against the working reality. The preliminary results of this project are discussed along with the impact on the curriculum.

Keywords: active learning; collaborative learning; assembly laboratory

INTRODUCTION

IN INDUSTRY, there is a constantly growing need for engineers who possess both academic and technical proficiencies. Meeting this need requires different and more innovative ways to impart knowledge. Traditional lecturing is an excellent mechanism for delivering large amounts of information but it also encourages passivity in students and compromises their interaction in class. This also dulls student creativity since the instructor is expected to provide all the necessary material and ideas. On the other hand, traditional laboratory experiences tend to be very focused and rigid on a specific topic, consequently lacking an integrative approach that comprises different fields of academic instruction. The aim of this paper is to present a collaborative effort to develop an interactive laboratory module that integrates course material from three traditionally independent areas within industrial engineering.

The development of this project is soundly rooted in proven learning methods including active learning, collaborative learning, and curriculum integration. Active learning, in which students perform activities beyond listening to a lecture and taking notes, has been effective in learning and applying course material [1]. Essentially, active learning is a learn-by-doing approach that results in one of the highest percentages of knowledge retention [2]. Cooperative learning, where students interact and learn from one another, has been shown to result in higher information retention, improved teamwork, better development of interpersonal skills, better attitude towards subject matter, and lower levels of anxiety [1, 3]. Johnson *et al* [4], found that one of the reasons for the higher retention achieved in cooperative learning approaches is due to cognitive rehearsal, in which students (like professors) learn best when they teach the subject. Felder *et al* [5] conducted a longitudinal study in which cooperative learning students outperformed a traditionally taught group on a number of measures, including retention and graduation rates. Johnson *et al* [3] synthesized research on the effectiveness of collaborative learning and found that, compared with traditional, independent learning, collaboration improved nearly all measured learning outcomes.

Curriculum integration and multidisciplinary studies have also become focus areas in improving engineering education [6, 7], as the role of the engineer has evolved from lone specialist to team player. In an effort to reflect this dynamic role of the engineer, educators have found benefit in utilizing a multidisciplinary approach in the classroom [8, 9]. The objective of this work is to use these ideas of active learning, cooperative learning, and curriculum integration to develop systemic thinking skills that require analysis, synthesis, and evaluation methods to solve engineering problems. This effort involves the collaboration of faculty to develop integrated laboratory-based teaching modules in the areas of manufacturing, ergonomics, and simulation that utilize a common experimental assembly system [10]. The manufacturing module addresses assembly systems engineering issues, production volume and rate considerations, and assembly quality considerations. The ergonomics component focuses on evaluating the physical demands of the system and how these relate to the physical capabilities and attributes of the human worker. The simulation

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component focuses on creating computer-based simulation models of the system, conducting experiments on the model, and drawing conclusions from the model about the behavior of the real system. All these components are implemented in a dynamic and reconfigurable environment in which the students are given the opportunity of contrasting their designs against the working reality. The uniqueness of this project resides in providing concurrent development of hands-on material for three core areas of industrial engineering in a common arena.

MOTIVATION AND TARGETED LEARNERS

The basic motivation for undertaking this project was to strengthen the industrial engineering curriculum at Rochester Institute of Technology (RIT). To do this, a more integrated approach was sought for teaching courses such as manufacturing, ergonomics, and simulation, which are traditionally thought of as independent topics within the curriculum. Furthermore, the aim of the experiential setup was to allow the incorporation of a multidisciplinary and team-based learn-by-doing approach to the theoretical knowledge in the areas of manufacturing, simulation and ergonomics and their interrelationship by being exposed to all the different facets for which industrial engineering may be applied in analyzing an assembly system.

Typically, a graduate from an industrial engineering program is expected to perform and contribute in all the areas mentioned above, sometimes in a common arena. However, the instruction provided to the students in undergraduate industrial engineering programs is usually isolated by course and without a strong and explicit connection across courses. This integrated approach provides the student with the opportunity of looking at the same process from three different perspectives, thus imitating real working environments. Additionally, the hands-on approach and open-ended nature of this experience could result in a more effective way of communicating and instructing, as well as improved the students' knowledge retention and assimilation. A higher level of student motivation and involvement was one of the expected outcomes since this interactive approach tends to be more appealing to the student.

The targeted student population includes all undergraduate students in the third and fourth year of Industrial and Systems Engineering at RIT (note that this program is a 5-year program which includes 1 year of mandatory co-op experience, and the academic year follows a quarter system). Under the current curriculum, students take courses in manufacturing engineering and ergonomics during the third year and simulation during their fourth year.

LABORATORY EXPERIENCE

Laboratory-based teaching modules are the means by which traditionally independent aspects of the industrial engineering curriculum are integrated to engage students in higher levels of systemic thinking and knowledge retention. Namely, the laboratory activity involves a common reconfigurable assembly system that students analyze using tools and concepts from each of three required undergraduate ISE courses: Manufacturing Engineering, Ergonomics, and Simulation. For each class students analyze the assembly case study, determine the best process and work station layout in light of their analysis, and then conduct an actual production run to evaluate the design. During this production run students have the opportunity to contrast their design with the actual operation of the system to identify shortcomings in the initial design or to verify that the system objectives have been met.

The assembly setup utilized in this application consists of four tubular-aluminum workstations linked by a manual, dual-track conveyor. This system is configurable in the following layouts: straight line, L-shape, U-shape, and closed loop (oval). The dual track system provides a dedicated return track for the roller pallets. Each workstation has a half-moon working surface for easy reach to the overhead accessories. Accessories such as bins, shelves, flow-through and push-back racks, light fixtures, tool balancers, status lights, etc., are used to provide an efficient and realistic assembly environment. Figure 1 shows the assembly system in use during the project.

If desired, the basic assembly line described above can be expanded to accommodate more complex products that may require additional stations or simply to allow creative design scenarios developed by student teams. This is accomplished by using a passive (gravity) Hytrol roller conveyor and by building additional assembly stations and fixtures on-site with modular plastic-coated steel tubing on and around the conveyor.

Fig. 1. Experiential assembly system.

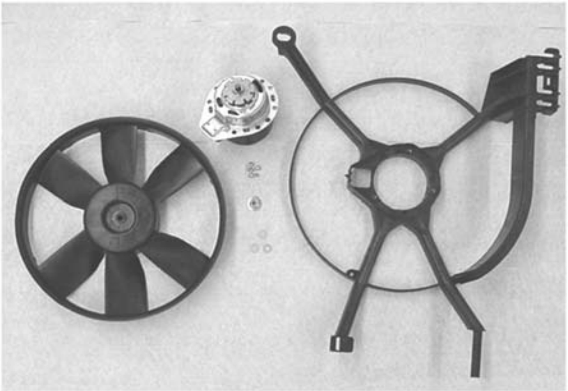

Fig. 2. Individual components of fan assembly.

Fig. 3. Automobile radiator fan assembly on a roller pallet.

The case study used in this experience is an automobile radiator fan assembly shown in Figs 2 and 3. This consists of fifty assemblies donated by a local, first-tier automotive supplier. The assembly consists of a base shroud, a motor subassembly, a 3-blade fan, three $\frac{1}{4}$"-20 flat screws with washers, and a reverse-thread wing nut. Assembly fixtures were manufactured in-house and attached to the roller pallets to facilitate the assembly process and provide stability during transportation. Other product cases that have been developed include power tools, computers, and automotive assemblies such as gear boxes and transmissions.

The entire system is modular and very easy to reconfigure in less that one-half hour. The line can be laid out and connected and the workstations can be modified (i.e. type and location of bins, tools, etc.) in a short time. Each station is equipped with barcode readers and flat screen monitors which, in conjunction with a database, allow for work instruction display and mixed production runs. Custom-developed software allows for monitoring of the line status and students are able to track metrics such as: job location and cycle time, throughput, WIP accumulation, queue size per station, idle time, station utilization, etc.

Under this environment, the students are able to study the product (dissection and reverse engineering), study the assembly process (task division and precedence, time study, workstation design, computer simulation, etc.), design several alternatives of the entire process (line layout, number and type of workstations, pace of assembly, etc), implement the best design, and conclude the activity with a real pilot run on the line. Furthermore, this flexible system allows for different groups to design and implement different solutions.

LABORATORY MODULES

Each of the three laboratory modules was conducted during the academic quarter in which the corresponding class was taught. Each of these modules is described separately below.

Manufacturing

The manufacturing module is offered as part of the undergraduate mandatory course 'Manufacturing Engineering' for all ISE students. During this course, the students are walked through the manufacturing sequence of such product as shown in Fig. 4.

At this stage of assembly, the students are sufficiently familiar with the individual parts composing the assembly and the issues around them (i.e. manufacturing processes, materials, etc.). The manufacturing component addresses assembly systems engineering issues (e.g. product dissection, component examination, task analysis and design, assembly time study, line balancing, number of workstations, line layout, etc.), production volume and rate considerations (e.g. bottlenecks, line pacing, etc.) and assembly quality considerations (e.g. non-conforming fraction, defects rate, etc.). In this interactive environment, students physically explore an open-ended, sequential thinking process that takes them from design to implementation. Students develop several different ways to assemble the product, document the steps and tools involved in the process, design and pace the assembly line to meet a target production, and discover the differences between different layout configurations.

The students then implement the chosen design and, more importantly, measure the impact of their design decisions by performing a pilot one-hour production run. During this time, they simu-

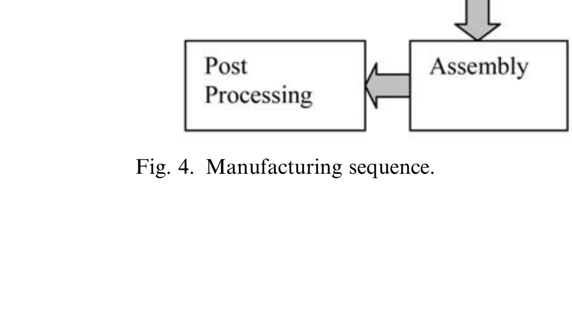

Fig. 4. Manufacturing sequence.

late three 20-minute shifts and rotate around workstations. Data recorded on a continuous basis include throughput and number of defective assemblies. Data on the status of the system are collected every five minutes. This includes the state of the line such as workstation utilization, accumulations on queue, starving workstations, blocked workstation and WIP in system. A discussion at the end of the experience reflects upon the discrepancies between the theoretical and actual performance.

Ergonomics

The Ergonomics component of the project analyzes the relationship between the physical dimensions of the workstation and the anthropometric characteristics of the target 'worker' population, who for the purposes of the lab is represented by the students in class. Students perform anthropometric measurements on the class as well as measurements of the vertical and horizontal location of the parts bin. Then by comparing the reach dimensions of the workers with the layout of the workstation, students are able to assess the compatibility and recommend design modifications.

Since the Ergonomics module takes place the quarter after the Manufacturing and Simulation modules, videotape obtained during the previous quarter is used to reacquaint the students with the assembly process prior to data collection. The video is used as a basis for introducing the problem and discussing the students' impressions and observations of how well the workstations fit them. The first part of the data collection requires the students to conduct an anthropometric survey of the class. Using meter sticks and tape measures, students identified the appropriate anatomical landmarks on each other and measure anthropometric variables such as stature, knee height, and wrist-wall length, among many others. Students then obtain measurement of the vertical and horizontal location of the parts bin used in the assembly operation. Using these data, students then prepare an overlay plot of the workstation dimensions along with the horizontal and vertical reach envelopes in the sagittal plane for a 5th percentile female and a 95th percentile male. From these diagrams students are able to evaluate the suitability of the workstation design by observing the overlap (or lack thereof) between the reach envelopes and the work location. To report their results students prepare a written laboratory report, complete with sketches of the workers and workstations before and after redesign.

Simulation

The simulation component of this project includes all aspects of a simulation study from start to finish. The students are shown the reconfigurable assembly/material handling system and the products that are to be assembled. The students are also given the very general task of designing an efficient assembly system, and they are given approximately five weeks to complete the entire project.

Following the steps of the simulation study taught in the lecture, the first step is to define the problem, its scope, and measures of performance. That is, the students defined what is considered to be an efficient assembly system. For this system, an efficient system is defined as one that results in high throughput, low cycle times, low work-in-process inventory, and low cost. The next step is to apply techniques taught in the manufacturing class to break down the assembly process into individual tasks and collect data on the time to perform each task. Using distribution fitting software, probability distributions are fitted to the assembly times for each task to be used as input to the simulation model. Using simulation software, a simulation model of the system is constructed for each alternative system configuration that the students identify. The simulation models are verified and validated using techniques such as traces, structured walkthroughs of the model, etc. After designing a set of experiments (determining the number of replications, length of replications, etc.), the simulation models are run and the output of the simulation runs are analyzed by constructing confidence intervals on the output performance measures. The system configurations were compared both from a statistical point of view and from a practical, engineering perspective. The students then make a recommendation for the most efficient assembly system design. Note that among the factors influencing the decision about the most efficient system are ergonomic factors such as personal time allowances when considering the utilization of the workers.

The entire simulation study is documented in the form of a web-page, which allows for the inclusion of the simulation models, data files, etc. as part of the final report and allows other students to view and learn from the project. Finally, the students in the simulation course give a presentation to the students in the manufacturing course who, in turn, implement the recommended system configuration in a pilot production run.

RESULTS AND OBSERVATIONS

In addition to the regular student evaluation form required by the college, an independent questionnaire was distributed among the students at the end of the fall quarter. The population size was 24 students and the total number of responses (returned questionnaires) was 23.

Some of the results from this survey include:

- 15 students ranked this assembly experience in the top two activities they liked the most overall.
- 20 students agreed they were more likely to remember the content delivered in these courses because of this experience.

- When compared to other traditionally-taught courses they had previously taken, 23 students preferred this approach over the traditional one.

Aside from the survey results, several other outcomes were observed or realized:

- Students actively participated (with enthusiasm) in all aspects of the laboratory.
- The interrelationships among manufacturing, ergonomics, and simulation issues were emphasized.
- Having been exposed to the assembly system in one class, time was saved by not needing to reorient or introduce the students to the system.
- The use of the assembly system is also being integrated into an introductory course to IE to study and demonstrate the topic of work measurement.

As we continue to utilize these laboratory modules we expect that other benefits will be realized. Additionally, we will use more surveys to assess the effectiveness of the modules.

FUTURE WORK

The approach described in this paper has resulted in successful collaborations with industry. A leading automotive manufacturer, which traditionally hires student from this program, has recently funded an expansion and further development of the laboratory. The plan calls for developing a flexible Production Systems Lab, where students get both exposure to global concepts and philosophies (e.g. supply chain) and local methods and techniques (e.g. material handling, line balancing, order picking, etc.). This includes development of a supplier area, raw material storage area, warehousing and picking area, and a customer area. The products to be used are mainly automotive components supplied by the company and the processes and methods are to be developed and integrated with the input from the automotive engineers. Simultaneously, the manufacturing course is being redesigned to incorporate these changes into the course content. It is anticipated that these changes and expansions will be completed for the Spring quarter of 2008.

CONCLUSION

In summary, the implementation of the experiential assembly system has fostered the integration of three traditionally independent areas of industrial engineering, manufacturing, ergonomics, and simulation. Through the development of these three laboratory modules, students are provided with a hand-on approach to these subjects where they can fully and actively participate in all aspects of the design and implementation of the assembly system. Further, the interrelationships among manufacturing, ergonomics, and simulation in terms of their impact on design and implementation can be integrated in a common arena. Finally, this project can serve as a template for the integration of curriculum topics of other disciplines.

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