AC 2012-3800: A FIRST-YEAR DESIGN PROJECT SOFTWARE TOOL TO EMPHASIZE PROBLEM SOLVING WITH COMPUTER PROGRAMMING IN THE DESIGN PROCESS

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A First-year Design Project Software Tool to Emphasize Problem Solving with Computer Programming in the Design Process

Abstract

The Engineering Education Innovation Center (EEIC) has offered, through its Fundamentals for Engineering, Fundamentals for Engineering for Scholars, and Fundamentals for Engineering for Honors course sequences, several hands-on laboratory experiences for first year engineering students that culminate in a quarter-long design-build project. The course sequences retain the traditional material covered - engineering orientation, engineering graphics, and engineering problem solving with computer programming while offering several design-build project topics. One important objective for the first-year design projects, commonly called cornerstone projects, is to provide a team-based experience that includes all aspects of engineering design and development. This objective also includes successfully providing students with awareness of, and experience with, the iterative nature of design throughout the design cycle. The sequences are one of the most innovative and successful of their kind, and have received national attention.

In order to assess this objective, a recent study was conducted using student team-based surveys on a weekly basis throughout the design for each cornerstone project offered in EEIC. Based from the lessons-learned from the student team-based survey, this paper addresses bridging the gap between the traditional material, specifically problem solving with computer programming, and the Advanced Energy Vehicle (AEV) cornerstone project with the use of Matlab's graphical user interface design environment (GUIDE). The paper provides a detailed discussion of the AEV project; project layout and deliverables; reasons and motivations for developing a design project software tool for the students to develop and use based from the survey data and classroom observations; and the integration and teaching strategy for implementing the tool within the design process.

Introduction

The Engineering Education Innovation Center at The Ohio State University offers three course sequences to first-year engineering students; Fundamentals for Engineering available to all students; Fundamentals for Engineering for Honors designed to challenge the University-designated Honors students; and the most recent, Fundamentals for Engineering for Scholars in which the students are part of a living/learning community and are exposed to green engineering topics and sustainability issues. Their acceptance is based on standardized placement exam scores and, in the case with Scholars, their extracurricular community involvement is also considered. Students that have been accepted to take either the Honors or Scholars sequences are not required to do so and can take respective alternative course sequences.

The course sequences retain the traditional material covered - engineering orientation, engineering graphics, and engineering problem solving with computer programming[1] while offering several design-build project topics. The current design-build projects include the fundamentals of potential and kinetic energy through model roller coasters, lab-on-a-chip with a nanotechnology component[2], fully functional small autonomous ground-based robots,[3-5] and the most recent being a model-scaled autonomous advanced energy vehicle (AEV).

There are a number of instructional elements common to all of these team-based cornerstone projects. The First-year Engineering Program (FEP) has settled on a project team size of typically four students, which matches well with the project workload and typical kinds of tasks to be completed. The teams are formed, mentored, and reviewed to ensure that the students receive timely feedback on their performance. The three main curriculum objectives and technical references[6,7] are used for each design-build project include;

1. *Project Management and Teamwork* - which includes, but is not limited to; time management and task scheduling, team communications and meetings, fair division of labor and team member responsibilities.

2. *Design Process* - which consists of: identifying the project requirements and constraints, gathering background information, brainstorming, identification of management of materials, preliminary analysis and initial design, and the build/test/modify/document cycle.

3. *Project Documentation* - which includes three parts:
   i. Project notebook - complete documentation of the project, and which was reviewed on a weekly basis
   ii. Final oral presentation - overview of design experience
   iii. Final written report - complete summary of all aspects of the design

Project management throughout the design process is regularly evaluated by requiring an updated project notebook. Each team tracks and manages the design-build project through notebook records that contain initial concepts, brainstorming notes, laboratory team memos, and in the case of the autonomous ground robots and AEV, weekly performance test summaries. The teams' final designs are evaluated during individual competitions and scored based on that year's design criteria. At the end of the project each team develops a final report and PowerPoint presentation to present as a team to the class and for evaluation by the instructional team.

These design projects have received national attention. With the increasing enrollment rates, FEP is continuously learning from and adapting in order to provide a successful bookend for the undergraduate engineering experience. Student-team based surveys were recently recorded on a weekly basis for specific design activities that were common among all of the projects and that were considered important for (FEP).

The following addresses lessons learned, based from student-team based surveys and its focus on the most recent developed design project, AEV, to further emphasize problem solving with computer programming specific to the design process. The background with the AEV project will be discussed, followed by the survey results including lessons learned and motivations within the specific project and (FEP) for utilizing Matlab. Finally discussion on the development of the tool, teaching strategy, and expected outcomes will be addressed along with future development and assessment in order to continue providing a valuable cornerstone experience.

The AEV Cornerstone Design Project

One important objective for cornerstone design projects is to provide a team-based experience that includes all aspects of engineering design and development. This includes student exposure to all activities within the design process from initial concepts through prototype development and testing to a final product. This objective also includes successfully providing students with awareness of and experience with the iterative nature of design throughout the design cycle.

The most recent cornerstone design project developed is a model-scaled AEV. It was developed specifically to focus on energy efficiency and energy management concepts for students in the Fundamentals for Engineering for Scholars course sequence. Experiences gained from existing design-build projects and from the students' point of view,[8] were used in the development of the AEV curriculum.

AEVs are small (<500grams), autonomous, electric motor-powered, propeller-driven vehicles that are suspended from and maneuver along a closed-circuit monorail track hung from the laboratory ceilings. The AEV structure and monorail support arm are designed and constructed by students using two millimeter thick PVC sheets. The propulsion system includes electric motor and propeller combinations. The energy storage system is a two-cell lithium polymer battery. An in-house, custom-made automatic controller and performance recorder system featuring off-the-shelf Arduino Nano microcontroller[16] and speed controllers were developed and provided to each team. Data is collected through the autonomous control system and is used to monitor current and battery voltage during a defined vehicle run in order to determine overall energy consumption and provide the necessary information for developing energy management modeling of the AEV. Although not required, aerodynamic body components are highly encouraged to draw out a team's artistic creativity and add visual appeal to their vehicles. The AEVs must also fit within the team's storage box, approximately six inches wide, twelve inches long and five inches deep, with or without the support arm attached.

The AEVs are designed and built based on a series of labs and performance tests that utilize desktop wind tunnels and cover topics such as electric motor and air-breathing propulsion performance and evaluation, system efficiency, automatic control programming, and energy management in completing the operational objectives provided.

In order to assess the effectiveness of aforementioned cornerstone objective and student exposure to all activities within the design process, student team-based surveys were conducted on a weekly basis throughout the design for the cornerstone project; and, in the case of the current topic, used to further develop material to improve the overall design projects, while maintaining the common curriculum objectives.

Student-team Based Survey

The surveying was anonymous and asked, within AEV, 36 teams (or approximately 144 total students), to record time spent on certain design process activities. The design process for the design projects was broken into seven activities including project management, a main objective for each design project which includes time management, task scheduling, team communications, and meetings. The additional activities were selected based on the common activities, such as brainstorming and lab specific tasks geared toward their respective design project. The activities on the survey include; identifying solution options, identifying constraints, performing research, performing analysis, evaluating analysis, and implementing design decisions. Along with the average percentage of total time spent for each activity throughout the design project, and the number of times the student team revisited the activity on a weekly basis was also recorded. This information was requested to provide insight into the students' experiences within the design cycle.

AEV Student-based Team Survey Results

Figure 1 shows the breakdown of the average percentage of total time spent and the number of weekly visits or revisits to the design process activities collected from student team-based weekly surveys for the design process activities for the AEV cornerstone design project.

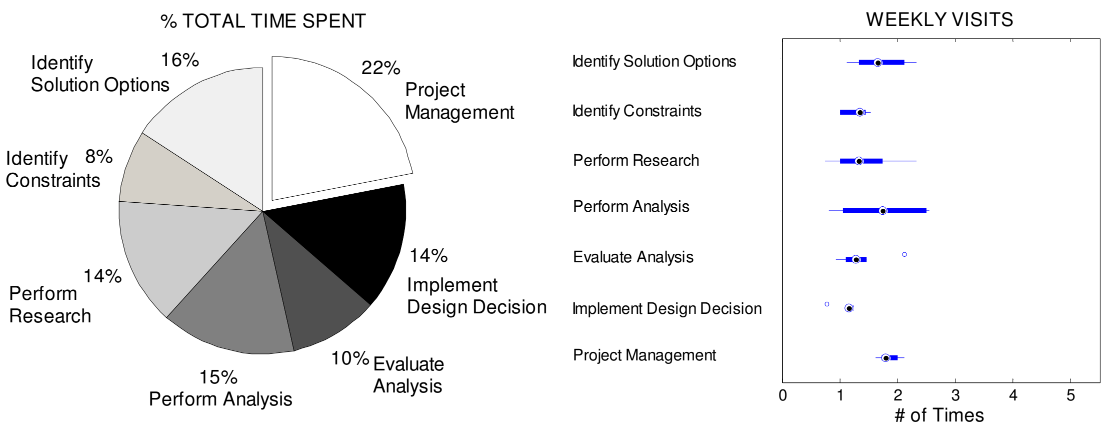

Figure 1: AEV Cornerstone Design Project – Student Team Survey Results.

Based on the percentage of total time spent, and given that the seven design and project management activities in the weekly team-based survey represent a reasonably full set of activities, it is encouraging that the AEV project incorporate a measureable amount of time spent performing each activity. The data reveals that students are getting experience in all of these important design activities, with no specific activity receiving less than 8% of a team's attention.

More complex design projects, and in the case of AEV, requires more visits and revisits to specific design activities, highlighting and reinforcing the iterative nature of design for the students. Some key observations can be made from the weekly visits in regards to where student-teams have to revisit specific activities. For instance, in regards to performing analysis it can be seen that the average revisit ranges from one to 2.5 times per week; and in the case the implement design decisions has a significantly less range with the average at approximately 1.2 times each week. Further explanation of each of these design activities in regards to AEV is required in order to evaluate potential reasons for this.

Performing analysis indicates the amount of time and revisits required for the teams to post-process the data for analysis, not including the separate activity of evaluating the results of the analysis for the design to make decisions to progress through the design cycle. At the time of the surveys the software utilized for the design process, specifically in post-processing AEV tests on the classroom track to determine the total amount of energy used from power-time curves was Microsoft Excel. This process was laborious, requiring the students to paste in thousands of rows of data and manually break apart the data in order to evaluate how their AEV operated throughout the track and at different points of meeting operational objectives. Combining the time for comparing run-to-run for different operational characteristics and physical changes to their designs, this process required, as indicated within the survey data, a wide range of require revisits and 15% of the total time spent throughout the design process.

Implementing design decisions indicates the amount of time and revisits required after lessons-learned from post-processing data to make either physical and/or control changes to their AEV to gain more experimental data and performance characteristics to various design changes. As previously indicated, the survey data reveals that the teams are only revisiting this on the order of one time each week for a total of 14% of their total time throughout the design process.

Once the students have performed the necessary performance analysis and gained the required information in order to evaluate their design, the process becomes repetitive and in the instance of using Microsoft Excel, time consuming with little or no educational value. The time spent and required repetition, one could argue, could be better suited for implementing design decisions to further increase the passes through the design cycle, specifically near the end of the term for finalizing the design and control strategy for meeting the operational objective as efficient as possible.

The tempo of each activity throughout the design process also reveals important information in regards to when student-teams are spending the majority of the time for each activity within the term. Figure 2 below shows the normalized time for each activity throughout the seven weeks spent within the laboratory performing labs or performance tests of their AEV designs, with the final designs at the end of week seven for the individual competitions and demonstrations of their final designs during week eight. The following sections will provide further insight into the student-team involvements within the designing activities.

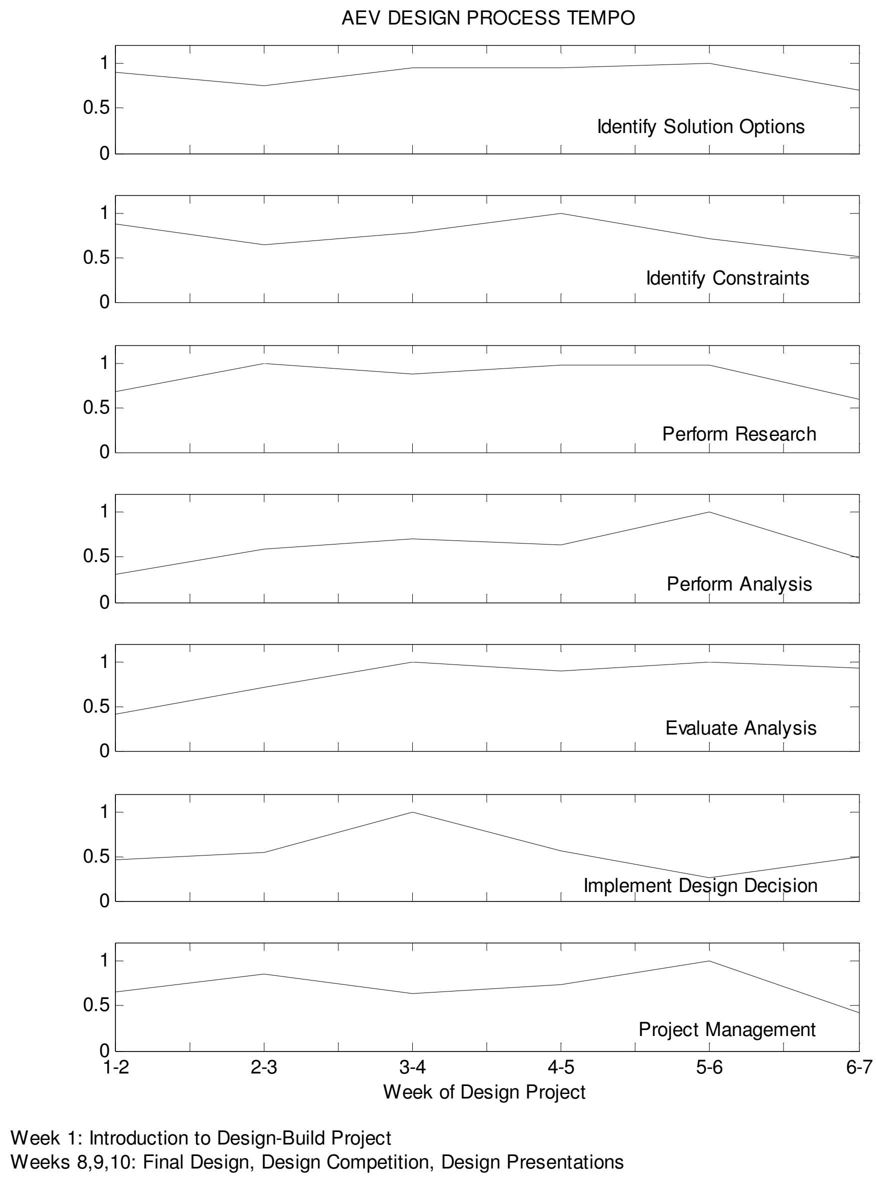

Figure 2: AEV Design Process Tempo

Observations made from Figure 2, indicate that near the end of the design project there was an increase in effort made in performing analysis with a significant decrease in implementing design decisions.

From the survey analysis and observations made within the laboratories, a design software tool was determined to have value to further emphasize problem solving with computer programming applied to the design process; while potentially decreasing the required and laborious performance analysis activity and increase the time spent and passes through the AEV design cycle exploring and evaluating design options. Include this with the effort and FEP direction to further increase the student awareness of Matlab, provided an opportunity to utilize the built-in graphical user interface (GUI), requiring the students to use previously developed Matlab programming skills to program within a provided GUI framework, furthering emphasizes the efficiency in data acquisition and post-processing within the engineering design process.

Design Project Software Tool Development

In the process of developing GUIs, there were two major objectives; improve the AEV design process for students, and to provide the opportunity and potential to increase and improve the student's programming skills. The design software had two goals to meet the objectives:

1. Improve and emphasize the iterative process of design by increasing overall time spent and weekly revisits to implementing design decisions by reducing the unnecessary repetitive tasks in performing analysis.

2. Provide the GUI skeleton such that the student would be responsible for coding within the GUI, based on previously developed Matlab skills and techniques taught in the classroom.

Revisiting Figure 2, week's four to six shows an increase in time spent on performance analysis, which consequently effects the time spent on implementing design decisions. Meeting the design software's goal would increase time available and the frequency to implement design decisions; and reduce the time spent on the unnecessary repetitive tasks in performing analysis. Furthermore, by involving the student in writing a section of the GUI code emphasizes, within the design cycle, that tools can be developed to improve the design process.

Currently, two Matlab GUIs have been developed; AEV Propulsion & System Efficiencies and an AEV Energy Analysis, Figures 3 and 4 below respectively. The AEV Propulsion & System Efficiencies GUI and AEV Energy Analysis GUI skeleton programs are provided to and developed by the students as performance tests to be completed within the laboratory classroom.

The AEV Propulsion & System Efficiencies GUI helps the student develop the effects of available power to AEV trajectory generation and to determine the respective propulsion system (motor and propeller) efficiency. The GUI, if desired, can record and save their data to a Microsoft Excel worksheet for use in creating tables and report writing.

The AEV Energy Analysis GUI provides a comparison between power curves for four different test runs of their AEV. This GUI was designed to communicate with the Arduino, providing the capability to upload the data immediately after a test run and view the energy analysis instantly.

The AEV GUIs remove the unnecessary laborious tasks that were required to be done in Microsoft Excel as previously mentioned and provide an efficient approach to performing analysis to uploaded data.

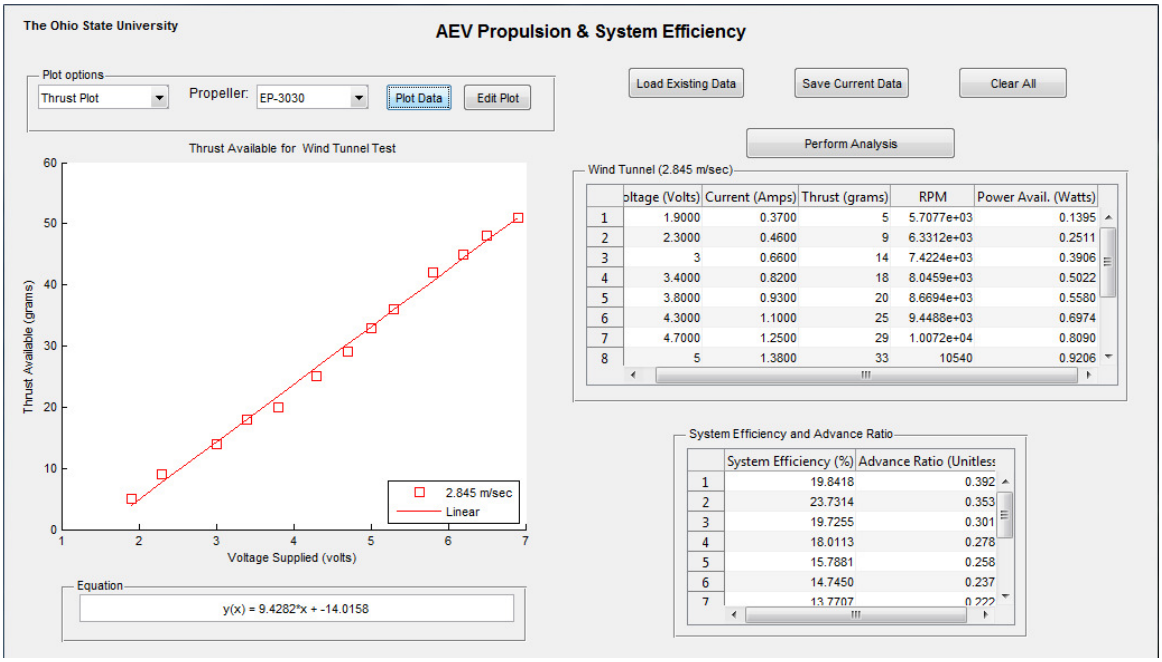

Figure 3: AEV Propulsion & Efficiency GUI

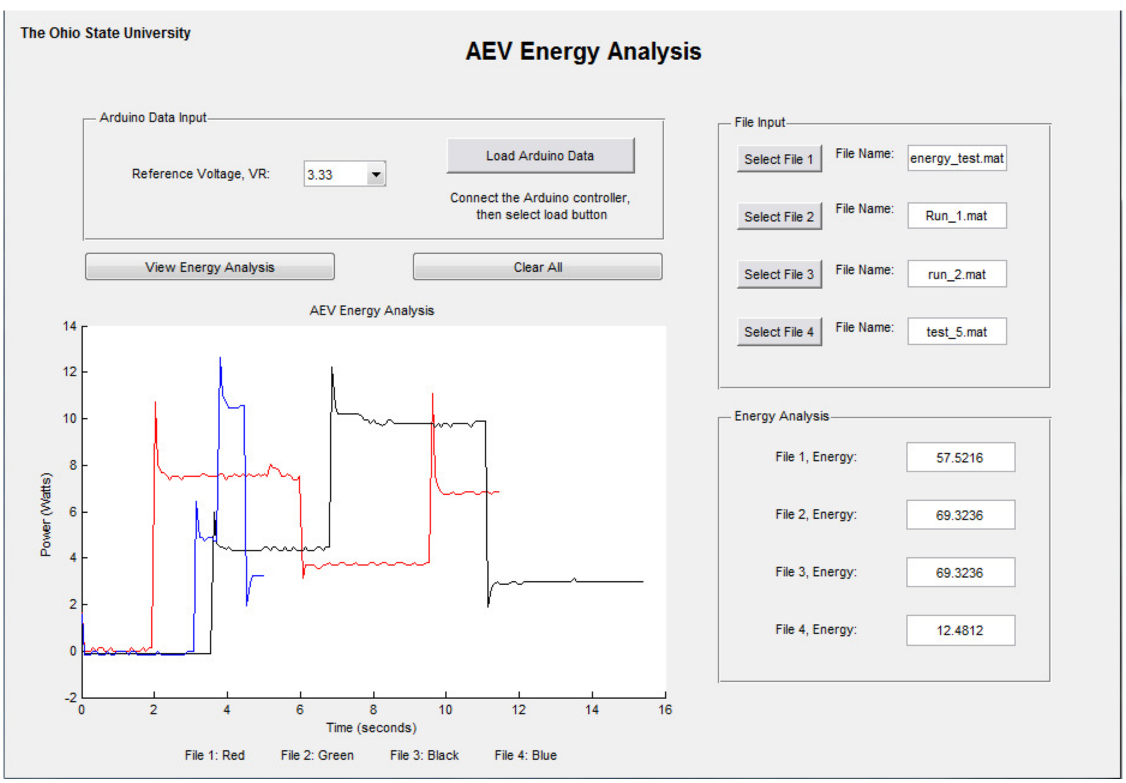

Figure 4: AEV Energy Analysis GUI

Implementation of the GUI Skeleton Program

The students are provided the GUI skeleton along with instructions on how to edit a Matlab GUI using the GUI layout editor command "guide." Instructional materials are provided and covered in the laboratory that demonstrates how to navigate through the GUI code utilizing the built-in features of the layout editor in Matlab. The student-teams are tasked to edit the code using previously developed programming skills. Sample data sets and results are provided for the students to verify proper algorithm and check program development and known results prior to performing analysis on individual team results.

Piloted Results and Comparisons and Upcoming Expected Outcomes

The Matlab GUI student-team developed software tools have recently been piloted within the AEV design-build project. The student-team weekly surveys were taken throughout the design project and implemented, collected, and analyzed consistent with the results shown and documented.

Preliminary results from the piloted software tools have shown promise in addressing the aforementioned issues. Results shown below from piloting the software, demonstrate that by using the software the students have decreased the amount of time and revisits out of classroom on performing the repetitive performing analysis activity, with an increase in revisits to implementing design decisions (Figure 5).

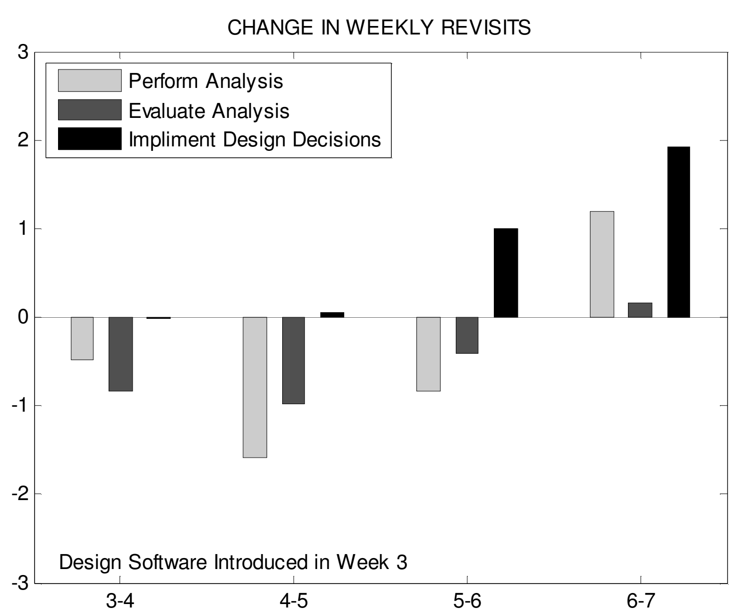

Figure 5: Change in Weekly Revisits Using the Design Software based from Previous Excel Methods – Preliminary Pilot Results

Also, preliminary results from using the design software demonstrate the peak times in which they are performing the design activities, specifically with performing analysis, evaluating analysis, and implementing design decisions, have shown that there is a steady increase in each activity over the design process to the final design deadlines (Figure 6).

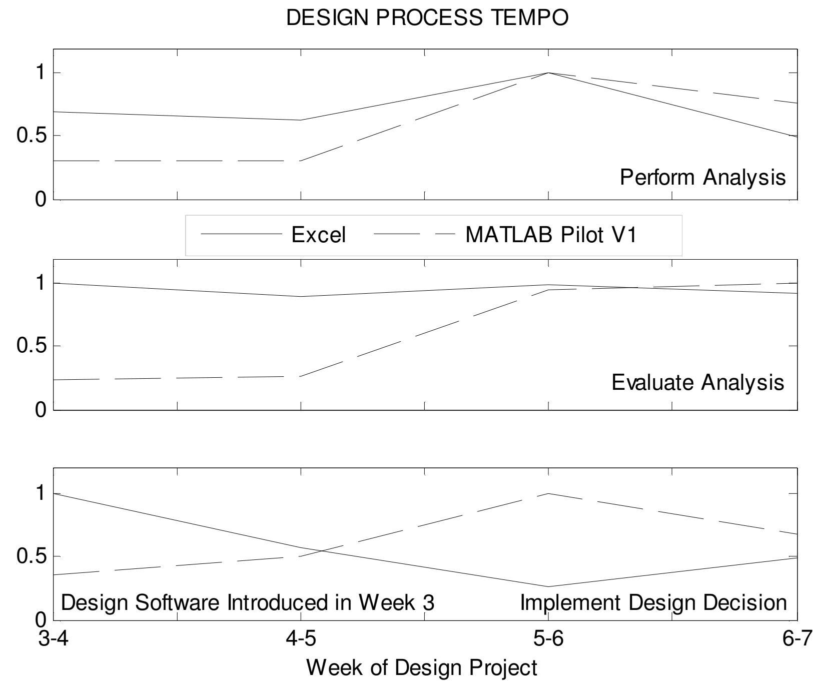

Figure 6: Design Tempo Comparisons with the New Design Software – Preliminary Pilot Results

The most notable change in trend from Figure 6 above is with the tempo for implementing design decisions. Using Microsoft Excel design software resulted in the students peaking in making design decisions early in the design process and steadily decreasing throughout the rest of the project. However, pilot results show that implementing the new design software has reversed this trend and student-teams continually increased the amount of time spent on implementing design throughout the design process until final designs were due and tested in week 7 of the term.

Based on piloting the design analysis software, several favorable outcomes are expected, once the full software package is complete and implemented within the AEV design project. The first, and in regards to the current topic, the time required for the repetitive performance analysis activity is expected to continue to decrease, leading toward more time available for implementing design decisions, increasing exposure to the iterative process of design. Additionally, it is expected that the students will gain an appreciation with the use of potential software tools and programming techniques to increase efficiency within engineering design process; and in the case of the FEP course sequences, the opportunity to further emphasize problem solving with computer programming in the design process.

Conclusion

From the three main curriculum objectives and technical references used by FEP, the AEV cornerstone design-build project was evaluated using student-team based weekly design process activity surveys. Evaluation of the student-team based survey, displayed a trend of increased time spent on performance analysis with a decrease in time spent on implementing design decisions. Two Matlab GUI skeleton programs were developed to reduce the time spent on the repetitive process within performing analysis encouraging an increase in implementing design decisions within the iterative design process. In addition, the student-teams are required to program sections of the GUI skeleton framework, providing the opportunity for the student to further practice programming skills that were previously developed in the course sequence.

The design software tools have been piloted within the current academic term and the student-team based surveys was consistently collected and analyzed, and comparisons made with the previous results. Several favorable outcomes have been demonstrated, including the amount of weekly revisits to implementing design decisions increased, increasing exposure to the iterative process of design. Additional favorable outcomes are expected once the full software package is completed and implemented within the AEV design project, , including exposure to and an appreciation in utilizing programming techniques to increase efficiency with problem solving in the engineering design process.

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