Framing Individual Laboratory Exercises with a System Conceptual Design and Team-Based Competition

Richard L. LeBoeuf, Tarleton State University, Stephenville, TX 76402 USA (e-mail: leboeuf@ Tarleton.edu) and Jorge T. Gómez, Universidad de los Andes, Mons. Álvaro del Portillo 12.455, Las Condes, Santiago, Chile (email: jtgomez@miuandes.cl)

A methodology is proposed for teaching seemingly unrelated concepts in the context of a comprehensive system conceptual design. Individual pre-lab and lab experiences are presented in the context of the objective and functional and performance requirements of the system. Thus, an understanding of component interfaces is developed throughout the semester. A comprehensive project-based analog design experience is given as an example. The project culminates with team-based system integration and a competition. The methodology integrated project-based learning, guided discovery, peer-instruction, teaming, competition and traditional individual pre-lab and lab work to increase engagement, learning and experience of students. It provided an engaging environment in which students learned components and circuits individually and incorporated them into a comprehensive system cooperatively in teams. The individual work prepared students to be effective members of their team, thereby avoiding the frustration of having ill prepared and disengaged team members.

Methodology

The educational objectives of the laboratory were to: 1) know the circuits and analog systems commonly used in the field of electronic design, 2) be able to mathematically and computationally analyze complex analog circuits, and 3) be able to design and synthesize analog circuits. Autonomous vehicles appeal to both students and faculty, so one was developed for this project. The system-level design requirements introduced during the first laboratory class were: 1) move from one corner to the opposite corner of a 2 m square beginning with an arbitrary orientation, 2) stop in a 25 cm square containing the beacon, without contacting it, 3) change the temperature of water based on a 500–1500 Hz tone corresponding to the range 15–30 °C, and 4) constantly emit a tone indicating the instantaneous temperature of the water in the range 1500–3000 Hz tone corresponding to the range 15–30 °C. In addition, the following constraints were imposed: 1) function autonomously, 2) use no microcontroller, and 3) be powered only with 9 V batteries. The competition judging criteria were as follows: 1) proximity of the vehicle to the target, 2) proximity of the water temperature to the desired temperature, 3) time to achieve the objectives, and 4) hardware costs.

Conceptual Design: Satisfying the requirements with standard analog circuits and components was guided by the conceptual design shown in Fig. 1, which encompasses all of the concepts of the course. Three subsystem block diagrams were given indicating the specific order of the laboratory topics (e.g., Fig. 2 shows the motion control subsystem block diagram). The complete set of topics provides a comprehensive framework for experience with a broad range of analog and mixed signal circuits.

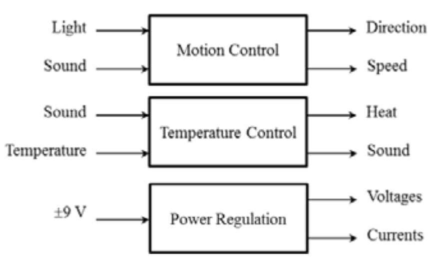

Fig. 1. Top-level conceptual design, which includes three major subsystems: motion control, Temperature control and power regulation.

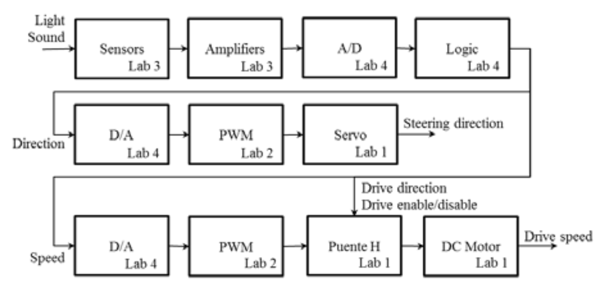

Fig. 2. Motion control subsystem conceptual design, which provides the basis for the first through fourth laboratory topics: motor control, pulse width modulation, sensors and amplifiers, and mixed signals. Note: A/D and D/A are analog-to-digital and digital-to-analog conversion, PWM is pulse-width modulation, and DC is direct current.

Laboratory Organization: The experience included both pre-lab tasks and lab exercises for each of the topics. Pre-lab assignments prepared students for labs by requiring them to perform the following tasks: 1) finding data sheets; 2) finding circuits; 3) performing circuit analysis; 4) specifying component values; and 5) simulating circuits. At the beginning of each lab, the professor and students discussed the circuit and component options. Each student had to build all of the chosen circuits individually and demonstrate circuit performance to the professor. Post-lab documentation included a notebook with designs and prototype testing results, including comparisons to pre-lab analyses and simulations. This methodology increased the demonstrated and self-perceived expertise of the students.

Results

The final grade was comprised of pre-lab, laboratory, and project grades. A survey was conducted to help evaluate the value of the new structure of the laboratory course. The survey results, shown in Table 1, clearly show that, from the students' perspective, the laboratory was very helpful to their understanding of the theory and that the final project and competition were incentivizing. The pre-lab work supported the lab work and the lab work supported the project activities. However, the pre-lab work was not perceived to be as important as the lab work. This was reflected in the students' reporting a higher tendency to use the circuits presented by the professor, rather than those the students found individually during the pre-lab activities. Generally the students thought the project was impossible for them before the course, whereas after the course, they were much more confident that they could achieve it.

Table 1. Results of survey of effectiveness of the pre-labs, labs, and project.

Affirmation	SA	A	I	D	SD
1. The labs helped understanding of theory	100	-	-	-	-
2. Labs oriented toward final project were incentivizing	89	11	-	-	-
3. Labs oriented toward a competition was incentivizing	33	33	22	11	-
4. The individual labs were useful for completing the project	89	11	-	-	-
5. Time allocated to the labs was sufficient	11	0	11	56	22
6. Pre-labs were fundamental for understanding the labs	22	44	22	11	-
7. The pre-lab circuits were used for the labs	-	33	11	33	22
8. When the pre-lab circuits were not used, the prelab was still helpful preparation for the lab	33	44	11	11	-
9. The project was based on the laboratories of one member of the team	-	-	11	33	56
10. Before this course, I thought the project was impossible	67	22	11	-	-
11. After the laboratories, I know how to do the realize the project	78	11	11	-	-

The numbers represent the percentage of students who responded Strongly Agree (SA), Agree (A), Indifferent (I), Disagree (D) and Strongly Disagree (SD).

The results of the competition widely varied. No team satisfied all of the requirements. Two teams had working printed-circuit board versions of all of the subsystems, but could not get the integrated system functioning in time for the competition. The teams developed circuit designs and board layouts, which they fabricated and populated. However, after many hours of troubleshooting and modifying the circuits, all of the teams reverted back to using protoboards for the on-board circuits. After attempting to build their own platforms from piece parts, every team ultimately chose an off-the-shelf platform which contained DC motor-driven wheels.

Conclusions

The project was motivating for students because it provided a framework for laboratory topics, which would otherwise be covered without the broader context. The challenge is to define a system that requires all of the specific components or design capabilities covered in a course, while having a simple enough system that students can develop it in the timeframe of a course.