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Interdisciplinary Collaborative Active Learning: The 'WOW!' Factor for Project Oriented Industrial Design and Electronic Engineering Courses*

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In this paper, we describe the guidelines for active learning activities for courses that share a final interdisciplinary project. Our observations are based on the interaction by students from two disciplinary contexts during the development of an academic project, specifically the design and assembly of a fully functional consumer electronic device. During this process our main objective was to put into place good practices for the combination of industrial design and electronic engineering disciplines using collaborative and active learning techniques. It is our intention to present the results of our studies and methodology as a reference for further experiments in the same line of research or as a case study for other disciplines.

Keywords: interdisciplinary; industrial design; electronic systems; computer mouse; RIRReD

INTRODUCTION

IN RECENT YEARS, non-traditional learning methodologies such as Collaborative Learning (CL) [1] and Project Oriented Learning (POL) [2, 3], among others, have been applied with general success in undergraduate academic programs at a number of universities around the world. Results show that, depending on the student context, these learning schemes perform well in providing reinforcement for individual learning.

In our experience during courses using CL at Tecnológico de Monterrey [4] we have found that in the first semesters of an academic program the best learning techniques are Problem Based Learning (PBL) and traditional individual approaches, while during the mid portion of the curricula CL is a good method because students are better focused on their academic responsibilities and have attained greater maturity. Specialization courses in the last stage of the academic program seek to integrate knowledge from previous experiences. Consequently, POL based courses are recommended and have shown good results in engineering groups. However, POL courses are academic-program specific and, even when they partially use CL, the interaction between students is reduced to a very limited context: the particular academic area of the discipline. For example, during the previous semester at Tecnológico de Monterrey, Electronic Systems Engineering students design and assemble digital interfaces to connect devices to personal computers using a USB, PC-Card, PCI or IrDA, but even though their working prototypes are fully functional, their visual aspect is usually unfinished. They are merely a bundle of wires and integrated circuit boards. The same situation is common in the industrial design bachelor-degree program at our university: the students sketch appealing devices with advanced functions and materials, ergonomically built and with an aesthetic proposal, but these devices are not operational because the students are expert in design and ergonomics, but not in electronics and computer engineering.

The academic courses described in this paper used didactic techniques like CL and POL. However, traditionally the interaction context for the students was limited to colleagues from their own discipline; this was an obstacle to completing fully functional final projects. Inspired by the idea of analyzing the professional interaction between students from two different academic disciplines

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carrying out activities for each specialty in an interdisciplinary context, and valuing their potential for enriching the learning methods outside the classroom, we combined the final projects of two courses so that students could develop a consumer electronic device together. These experiments were carried out on two occasions with groups of up to 40 students, although some of the conditions varied.

Although project-oriented interdisciplinary courses may be common learning technique in some universities, the relevance of our work lies in the nature of our main objective: the assessment of the learning process that occurs with interacting students. This does not imply that technical aspects for final projects were not relevant. To address this aspect and support the technical success of the projects, the instructors devoted extra hours to planning the activities that allowed achievement of the goals for each of the final projects. However, the main objective of this effort was to formulate the guidelines for the didactic success of the interdisciplinary learning activities.

'Active Learning' includes all educational activities resulting in active study behavior, such as assignments, group cooperation, etc. The most crucial characteristic of Active Learning is that it entails the empowerment of the learner, providing tools for life-long learning [5].

Tecnológico de Monterrey offers undergraduate courses oriented towards solving industrial projects, commonly known as design clinics [6]. These courses focus on solving real problems requiring collaboration by several students but, unfortunately, not always using an interdisciplinary approach. In a best-case scenario, working groups with different professional profiles deal with the problems from multiple perspectives. However, these courses are more focused on the success of the projects than on the development of effective CL activities, and the potential to use a student's interactions to promote active learning is generally ignored. Moreover, the global economy and prestigious academic certifying organizations such as the Accreditation Board for Engineering and Technology (ABET) consider the ability of graduates to work effectively in interdisciplinary teams a desired outcome of engineering education [7, 8]. At present, we have no other coordinated effort to join the electronic systems and the industrial design disciplines to work on the creation and development of a consumer electronics product, nor do we have a study to analyze this kind of interaction between students for the purpose of obtaining good learning strategies for these professional profiles.

At Tecnológico de Monterrey, all the academic courses are structured by their technical/scientific content and enriched with different Active Learning (AL) learning techniques, such as Problem Oriented Learning (POL). This methodology is supported by different learning tools that lead the student to investigate certain subjects individually, to create discussion and debate or to visit businesses related to the study area. These activities promote a participative, creative environment in which students develop more abilities and learn by themselves, with an instructor as a guide.

The POL methodology allows the students to become discoverers, integrators and presenters of ideas for solutions to their own projects. The student role is to contribute constantly to discussions and, based on those discussions, the instructor can give the recommendations and tutorial support he or she considers suitable. In addition, the methodology emphasizes the use of technology and collaborative work, which allows for the discovery of interdisciplinary connections.

Among the advantages of POL, one that can be clearly seen is the change in the teacher–student relationship. A competitive environment is encouraged between students, leading them to collaborate. The learning approach also motivates students to explore new ideas. A student feels motivated, especially due to the fact that he or she is producing solutions, planning and directing the project, finding new ways to present a final project, and, finally, integrating what he or she has learned. Larger interaction with a work group requires a student to work collaboratively with others. Students develop summarizing skills and data construction that help them, among other things, to link ideas from different disciplines. Students face unpredictability, ambiguity and complexities; they face different obstacles during the process, search for sources and confront different challenges. In overcoming these obstacles, students acquire and develop new abilities using tools and real-life resources; these abilities include social skills, personal administration and self learning. With this technique, the 'important' work is done by the students; in particular, because they must learn in a guided fashion. At the same time, the instructor and the student discover how students can learn more easily: each provides resources and participates in learning activities, thus becoming a tutor or a teammate.

POL proved to be a successful technique for senior year courses. This strategy is centered on the student and promotes intellectual independence through the development of a project in the student's disciplinary context, organizing his/her learning process around the solutions proposed to implement the project [9–12].

In our experience as instructors, and as reported in other studies [13], a very important factor for the success and quality of an academic project is that those involved find the project interesting. We believe that a real-world, 'hands-on' interdisciplinary experience contains motivating factors for this. In particular, for our experiments, we focused on designing and assembling a fully functional consumer electronic device. In the first case the device was a computer mouse and on the second occasion, it was a wireless mobile terminal for reporting information to a computer (RIRReD: Red Interactiva de Recopilación de Respuestas en Demanda).

To illustrate the morale that the technical success of this type of project creates in students, we have coined the expression 'WOW!' as an adjective for relevant factors in the success of this type of interdisciplinary interaction, which we can also associate with the visual and functional impact of the created devices when they are shown to the students and to other people not involved with the course.

From the student point of view, the 'WOW!' factor has to do with the functional technical aspects of the final product, as well as his or her role as a professional throughout the development [13]. On the other hand, from the instructors' point of view, the relevant factors are more closely related to the success of the didactic techniques and learning activities used.

Beyond the technical aspects, during our experiments, there were three very relevant factors for the students: *learning from their classmates, learning from experts (instructors)* and *learning to be experts.* For the instructors, the methodology used to develop the experiments was of particular interest because of the following aspects: *the use of student-to-student learning outside the classroom as a learning method,* and *the benefits of having the students carry out the role of experts as an active learning tool.* In the following section we discuss these aspects further.

LEARNING IN COLLABORATIVE ENVIRONMENTS

In 2002, Tecnológico de Monterrey, Monterrey Campus's Computer Science Department, developed an academic program for an advanced course in computer interfacing for the electronic systems engineering curricula; that is, Computer Interface Programming (PIC, from its initials in Spanish). In this course, students learn how to design the hardware and how to program the firmware of embedded devices to plug into personal computers, using buses and interfaces such as a USB, PC-Card, PCI, and IrDA, along with their specific device drivers for Microsoft Windows® and Linux® operating systems. This course was designed to be project oriented: each topic has a project to be developed, and during the last stage of the semester each student selects a final project with a specific application and use for any of the technologies learned. During the initial semesters, we tried individual learning and work schemes, but lately we have found that better projects and improved learning skills were reported with CL. We believe this course gives our students distinctive abilities in the professional electronic system design field because, after the course, students are able not only to design electronic devices, but can also program the firmware and their device driver. This is almost all that is needed to produce a consumer electronic product. However, the projects developed generally end as laboratory prototypes because they lack a properly manufactured enclosure; in other words, our prototypes have the desired functionality, but not an attractive appearance and this is certainly one of the most important aspects for commercial acceptance of a product.

The curricula for Tecnológico de Monterrey's industrial design bachelor-degree program [14] are structured with seven sequential industrial design laboratory courses, where knowledge from several simultaneous or previous courses is integrated to develop short-term final projects. Consequently, POL is used as the default didactic technique. The course called Industrial Design Workshop III (TDI-III, from its initials in Spanish) is given in the fifth semester of the academic plan for this degree program. Blackboard (Bb) is used as a computational tool to create a virtual platform where students can view the course structure, its philosophy, objectives and assignments in a location- and time-ubiquitous scheme. In addition, Bb is the default tool for document archiving and for student interaction with instructors and each other.

During TDI-III, students carry out three exercises: first, they complete a diagnostic assignment oriented towards designing a mechanical toy. This is a short-term, individual project (a week and a half). For the next five weeks teams of two work on designing a didactic toy, as a project linked to a governmental institution or an institution with limited economic resources. Finally, the last seven weeks of the course are devoted to designing a technological device, using plastics and methods studied in the course. The results reported in this paper are from this third exercise completed by a group of students on this course, during their directed interaction with electronic systems engineers. The industrial design students sketch attractive devices with advanced functions and materials, ergonomically built and with an aesthetic proposal, but these devices are not operational. In a real-life environment, both engineers and industrial designers collaborate to create fully functional products.

Learning from classmates

During the summer of 2005, instructors from the PIC and TDI-III courses had the chance to work collaboratively on joint academic projects to involve students in the complete process for the production of a fully-functional consumer electronic device, specifically, a computer mouse. This approach gave the electronic systems engineers a new way of thinking about the design of an electronic product, paying attention to the final product dimensions, ergonomic functionality and other considerations provided by industrial design experts. Moreover, the interaction process develops efficient time-organization and self-learning skills as students have to explain their designs to each other and justify their decisions during their project meetings. This process also promotes student creativity and motivation, as their prototypes will have a finished look when completed.

In a closed-discipline project course, industrial design students usually finish with project proposals for toys of outstanding creativity, using advanced materials in top-quality prototypes of noteworthy aesthetics, excellent ergonomics, and feasibility, but with gaps from the technological point of view due to ambiguous or incomplete specifications, and, as a result, low motivation for further learning [15]. In an interdisciplinary approach, the interaction with electronic systems engineers allows them to confront technological, economic, managerial, and social issues that provide them with experience in problem solving that will enrich the way they tackle real-world situations, and if the project is carefully lead to success, this will contribute to student satisfaction and self-motivation in the profession.

Learning from experts

The success of the POL [16] paradigm is based on the assumption that every individual in a working group will assume the role of an expert for a specific assignment during the development of the project, so if each element of the group performs well, the entire project will succeed. CL is also useful for POL based courses because this methodology promotes active learning by making each expert explain to his or her mates the activities covered under the initial work plan. For the development of a consumer electronic product, the expertise from electronic systems and industrial design must be merged, and since our courses deal with these areas of knowledge, we have decided to use POL and CL for joint academic projects and evaluate student behavior during the process.

To ensure the technical success of the projects, each of the instructors devoted the first part of the course to the presentation of concepts and methods that instill in students the required technical abilities to approach the problems presented for the final project. In the case of the PIC course, students were trained in the techniques required to design and build electronic devices that can be connected to a computer, using different interfaces, and in the programming of device drivers and required computing applications. In this case, during the second month the students programmed a microcontroller from the Cypress CY7C63723/CY7C63743 series to carry out the communication functions with the computer using an USB interface and those of a conventional mouse, using simple contact sensors.

On the other hand, TDI-III is devoted to three main themes: 'the toy,' 'plastics materials and their processes,' and 'personal interaction,' based on the pedagogic objectives of this course:

1. to design a toy for the integration of advanced technology, enjoyment and personal interaction;
2. to build a top quality prototype or model;
3. to research state-of-the-art toys, advanced technology in Mexico and around the world;
4. to gain knowledge about technology and how it is used in new devices;
5. to learn about current toy design trends and to come to appreciate modern telecommunications as educational and interactive work tools.

Industrial design students apply the concepts learned in the design of a cutting-edge technology device.

Learning to become experts

For both courses, TDI-III and PIC, an important objective is for the students to acquire the knowledge and abilities required to perform as experts in their respective knowledge areas. In view of this, the final stage of the course focuses on students working on an application project, where they demonstrate their capacities for proposing, designing and making equipment, appliances or objects that are congruent with the specific technical objectives of each course.

In the PIC course, students design, assemble and configure integrated circuits with a specific application and make their own device drivers and corresponding programs to set them up when connected to a personal computer. This course is theoretical, but has a very relevant practical component: to guarantee that the students are capable of building and configuring expansion devices for computers, they must demonstrate, in a practical way, their level of excellence in this process by carrying out each activity with criteria comparable to that of an expert.

For the TDI-III course, students familiarize themselves with the concepts of the previously mentioned subjects, learn several techniques for spurring creativity and innovation, develop research, analysis, observation, conceptualization, experimentation and validation of a proposal and build models and prototypes going through the steps of a traditional product design methodology.

TEACHING AS AN ACTIVE LEARNING RESOURCE

Our experience as instructors reveals that one of the best ways of assessing how well we have learned a concept is to try to explain it to others. This is a basic idea of collaborative learning and is also a pillar of our platform for interdisciplinary work.

The use of teaching as a learning tool

Our students formulate conceptual designs based on concepts and techniques that they learned in our courses and throughout their bachelor program. In both courses, to ensure a deep understanding of the objects of learning, we turn to exposition and discussion with colleagues about the arguments sustaining each of the final project proposals.

During the third learning unit of the PIC course, students are asked to put into practice their knowledge about computing engineering, electronics and programming to design and build a basic computer mouse, using materials and components that allow them to present it as at least a laboratory prototype.

Similarly, students in the TDI-III course must research and analyze state-of-the-art technology, child psychology, ergonomics, processes and materials involved in their design proposal. Subsequently, the students have to explain to the instructors and classmates from their own discipline the technical capabilities of their design and propose the integration of sensors to include additional functions in the device.

Students in the role of experts

In the case of students on the PIC course, once students have presented their designs to classmates from their discipline, they must explain them to the Industrial Design team students, taking into consideration the use of terminology suitable for non-experts in their technical area, but using a level of conceptualization adequate for coming to an agreement on a functional understanding of the device.

The Industrial Design students, on the other hand, were asked to use creative methods to support their ideas and prepare sketches of conceptual designs of the device to be assembled as a final project. This was done to validate technical design aspects before presentation to their counterparts in Electronic Systems. Once this is done, students present and validate their designs, and obtain feedback from the electronic and computer engineering perspective.

The role of experts in active learning

By the final part of the semester, students from both courses have been fully instructed in the techniques and concepts required to assemble their final projects. At this point, students are experts in their specialty and can explain the technical aspects of their design at any level of conceptual abstraction. Students must be experts to be able to adapt their designs on the basis of the restrictions imposed by the resources available or on changing situations regarding any of the disciplines involved; this is a factor for the successful development of the project.

ACTIVE LEARNING FOR INTERDISCIPLINARY EDUCATION ENVIRONMENTS

The experiments in our work were developed in the context of two engineering disciplines traditionally seen as independent of each other; nonetheless, the interaction of both is necessary for the design and construction of most common consumer electronics, which requires experts from both fields to create products of optimal quality. This motivated us to begin studying the interaction among the students who are to become these experts, as we need to prepare them to perform effectively during this type of interaction. This section describes the experiments performed in the design and construction of the computer mouse and the RIRReD project device.

The importance of being an expert

In the electronic engineering context, this situation leads to poor creativity and, in some cases, low performance, since the interaction between students during the development of the project is limited to classmates of the same discipline. For industrial design, this learning approach leads to very creative project proposals, like the one presented in Fig. 1, a conceptualization of a toy-lamp that can walk on walls and ceilings, but the projects are functionally incomplete and ambiguous due to the lack of knowledge of electronic technology. Moreover, this way of learning does not prepare students for the work environment because in the professional world the interaction among several disciplines is necessary for the development of a commercial project or a consumer device.

For the particular case of electronic systems engineers, the completion of a fully functional project with a well-crafted enclosure promotes better electronic designs by taking into account not just technical matters but also ergonomics, visual aspects, and production and size constraints. This approach provides students with a more realistic insight into the product development process, closer to a professional situation. On the other hand, when industrial design students interact with engineers and realize that not every proposal is feasible, they observe technological constraints and resource restrictions for implementing their ideas into a working device. In general, this multidisciplinary working method makes students confront situations that are closer to the real world.

Noticing aspects that were covered only superficially in these courses, the instructors decided to propose the development of the final project for

Fig. 1. Electronics projects work, but are not appealing to the eye, while industrial designs are creative but not operational.

both courses with a single objective: to end the semester with the development of commercial electronic devices. This interaction between the LDI (Industrial Design Bachelor) and ISE (Electronic Systems Engineer) students took place during the final part of the academic semester, as they worked through the complete process of designing and producing a device.

This project led the students to consider the perception that each group had of the other profession. The engineers changed their perception of product design, becoming aware of dimensions, functionality and aesthetics, aspects that designers regularly take into consideration. The opposite was also true, as designers learned to consider technical aspects and circuit requirements to adapt their design, creating a collaborative environment between the two disciplines.

The consumer electronic design initiative

The first experiment carried out was the design of an interactive computer 'mouse', which can also be classified as an entertainment device.

During the first semester of the interaction, the PIC group was composed of six ISE students and at the same time the TDI-III group was made up of 20 students. To ensure interdisciplinary working teams, the teachers decided to form six teams, each with three designers and one engineer. During this setup stage each engineering student selected a team randomly, without prior knowledge of the design students.

Both groups had different schedules and activity agendas, therefore the instructors had to plan a series of activities in advance within their academic calendars to bring the groups together and to prepare for interaction. According to the calendar, TID-III students had seven weeks for the development of the project (which was the final project for the semester). Meanwhile, for PIC students the project would start during the third block of the semester, when a USB device would be developed [17].

Since ISE students were required to assimilate specific technical concepts in advance, it was decided that they should begin the project by preparing a functional circuit prototype of the mouse which would be the basis for the work to be done by the LDI students. Time for design, measure adjustments, and assembly was taken into consideration so that a fully functional mouse could be obtained as a final result, as shown in Fig. 2.

Simultaneous to the preliminary electronic design by the ISEs, LDIs prepared a series of sketches and brainstormed ideas that, after a series of meetings, would make up the final design of the device, and both groups could then enter the redesign and adjustment phases.

This collaborative learning process took place outside the classroom. Students interacted during their study time and were requested to write a report defining the roles of each of the team members and their contribution to each of the sessions. In addition, students used as a support Blackboard (Bb) [18], a web-based institutional interface in which students can share data, participate in discussion boards, and even interact with the instructors via e-mail; instant messaging (IM) systems such as Microsoft MSN were also used.

The factors of interest

Aside from the students' interest in obtaining a good grade, some of the interest factors in designing and building a fully functional, high-quality final project were as follows:

- being able to take a simple laboratory prototype to a full production concept;
- performing the role of experts in specific aspects of the development of the device, knowing that they would have the final say in the ultimate design and fabrication;
- being able to design and build by themselves a device comparable to commercially available products;
- having guaranteed success in the technical execution of the project by building on previously completed activities.

Revisiting the consumer electronic design project

In the January–May 2006 term, another interaction between these two groups was conducted; however, the PIC course was not programmed. The interaction between design and engineering students took place with a different focus. For

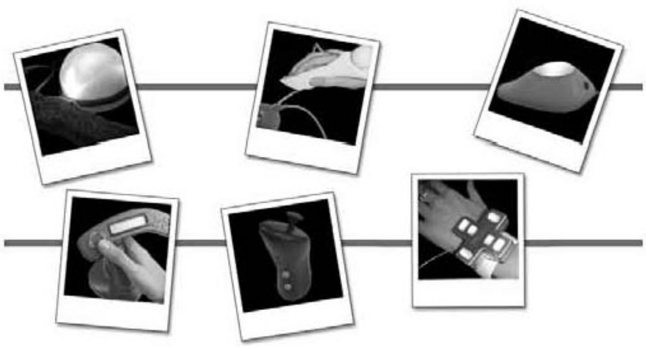

Fig. 2. First interdisciplinary final project prototypes.

this second term, two groups of LDI students participated; TDI-III's theme was the same, the development of a high- technology toy or an interaction device. On the other hand, the Computer Science Department had a project for a device called RIRReD (Interactive Network for Answers Recompilation on Demand). The objective for the LDI students became the development of the casing for the RIRReD device with the technological limitations established by the Computer Science Department.

RIRReD is an individual device used to gather data in a network that provides support for didactic techniques in the classroom and allows the instructor to measure promptly the results of surveys, quick exams, etc. RIRReD is a compact device that is 8.5-cm long, 4-cm wide and 2-cm thick. It has a USB connection for a computer and four buttons (one for each multiple choice answer) plus one reset button and an access for the battery. The general concept for this project is shown in Fig. 3.

During this academic experiment, the LDI students had tutorial support in the electronic aspects of the device. Even though the electronics were already designed, it was important to have support from an engineer, particularly for technical adjustments of dimensions, buttons and lights layouts, the space for the battery, and the USB port.

The methodology used during this experiment was the same as in the past: each of the student meetings was conducted outside the classroom, with or without an instructor, and had to be recorded in minutes describing each teammate's role and contribution.

The phase of conceptual development was complemented with different methods, such as Random Words and Brainstorming [19] with free sketching; this was done with the intention of developing the students' creativity and obtaining more innovative ideas. The LDI students could suggest extra technologies for the RIRReD that would be left in the conceptual phase; they could, however, be a guideline for ideas for the development of a new circuit. The previously stated objectives were accomplished and the result was eight proposals for RIRReD, six with USB ports and two with a control type device; some of these prototypes are shown in Fig. 4.

This second case produced the same interest factors as the mouse project. As in the first case, the teams were composed of people from both areas, interaction was more complete and engaging, as well as more complex and demanding, both for the students and the instructors.

The factors of success

Interdisciplinary experiments such as those presented in our work have been carried out and researched, but in many cases there has been difficulty in leading these experiments to success. Our experiences have been quite the opposite, and we attribute this to the following factors:

- setting challenges and goals appropriate to the level of student expertise;
- taking into account the required time and competencies (knowledge, abilities, aptitudes and values);
- having the infrastructure, materials, tools, techniques and alternate options that allowed the students to carry their proposals to a successful conclusion;
- carefully planning the preparation activities for each group by setting them up in way that ensured that students had the technical expertise needed in their performance areas prior to the interdisciplinary work;
- advising the students so that their proposals were adequately limited by the constraints of the academic courses in which they were developed.

The WOW factor for students

Once the projects were completed, students expressed their opinions about the final project, both orally and in writing, through the Bb platform. In general, the academic impact of this

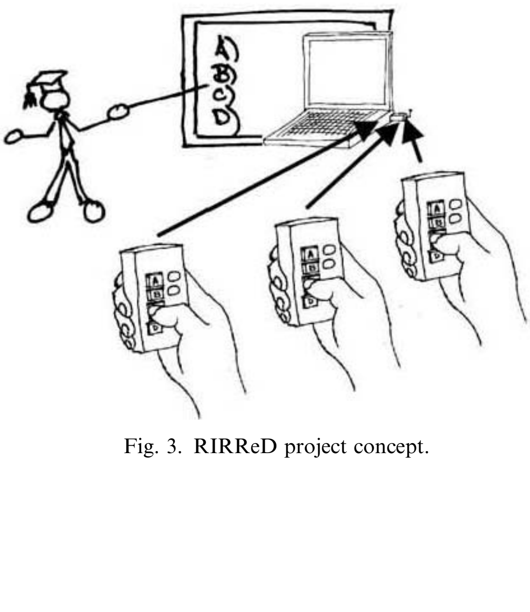

Fig. 3. RIRReD project concept.

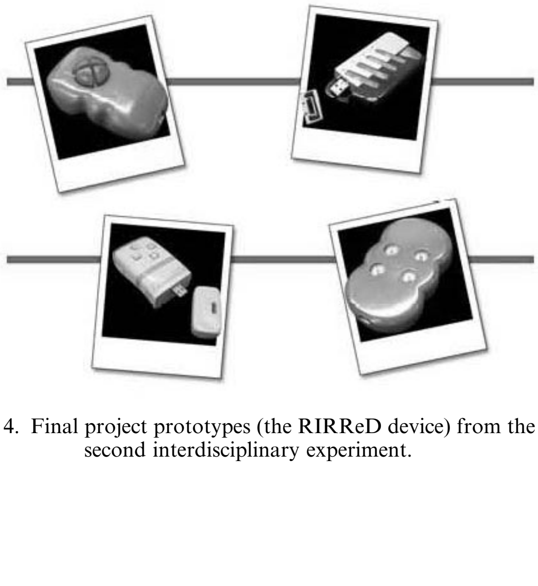

Fig. 4. Final project prototypes (the RIRReD device) from the second interdisciplinary experiment.

interdisciplinary experience was considered enriching. The following aspects can be highlighted.

- The methodology permits the use of creativity, but in a realistic way, congruent with the technical and material constraints.
- The fact that the final product is a fully functional device is highly motivating, giving the students the conviction that they are capable of designing commercially feasible products in their professional field.

The WOW factor for instructors

From the didactic perspective, we as instructors can highlight that this type of interdisciplinary experience gives students the opportunity to assume the role of experts within their field, and to adjust their designs and concepts to constraints relevant to a real production process. In addition, performing an expert role reinforces the use of collaborative and instructional techniques among teammates as a tool for active learning. Finally, instructors obtain satisfaction watching their students take pride in the results of their work.

ADVANTAGES OF INTERDISCIPLINARY COLLABORATIVE ACTIVE LEARNING

Our methodology applied in two undergraduate courses in independent contexts gave us the opportunity to confirm the advantages of collaborative active learning during the development of an interdisciplinary final academic project. Our observations indicate that students produce better final work, as they are more motivated and committed to performing at high standards of quality, which confirms similar conclusions from other related works [15]. Learning is also reinforced as students take on the role of experts, explaining and justifying their design to students with a different professional profile, and resolving implementation problems caused by limited time and resources.

The observations obtained through our experiments suggest that this methodology can be further structured for future application, and that it may also incorporate other professional disciplines or be adapted to other academic environments.

Enriching experiences

In general, results from both experiments could be reported from the following three perspectives: overall final device quality and performance; optimality of collaborative work methodology; and interaction attitudes.

In the mouse project, from the first interaction, each working group of students was organized into two areas: design and electronics because only six engineers were available. The electronics component consisted of just one person on each team, while four to five designers were assigned to each group. Role playing was an interesting collaborative work methodology to test in our experiment. In addition, the electronics engineer or the industrial designer was assigned one of the following roles during each formal interaction: group leader, secretary, or working collaborator. Interactions, formal and virtual, were registered and archived in Bb File Exchange, Digital Drop Box and Discussion Forum. This scheme proved to be optimal for this kind of academic project. Further observations will be discussed next.

The recorded interactions between students showed three exceptional aspects, described as follows: in each group, collaborative work methodology promoted role commitment. However, we noticed that the project leadership was not kept as initially arranged by students. Instead, this shifted from time to time in almost every group. This leadership issue is particularly interesting since each group should have a design leader and an engineering leader, but project leadership changed mainly among the industrial design students. In the next section, we will state our conclusions about this.

Documented evidence in Bb discussion groups led us to review another noteworthy aspect of our experiment. Every group started the suggested activities on time and reported their project progress punctually; these periodic reports influence the monthly grade of every student, not just for TDI-III, but also for the PIC course. We believe that these conditions make students more responsible towards their teammates. They are not affected by the evaluation performed by instructors from the other field, but they do feel committed towards their counterparts' good evaluations.

Another interesting observation was that the explanations among students, specifically to clarify technologies or limits to the project, were technically justified and written in expert language. We consider this one of the most valuable aspects of the project because students actively assumed the role of experts while explaining their ideas to their teammates. This is important because this behavior is not the same when CL techniques are applied to groups of the same discipline, and because the knowledge of certain concepts is assumed. This experiment allowed the students to assume the role of expert in a real project, with the responsibility to technically justify their decisions and commit to the team's working plan.

Our guidelines

Our experience shows that to repeat the success of these implementations, the following aspects are required:

1. selecting the general subject of the partial and final projects so that knowledge from both courses is integrated, and ensuring that students have the appropriate competencies once they begin their interaction;
2. limiting the scope of the projects to make them congruent to the cognitive level of the course;

but also making them real-world projects (this could be difficult to achieve but, as verified in our work, it is a key factor for motivating the participants);
3. establishing time, resource and cost constraints congruent with course work loads;
4. planning learning activities in a way that reinforces concepts and methods throughout the development of the project;
5. establishing from the start detailed metrics for project evaluation, including the final result and the design and construction process;
6. preparing the appropriate documentation forms and explaining them to students;
7. identifying knowledge areas required for the completion of a project and assigning students of each professional profile to teams in the right proportion, ensuring that each team has the necessary techniques to complete the product;
8. following the advances in each project's development and suggesting modifications to the working plan when convenient;
9. documenting team interaction through written minutes, whether formal or informal, electronic or on paper.

MORE TO LEARN

From interdisciplinary to multidisciplinary

Future extension of our work may include students from other academic disciplines in this type of final project, with which we will try to analyze the effect of these work environments in multidisciplinary contexts and broaden the reach of our guidelines for the development of academic activities for these types of courses.

We believe that POL confined to one discipline is a limited learning strategy, while the use of POL and CL in multidisciplinary groups can promote active learning attitudes and reinforce individual learning. Also, this interaction can effectively lead to teaching optimal project planning activities, using resources efficiently, and promoting group commitment and the development of better interpersonal skills.

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