Active Learning in first-year engineering courses at Universidad Católica de la Santísima Concepción, Chile

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ABSTRACT

This paper describes our experiences using Active Learning in four first-year computer science and industrial engineering courses at the School of Engineering of the Universidad Católica de la Santísima Concepción (UCSC), Chile. This work corresponds to the implementation stage of the curriculum reform using a CDIO-based approach that is currently underway at the School of Engineering, and which was previously described in [1]. Before this curriculum reform process, both first-year computer science and industrial engineering students had only one introductory course to their field of study, meeting just once a week for an hour. After the curriculum reform process, first-year computer science students take an Introduction to Computer Science course during the first semester, and a Programming Laboratory during the second semester. Similarly, the industrial engineering program now includes an Introduction to Industrial Engineering in its first semester and an Engineering Communication course in its second semester. These four first-year courses have been designed using CDIO standards 1, 4 and 8 as guidelines and have been formulated to include active learning in its many forms such as project-based learning, problem-based learning, case studies, small group discussions, oral presentations and reflective memos. The impact of the redesign of these first-year courses was assessed via anonymous student surveys taken the first week of class and at year end. Students also had to submit a short reflective memo on their experiences with each course. Our results show an improvement in student understanding of their professional endeavor and increased student motivation for their engineering programs. Student surveys registered high degrees of satisfaction with active learning techniques. Students also really appreciate working in teams, and receiving immediate feedback both from their instructors and their peers.

KEYWORDS

Active Learning, CDIO-based curriculum reform, engineering education.

INTRODUCTION

In 2008, the School of Engineering of the Universidad Católica de la Santísima Concepción began its curriculum reform process using a CDIO-based approach of five engineering programs. The Conceive and Design phases have been completed to date, and the Implementation phase was begun in 2011. Several results of the first two phases were presented at the 2011 CDIO Conference [1]. This paper focuses on the implementation phase relative to the first year of two engineering programs, Computer Science and Industrial Engineering.

Most engineering programs in Chile are six-year programs leading to a professional degree [2], [3]. At the Universidad Católica de la Santísima Concepción, the first three years of its engineering programs were dedicated toward building a strong foundation in mathematics and sciences such as physics and chemistry. Even though the first three years included a few technical and professional courses, most of them were taught in the program's last three years. Feedback from students gathered through our last program accreditation process in 2010 showed that their motivation was affected by this math and science-heavy curriculum, and by the fact that students did not become properly familiarized with their chosen profession until relatively late in their studies.

FIRST-YEAR CURRICULUM REFORM

The curriculum reform process at UCSC addresses this motivational problem in the first years by incorporating first-year courses designed following a CDIO-based approach [4] and using CDIO standards 1, 4 and 8 as guidelines [5]. This section briefly describes these courses. As can be determined from the course descriptions, the courses follow CDIO standard 1 (*CDIO as Context*), in that they aim to illustrate the Conceive-Design-Implement-Operate principle, and also CDIO standard 4 (*Introduction to Engineering*), in that they provide a framework for the practice of the particular engineering discipline and stimulate students' interest in, and strengthen their motivation for their field of study. These courses also focus on developing personal and interpersonal skills and attitudes that are essential for their academic and professional development. How these courses relate to CDIO standard 8 (*Active Learning*) will be described in the Active Learning section.

The first-year course load of the computer science program at UCSC was modified to include two semester-length introductory courses, as shown in Figure 1.

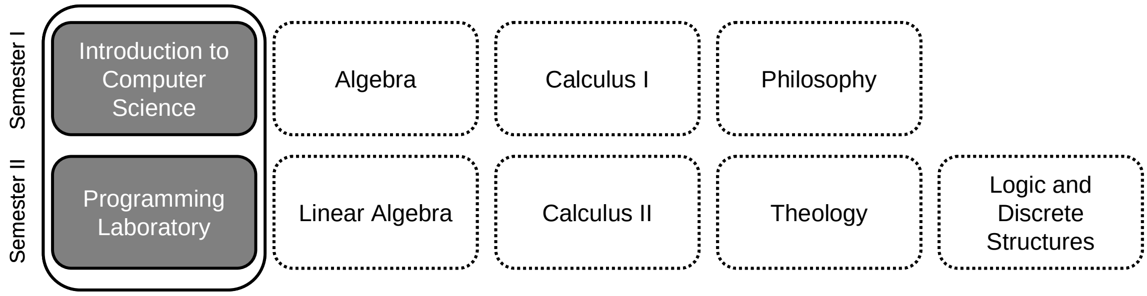

Figure 1. Computer Science first-year course load

In the first course, Introduction to Computer Science, students become acquainted with their chosen field and professional role and with the software lifecycle by developing a project from its conception to its operation. This course aims to develop skills such as oral and written communication skills, planning, model construction, the elaboration of problem solving strategies, critical analysis and teamwork. This course meets for 8 hours a week.

The second course is a Programming Lab where teams of students analyse computer science problems and design solutions following a structured approach, in which each stage of the process is supported by specific tools and techniques. This course allows students to engage in programming and also to develop personal skills for self-learning and teamwork. This course meets for 5 hours every week.

The first-year course load of the industrial engineering program at UCSC was also modified so as to include two semester-length introductory courses, as shown in Figure 2.

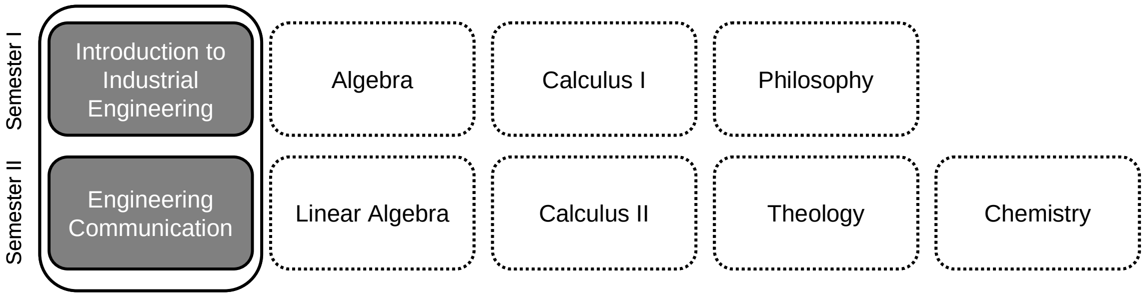

Figure 2. Industrial engineering first-year course load

The first course is called Introduction to Industrial Engineering, and prepares students for their academic life by giving them the tools necessary to understand the vision, activities and problem-solving skills of an industrial engineer, taking into account the scientific background and technological foundations of their field of action. It seeks to cultivate the ability to analyze problems and propose solutions through systematic decision-making processes. It also aims to develop skills for independent work planning and team work, and gives students the basic tools to improve their reading comprehension and written communication skills. This course meets for 8 hours a week.

The Engineering Communication course during the second semester provides students with several communications skills, particularly oral expression skills and the use of graphical display tools. Students also receive training on basic tools for project planning. This course meets for 4 hours a week.

Table 1
CDIO syllabus goals associated with each first-year course

CDIO Syllabus goals		CS1: Introduction to computer science	CS2: Programming lab	IE1: Introduction to Industrial Engineering	IE2: Engineering communication
Technical knowledge and reasoning	1.2 Core engineering fundamental knowledge	x	x	x	X
Personal and professional skills and attributes	2.1 Engineering reasoning and problem solving		x		
	2.3 System thinking			x	X
	2.4.6 Curiosity and lifelong learning		x		
	2.4.7 Time and resource management	x	x	x	
	2.5.3 Proactively planning for one´s career	x			
Interpersonal skills: teamwork and communication	3.1 Teamwork	x	x	x	
	3.2 Communication	x		x	X
	3.2.3 Written communication	x		x	X
	3.2.4 Electronic/Multimedia communication	x		x	X
	3.2.5 Graphical communication				X
	3.2.6 Oral presentation and interpersonal communication	x			X
Conceiving, designing, implementing and operating systems in the enterprise and societal context	4.1 External and societal context	x		x	
	4.2.1 Appreciating different enterprise cultures	x			
	4.3 Conceiving and engineering systems	x			X
	4.4 Designing	x			

Table 1 presents the first-level, second-level and third-level CDIO Syllabus goals associated with each of these four first-year courses. Many of these skills and attitudes are developed across the curriculum and so they are addressed again in later courses. Moreover, several of these, such as effective communication, teamwork, and lifelong learning, are present in the UCSC institutional pedagogical model, and constitute part of the hallmark with which UCSC strives to brand all its graduates.

ACTIVE LEARNING

The design of the four first-year courses mentioned above follows CDIO standard 8, and incorporates active learning methods such as small group discussions, demonstrations, concept questions, case studies and project- and problem-based learning, among others.

In particular, the Introduction to Computer Science course applies project-based learning by assigning students to small teams that work on different projects on subjects as diverse as storytelling via Alice: a 3D programming environment [6], and LEGO robotics. Students learn programming tools and techniques via mini labs. Also, three times during the semester they must submit status reports and give oral presentations describing their project status. Additionally, computer science professionals are invited to talk about their work and their role in industry and society. After each talk, students must turn in a reflective memo relating the talk's subject to their own career interests and future goals. Incoming students are divided in groups of about 20, and each group is assigned an instructor to guide students with their project, another instructor to help them understand their chosen field and professional role, and a third instructor to assist them in developing oral and written communication skills.

The Programming Lab course follows a problem-based learning approach. Initially, students are introduced to software development via lectures, demonstrations, animations and brainstorming. Then, students learn how to program by solving problems using the analysis-design-programming-testing methodology. In each class session, the instructor solves a few problems applying this methodology, and then students must individually apply it to solve other given problems. In the last part of the course, students are divided into teams to solve harder, randomly-assigned well-structured projects. Each team must organize itself, define roles and communication schemes, schedule their work and turn in a weekly progress report. Finally, teams present their results, assess their teamwork and discuss the technical difficulties they encountered and the programming methodology used.

In the Introduction to Industrial Engineering course, students learn about the industrial engineer's field of work and role in society by creating videos in teams, in which they interview practicing professionals. Several industrial engineering topics such as project management and planning, leadership and teamwork, systems theory and decision criteria are introduced via small group discussions and debates, concept questions and mapping, student-created charts and models, brainstorming and case studies. They also learn about their field by dividing into teams and solving typical industrial engineering problems such as the cutting stock problem. In many cases, teams must present their work via oral presentations and written reports.

The Engineering Communication course introduces students to a wide range of graphical engineering communication tools such as graphs, flow and process diagrams, Pareto diagrams, cause-effect diagrams, graphs and networks. Teams of students review these topics by analyzing newspaper clippings, debating their usefulness and discussing alternative ways of presenting the data. Other topics such as logistic networks, plant layout diagrams, product line representations and organizational structures are reviewed via case studies in which student teams must visit local industries and develop their own graphical models. Students also learn technical drawing by interpreting and describing blueprints and by solving problem sets. Student teams present their results via oral presentations and written reports.

Additionally, in all courses except for the Programming Lab course, course instructors work in coordination with personnel from the Spanish department to support the development of those written and oral language skills needed by the students in the context of their coursework.

Table 2 relates the active learning methods used in each course with the CDIO Syllabus goals presented in Table 1.

Table 2
Active learning methods used in first-year courses to develop CDIO Syllabus goals

CDIO Syllabus goals		Problem set	Brainstorming	Demonstrations	Concept mapping	Student-created charts, flowcharts, models	Conceptual questions	Case studies	Mini labs	Macro labs	Small group discussions	Student debates	Presentations	Reflective memos	Student field work with reflection	problem based learning	Project based learning
Technical knowledge and reasoning	1.2	CS2	IE1 IE2	CS2	CS2		CS1 CS2 IE1 IE2	CS1 IE1 IE2	CS1		IE1 IE2	IE1			IE1	CS1	
Personal and professional skills and attributes	2.1	CS2	CS2	CS2		CS2					CS2					CS2	CS2
	2.3				IE1 IE2			IE1			IE1 IE2	IE1					
	2.4.6	CS2							CS2	CS2						CS2	
	2.4.7					CS1 IE1					IE1						CS1 CS2
	2.5.3													CS1	CS1		
Interpersonal skills: teamwork and communication	3.1					CS2		CS1 IE1			CS1 CS2 IE1 IE2	IE1 IE2	IE1			CS2	CS1 CS2
	3.2					CS1					CS1 IE2		CS1 IE1 IE2	CS1 IE1	CS1		
	3.2.3				IE2			IE2					IE1 IE2	IE1			
	3.2.4	IE2				CS1 IE2			CS1 IE1 IE2				IE2				CS1
	3.2.5	IE2				IE2							IE2				
	3.2.6							IE2					IE2				
Conceiving, designing, implementing and operating systems in the enterprise and societal context	4.1	IE2	IE1			IE2	IE1				IE1 IE2	IE1		CS1	CS1 IE1		
	4.2.1													CS1	CS1		
	4.3																CS1
	4.4																CS1

RESULTS AND DISCUSSION

The impact of the redesign of these first-year courses was assessed via anonymous student surveys. 72 computer science students and 123 industrial engineering students were surveyed the first week of class, and 54 computer science students and 72 industrial engineering students were surveyed at year end. Each program did an independent evaluation, which led to slightly different surveys. Students also had to hand in several short reflective memos throughout each course. Space requirements preclude us from presenting full results, so representative results are shown in the following subsections.

Computer science survey results

Computer science students were asked to rank the personal and professional skills and attributes, and interpersonal skills associated with each first-year course, as shown in Table 1, by their perceived level of achievement. These rankings are shown in Table 3.

Table 3
Level of achievement of personal and interpersonal skills

Rank	Introduction to Computer Science	Programming Laboratory
1	Teamwork	Teamwork
2	Time and resource management	Time and resource management
3	Oral and written communication	Curiosity and lifelong learning
4	Proactive career planning	Engineering reasoning and problem solving

In both courses, first-year students rank teamwork and time and resource management at the very top of their achievements list. This is encouraging, as these personal and interpersonal skills are of paramount importance in academic and professional life. Also, it is a well-known fact that many first-year students accepted to the school of engineering at UCSC present deficiencies in oral and written communication skills. Students perceive low to moderate levels of achievement in these skills in both courses, even though instructors from the Spanish department assisted Introduction to Computer Science students throughout the semester. This joint endeavour by Engineering and Spanish department instructors is a novel experience that we hope can be improved in the future.

Students were also asked to rank the different active learning techniques used in each course shown in Table 2, by their perceived usefulness to the achievement of each course's learning outcomes. Table 4 summarizes these results.

Table 4
Usefulness of teaching and learning methodologies

Rank	Introduction to Computer Science	Programming Laboratory
1	Project-based learning	Project-based learning
2	Concept questions	Small group discussions, demonstrations
3	Small group discussions	Problem-based learning
4	Problem-based learning	Mini labs
5	Mini labs, reflective memos	Concept questions

Students appreciate working on medium to large projects that are challenging and well-structured. Concept questions are also highly ranked, as students find them thought-provoking and helpful for critical thinking development. It is illustrative to note that most methods identified by the students as useful are team-based techniques, and so are likely to encourage teamwork and help develop time and resource management skills. Thus, these results are in accordance with Table 3.

Surveys taken for our program accreditation process showed that most first-year computer science students entered the program without a clear and complete understanding of their chosen field, and that they acquired a fuller comprehension of their program goals much later in their studies. In order to measure the impact of our reforms, students were asked to identify skills and attitudes relevant to the computer science program goals through surveys taken at the beginning and at the end of the first year. Figure 3 presents evidence that students now have a better understanding of their program goals.

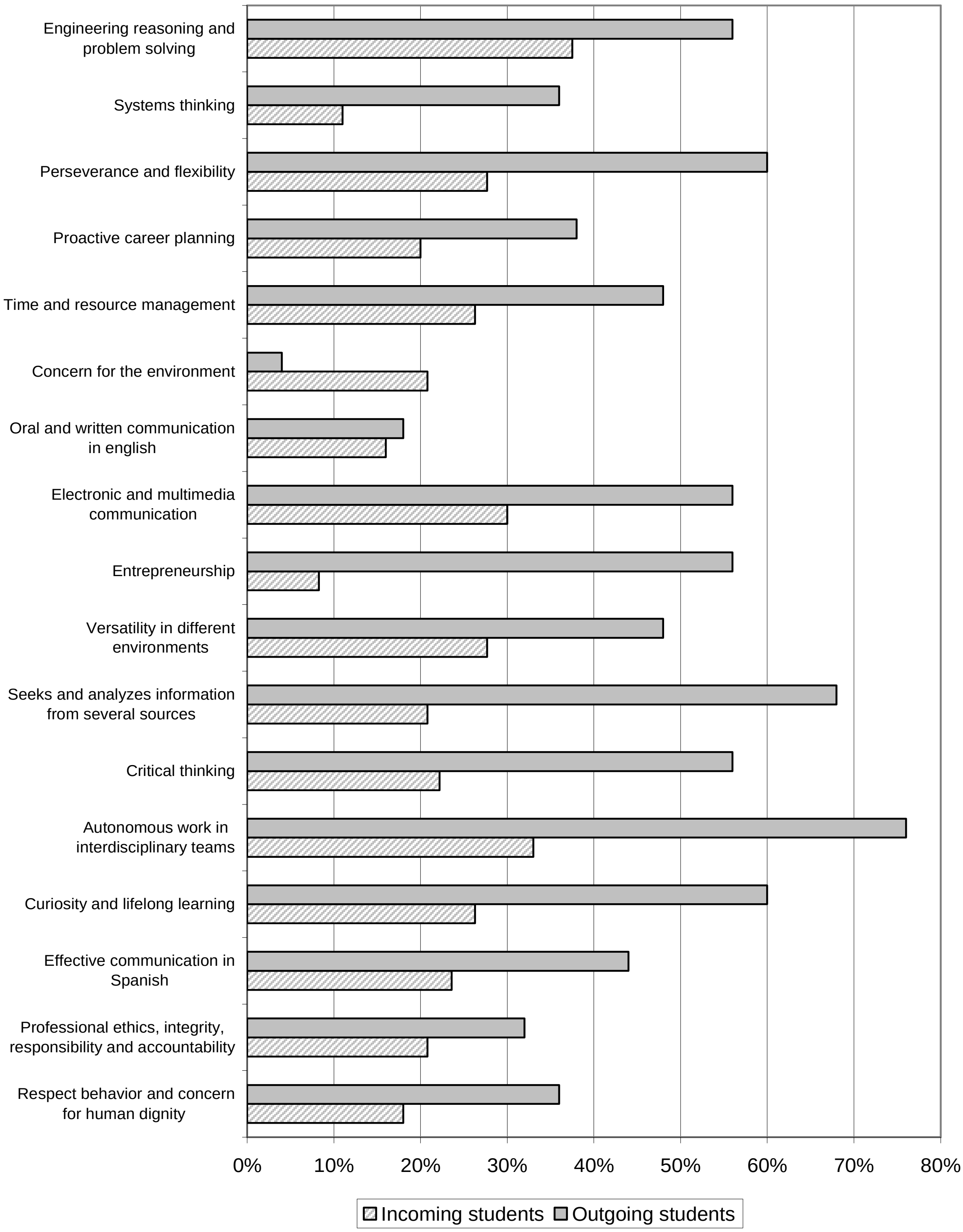

Figure 3
Skills and attitudes that students recognize in the computer science program goals

The survey also captured student opinions of the instructor's role and of themselves. Students were asked to evaluate whether the instructor actively guided their learning, and also whether the activities designed by the instructor facilitated their learning process. Also, they were asked to evaluate their own participation in said activities. In Figure 4, the higher bars correspond to the Introduction to Computer Science course and the lower bars belong to the Programming Lab course.

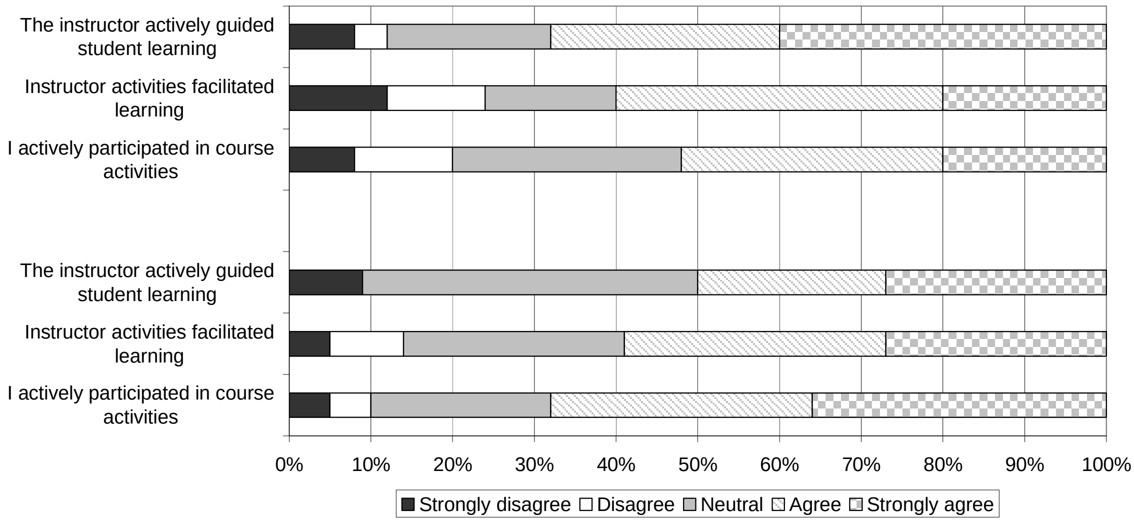

Figure 4.Instructor and student roles in first-year CS courses.

From the results, we see that the instructor's new role as facilitator rather than lecturer is not fully recognized by the students. Possible causes for these results are that students themselves have a hard time taking on a more active role in class, and also because not all instructors have received formal training in active learning techniques. This is being addressed by a newly-created UCSC Teaching and Learning Center.

Industrial Engineering survey results

Industrial engineering students were asked to evaluate the usefulness of their first-year courses to the development of their personal and professional skills and attitudes as well as interpersonal skills related to teamwork and communication shown in Table 1. Figure 5 lists some of these skills indicating the courses' perceived usefulness to their development.

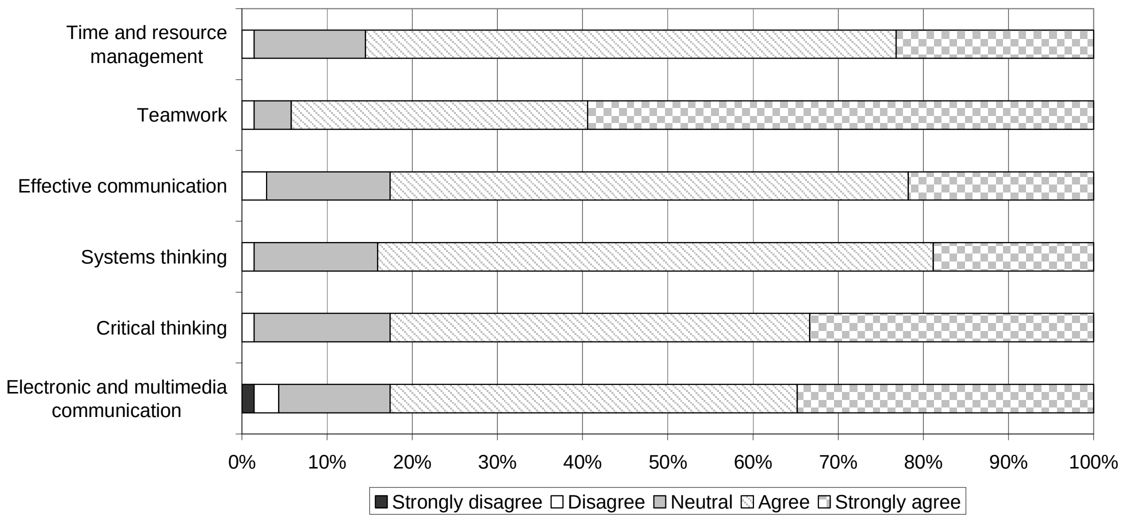

Figure 5. Perceived course usefulness to skill development

Figure 6 shows the perceived usefulness of the active learning techniques listed in Table 2 to the accomplishment of the courses' learning outcomes.

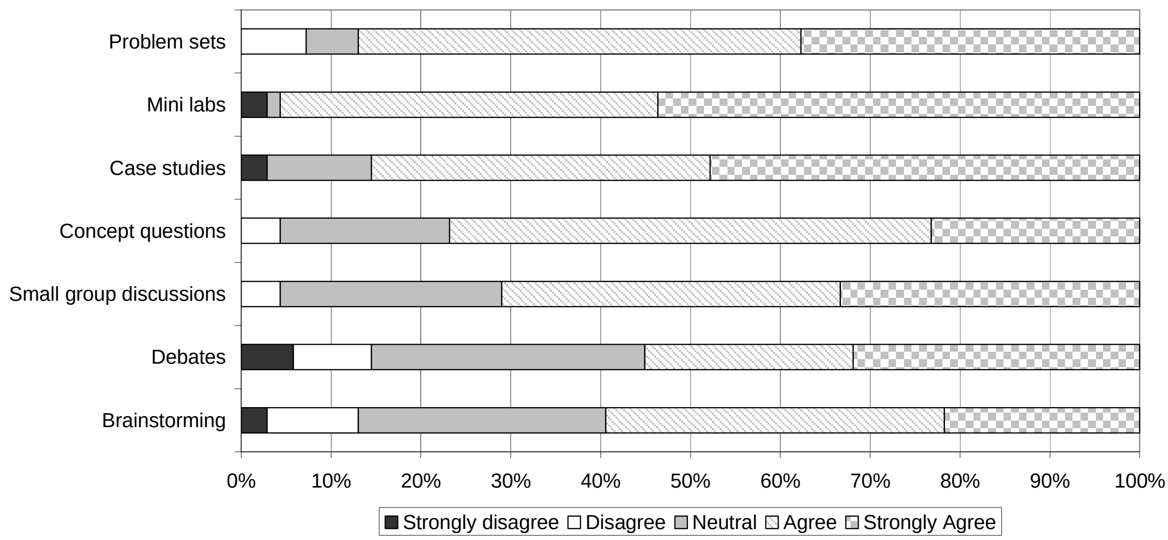

Figure 6. Perceived usefulness of active learning techniques.

Likewise, Figure 7 shows the percentage of students reporting the achievement of specific learning outcomes associated with the Introduction to Industrial Engineering and Engineering Communication courses.

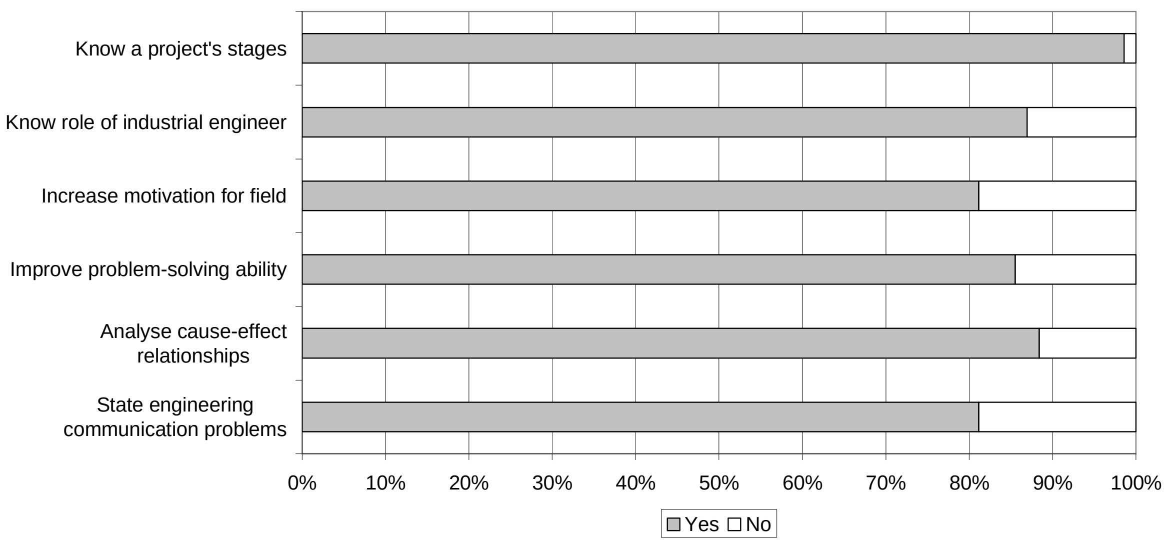

Figure 7. Perceived learning outcome accomplishment in the Industrial Engineering first-year courses.

Finally, Table 5 summarizes the various skills and attitudes that students recognize in the industrial engineering program goals at the end of the first year. These results show that, by year end, most first-year students have become familiarized with their chosen profession's field of work and professional endeavors.

Additionally, survey results state that 58% of industrial engineering students acknowledge having actively participated in class, 74% answered that the instructor properly guided their work and 78% recognized that the instructor's activities helped them achieve their learning outcomes.

Table 5
Skills and attitudes that students recognize in the industrial engineering program goals

Industrial Engineering program goals	Percent
Engineering reasoning and problem solving	98%
Systems thinking	85%
Perseverance and flexibility	73%
Proactive career planning	44%
Time and resource management	97%
Concern for the environment	56%
Oral and written communication in English	50%
Electronic and multimedia communication	81%
Entrepreneurship	85%
Versatility in different environments	68%
Seeks and analyzes information from several sources	72%
Critical thinking	98%
Autonomous work in interdisciplinary teams	82%
Curiosity and lifelong learning	69%
Effective communication in Spanish	89%
Professional ethics, integrity, responsibility and accountability	66%
Respect behavior and concern for human dignity	72%

Comments from reflective memos

In both programs, students were asked to comment on the active learning techniques used in their classes, and on their experience working in teams. In general, students recognize some difficulties associated with becoming more actively involved in their own learning process, and their instructors´ new role. For example, one student said "*It was a good class, but I had to keep up on the reading material uploaded by the teacher*". Another student stated "*The teacher never explained in detail how to use an array; she just put us to program with them*". A student even said that the course was "*Too much work for the student, I prefer traditional courses*". On the other hand, most students value the increased interaction with their peers, which is illustrated by comments such as *"Whatever I don't know another teammate knows, and so we complement our knowledge and ideas to make a better project*". Another student says "*Very interactive class, I feel more motivated in it*".

CONCLUSIONS

The results discussed in this study correspond to the first cohort of students that took these four first-year courses in 2011. Our results, gathered from student surveys and from the students´ reflective memos, show an improvement in student understanding of their professional endeavour and increased student motivation for their engineering programs. Active learning methods help students rapidly make connections between theoretical issues and practical situations, thus helping them learn in context. The surveys also registered high degrees of satisfaction with some active learning methods, such as project-based learning, small-group discussions, demonstrations and case studies. From the reflective memos, we learn that students really appreciate teamwork and receiving immediate feedback from their instructors and from their peers.

From the student surveys and from our own experience with these new first-year courses, we see that, initially, students have a hard time getting used to the new role of the instructor from being a lecturer to being a learning facilitator. Also, it is hard for them to overcome their passiveness and inertia and to get them to actively participate in class. Moreover, in some cases, students refused to take charge of their learning and complained about the instructor's new role. But, by the end of the courses, most students appreciate being actively involved in their own learning process.

The introductory courses described above were taught by several instructors, some of which had not undergone training with active learning methods, so they had to learn this novel approach throughout the course. Instructor inertia and a lack of experience in active learning methods are factors that are being addressed through the UCSC Teaching and Learning Center. Instructors teaching an active-learning based course agree on the need for substantial time investment in course preparation and student assessment. Also, instructors must constantly stimulate students through concept questions, examples and demonstrations to guide the learning process and motivate students. Thus, course instructors could better serve the needs of the students with the help of more teaching assistants.

Many first-year students accepted to the school of engineering at UCSC present deficiencies in oral and written communication skills. The incorporation of Spanish department instructors is a step in the right direction that requires a better articulation between the disciplines and continuous coordination among instructors.

A lesson learned from the past year's experience incorporating active learning to these first-year engineering courses both by students and instructors was the need for new suitable learning spaces. Consequently, there is work underway on remodeling and on creating new labs, and also ongoing work on a new classroom building that will begin operations in 2013.

This has also been a valuable experience for all people involved. We had previously collaborated in engineering program conception and design, as shown in [1]. We are certainly still learning to collaborate in implementing and operating these redesigned programs. In the future, we expect to develop and unify systems for continuous program monitoring and evaluation.

New generations will face a rapidly-changing world with new challenges and opportunities. At UCSC, we are confident that our new CDIO-based curriculum is a step in the right direction, by helping students become autonomous and self-reliant professionals.

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