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, Chile. This work corresponds to the implementation stage of the curriculum reform using a CDIO-based approach currently underway at the School of Engineering. Before this reform, students had only one introductory course to their field of study, meeting one hour a week. After the reform, computer science students take an Introduction to Computer Science course and a Programming Laboratory. Similarly, the industrial engineering program now includes an Introduction to Industrial Engineering and an Engineering Communication course. These 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 redesign impact was assessed via anonymous student surveys and reflective memos. Our results show improved student understanding of their professional endeavour and increased student motivation for their engineering programs. Student surveys registered high degrees of satisfaction with active learning techniques, working in teams, and receiving immediate feedback from instructors and peers.*

KEYWORDS: Active learning; CDIO-based curriculum reform; engineering education.

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1 INTRODUCTION

In 2008, the School of Engineering of the Universidad Católica de la Santísima Concepción (UCSC) 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 (Loyer et al, 2011). 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 (Music, 2002; Vial, 2005). At the UCSC, 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

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familiarised with their chosen profession until relatively late in their studies.

2 FIRST-YEAR CURRICULUM REFORM

The curriculum reform process at UCSC addresses this motivational problem in the first years by incorporating first-year courses inspired by Johns (2006) and designed following a CDIO-based approach (Crawley et al, 2007), using CDIO standards 1, 4 and 8 as guidelines (Brodeur & Crawley, 2005). 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 illustrate the Conceive-Design-Implement-Operate principle (Crawley, 2008), 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.

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. It 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. It meets for 5 hours a 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.

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 analyse 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. It 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. It meets for 4 hours a week.

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

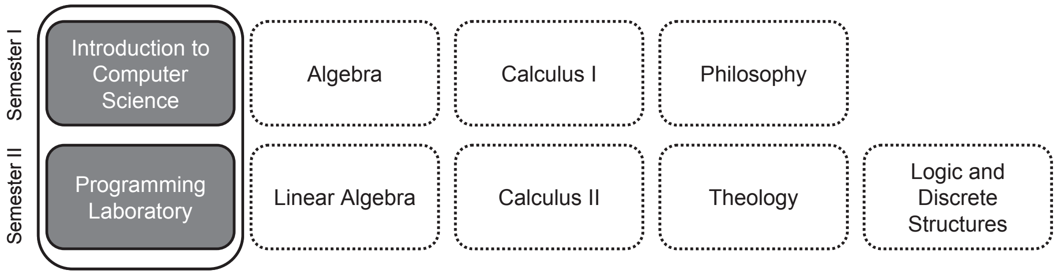

Figure 1: Computer Science first-year course load.

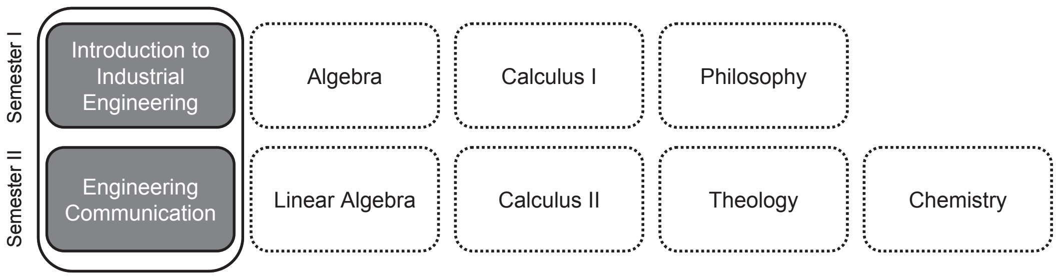

Figure 2: Industrial Engineering first-year course load.

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

CDIO Syllabus goals		**CS1**	**CS2**	**IE1**	**IE2**
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			

CS1: Introduction to Computer Science; CS2: Programming Lab; IE1: Introduction to Industrial Engineering; IE2: Engineering Communication

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.

3 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 (PBL), among others (Hall et al, 2002; Smith et al, 2002; Prince & Felder, 2006; Mills & Treagust, 2003).

In particular, Introduction to Computer Science students are divided in groups of about 20. 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. This course dedicates 4 hours a week to project-based learning (Mills & Treagust, 2003; Prince & Felder, 2006) by assigning students to small teams that work on different projects on subjects as diverse as storytelling via Alice: a 3D programming environment (Dann et al, 2011), 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. The course dedicates 2 hours a week to learning the role of computer science professionals in industry and society by having computer science professionals 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. Finally, students meet with an instructor from the Spanish Department of the university for 2 hours a week to improve their grammar, essay writing and oral presentation skills.

The Programming Lab course follows a PBL approach (Ellis et al, 1998; Eversen & Hmelo, 2000). In this approach, students work with classmates to solve complex and authentic problems that help develop content knowledge as well as problem-solving, reasoning, communication, and self-assessment skills (Center for Teaching and Learning, 2001). These skills are declared explicitly as learning outcomes in the course syllabus. This active methodology is based on the idea that students learn more effectively when they can experiment and solve problems requiring intellectual effort where answers are not known beforehand, thus requiring them to make decisions in the analysis and design stages (De Miguel, 2006). At the same time, the essence of cooperative learning is positive interdependence: students recognise that "we are in this together, sink or swim". Cooperative learning situations are characterised by individual accountability, where every student is accountable for both learning the assigned material and helping other group members learn; face-to-face interaction among students; and students appropriately using interpersonal and group skills (Johnson et al, 1999).

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 organise 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 via a reflective memo. At the same time, the instructor applies a process-product rubric to assess technical aspects of the project, and a teamwork assessment rubric.

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, to study their work endeavours and determine their strengths and weaknesses in their field.

Several industrial engineering topics such as project management and planning, leadership and teamwork are introduced via student field work with reflection. Students are divided into teams and asked to identify simple business problems and propose solutions using decision criteria, through small group discussions. The systems theory and decision criteria topics are introduced via small group discussions and debates, which are expected to develop knowledge, understanding and judgement among those taking part (Brookfield & Preskill, 1999), concept questions and concept maps are used to represent meaningful relationships between concept through a visual representation, and provide students with a schematic summary of what has been learned (Novak & Gowin, 1984), student-created charts and models, brainstorming and case studies. In these last two cases, course instructors present the course materials. Then, concrete cases of varying length are studied, following the course's design and in accordance to its goals and themes (De Miguel, 2006). 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 (Frías, 1998).

The Introduction to Industrial Engineering course dedicates 6 hours a week to industrial engineering topics, while 2 hours a week are dedicated to written communication skills, taught by an instructor from the Spanish Department of the university.

The Engineering Communication course exposes students to a wide range of graphical engineering communication tools such as graphs, flow and process diagrams, Pareto diagrams, cause-effect diagrams (Ishikawa, 1994), graphs and networks. Teams of students review these topics by analysing 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 organisational 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.

The Engineering Communication course dedicates 3 hours to industrial engineering topics and 1 hour to oral communication, with an emphasis on effective presentations, which is taught by an instructor from the Spanish Department of the university.

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

4 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.

4.1 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.

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

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

CDIO Syllabus goals		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
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		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

1 = problem set; 2 = brainstorming; 3 = demonstrations; 4 = concept mapping; 5 = student-created charts, flowcharts, models; 6 = conceptual questions; 7 = case studies; 8 = mini labs; 9 = macro labs; 10 = small group discussions; 11 = student debates; 12 = presentations; 13 = reflective memos; 14 = student field work with reflection; 15 = problem-based learning; 16 = project-based learning.

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

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 summarises these results.

Students appreciate working on medium- to large-size 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

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

Table 5: CIDD teaching skills program.

ID	Certification	Description
PCP1	Learning outcomes-based course design	Educate faculty in designing courses based on learning outcomes and in developing course programs and syllabi using student-centred methodologies.
PCP2	Active learning methodologies	Educate faculty in the theory and practice of several active learning methodologies.
PCP3	Learning outcomes assessment	Educate faculty in learning outcomes assessment techniques.
PCP4	IT Use in teaching and learning processes	Show faculty how to develop instructional strategies and effectively apply information technology to the learning process.
PCP5	Teaching communities	Promote the exchange of teaching experiences among faculty, and the systematisation of their teaching innovations.

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. In particular, there is significant improvement in recognising several skills and attitudes such as "Entrepreneurship", "Seeks and analyses information from several sources" and "Autonomous work in interdisciplinary teams" thanks to the talks by CS professionals and mainly to the project- and PBL methodologies. In contrast, the decrease in recognition of the "Concern for the environment" attitude may be explained by noting that students, in general, are aware of environmental issues. However, as they do not actively learn about these topics in these introductory courses, student perception about their importance in the program decreases. These topics are in fact addressed by other courses later in the program.

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 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 upper bars correspond to the Introduction to Computer Science course and the lower bars belong to the Programming Lab course.

From the results, we see that the instructor's new role as facilitator rather than lecturer is not fully recognised 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 the Centro de Innovación y Desarrollo Docente (CIDD) (UCSC, 2012), a newly-created UCSC teaching and learning centre to aid the development of teaching skills and boost innovations in student-centred teaching and learning processes. This centre offers a teaching skills program which certifies full-time and part-time faculty in five competences. Each competence is certified through 40 hours of work, which include a workshop, its implementation in a specific course, which is periodically monitored and guided throughout a semester, and a final report. Table 5 presents a brief description of each certification.

It must be noted that this faculty enhancement process has been slow, and it has been extended

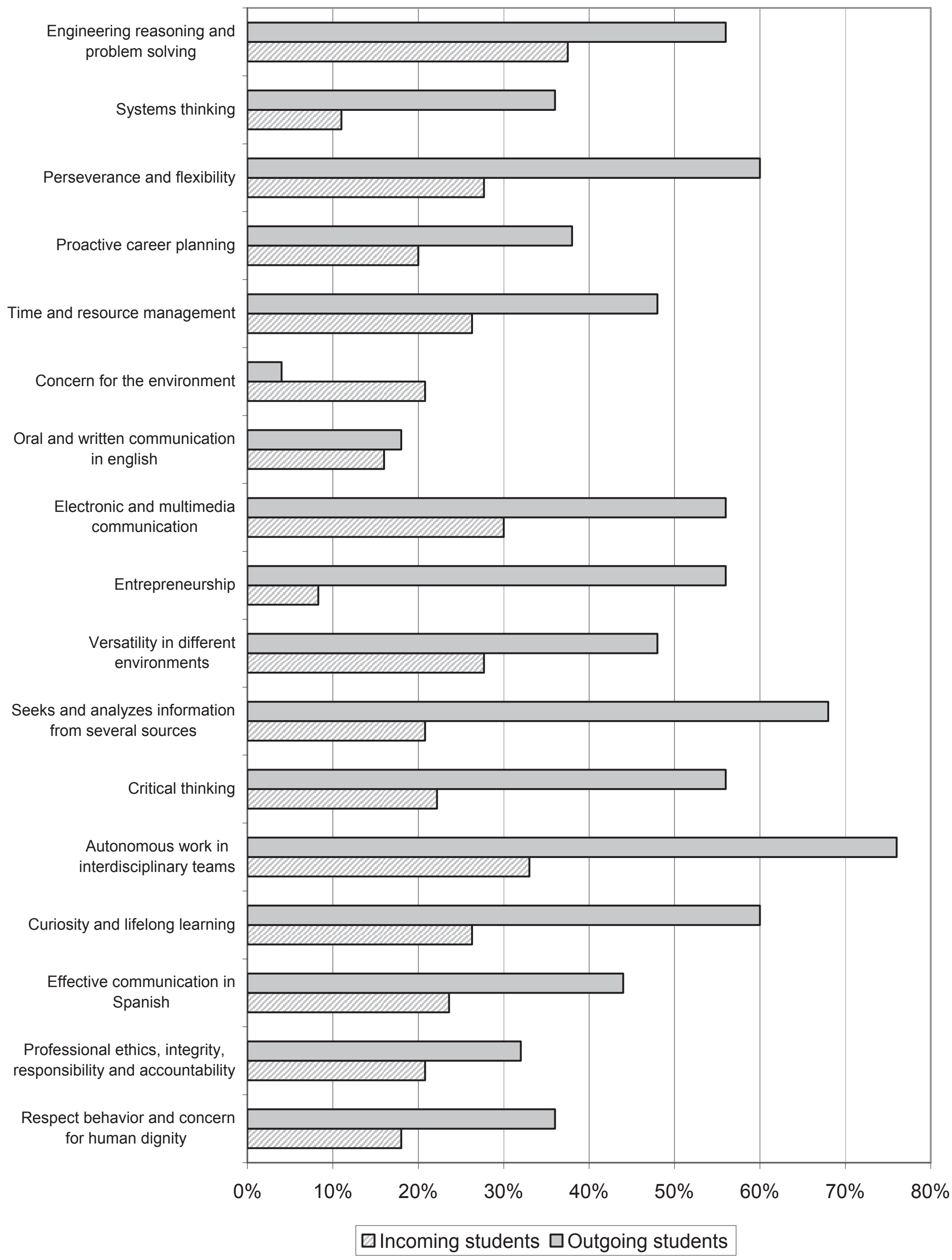

Figure 3: Skills and attitudes that students recognise in the computer science program goals.

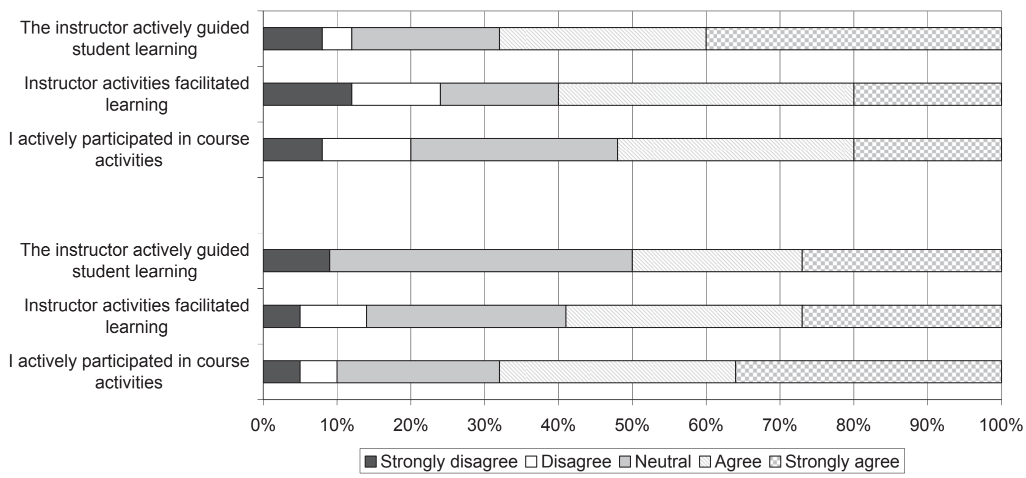

Figure 4: Instructor and student roles in first-year CS courses.

progressively during the implementation phase of the curricular reform.

4.2 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 6 shows the perceived usefulness of the active learning techniques listed in table 2 to the accomplishment of the courses' learning outcomes.

Likewise, figure 7 shows the percentage of students reporting the achievement of specific learning outcomes associated with the Introduction to

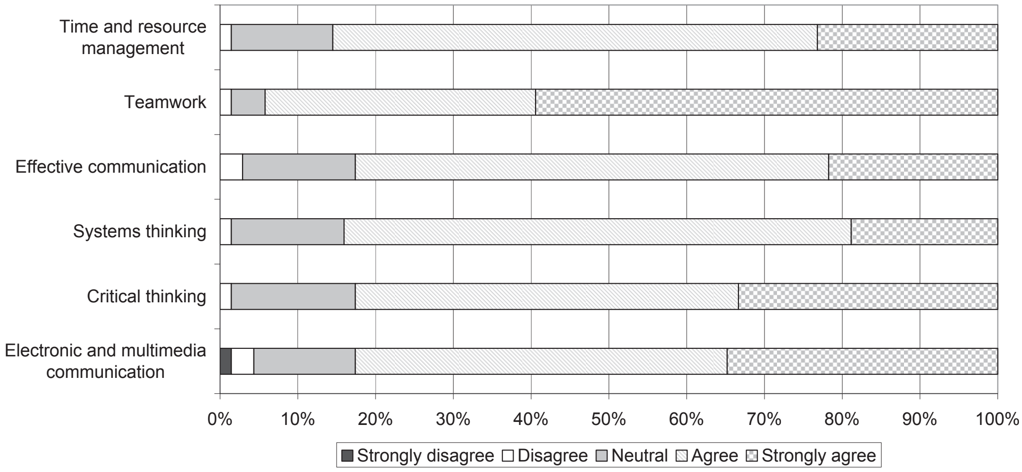

Figure 5: Perceived course usefulness to skill development (first year IE courses).

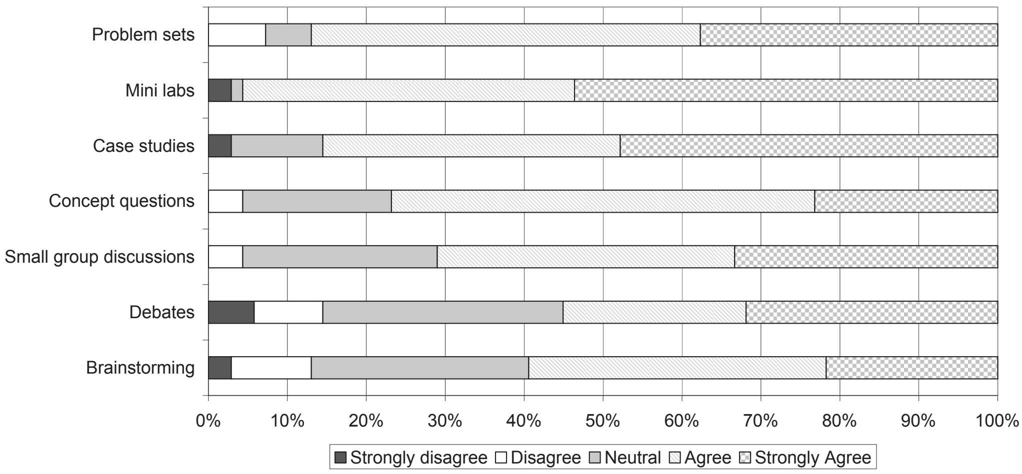

Figure 6: Perceived usefulness of active learning techniques (first year IE courses).

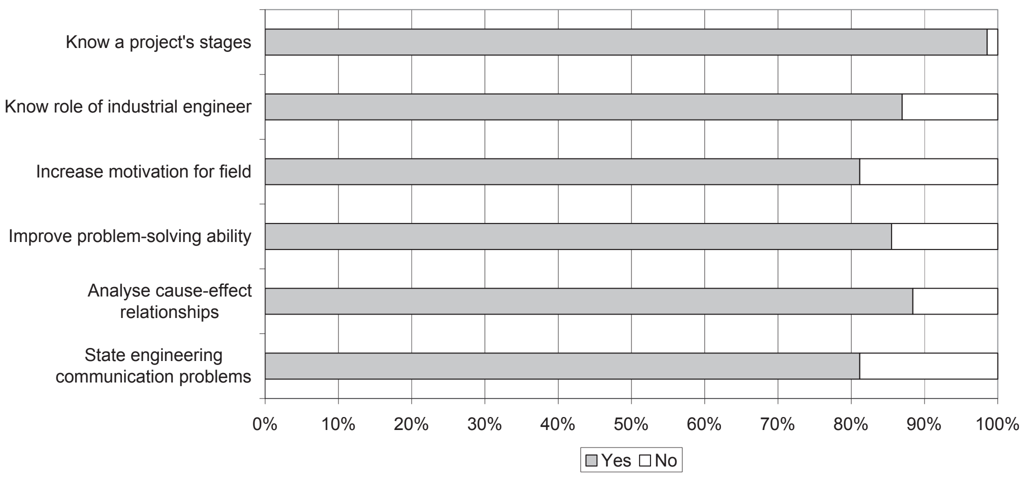

Figure 7: Perceived learning outcome accomplishment in the Industrial Engineering first-year courses.

Industrial Engineering and Engineering Communication courses.

Finally, table 6 summarises the various skills and attitudes that students recognise 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 familiarised with their chosen profession's field of work and professional endeavours.

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% recognised that the instructor's activities helped them achieve their learning outcomes.

4.3 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 recognise 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 said "Very interactive class, I feel more motivated in it".

Table 6: Skills and attitudes that students recognise in the industrial engineering program goals.

Industrial Engineering program goals	
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 analyses 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 behaviour and concern for human dignity	72%

5 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 small-group discussions, demonstrations, project-based learning, 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 Centre. 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 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 remodelling 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. Previous collaboration in engineering program conception and design is described by Loyer et al (2011). Academic teams are certainly still learning to collaborate in implementing and operating these redesigned programs. In the future, the authors 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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