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ORIGINAL PAPER

Active learning in engineering education. A review of fundamentals, best practices and experiences

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Abstract

Universities and international organizations are adopting and promoting Active Learning strategies, respectively. Reasons are varied, including that this approach has proven to prepare competitive students who are skilled to address the main problems of society once they enter the labor market. Active Learning is a student-centered-learning approach that involves the learner directly in the process. It consists of letting students be the main actors of the learning process by performing meaningful activities and critically thinking about what they are doing. In this research, a review of Active Learning is performed. The focus is on presenting concepts and practices central to Active Learning that leading universities are deploying, universities such as Massachusetts Institute of Technology, North Carolina State University and Aalborg University. Also, the authors describe in this paper a case from their experience with Active Learning techniques in specified areas of engineering education at Tecnologico de Monterrey. Results indicate that this approach supports the development of in-demand competencies such as Teamwork, Problem-solving and Analysis. In addition, students' performance and retention rates are improved. In the engineering field, students can acquire and practice different technical skills under supervision. Active Learning is a very flexible approach that can be integrated in a gradual manner by any organization. The authors have constructed this research to be a useful guide to Active Learning practices. It can support engineering professors and people interested in knowing or adopting this approach for improving their students' results.

Keywords Active learning · Challenge based learning · Educational innovation · Engineering education · Leading universities' practices

1 Introduction

The enrollment of students in *Science*, *Technology*, *Engineering and Mathematics* (*STEM*) careers (educational curricula), which are essential for the competitiveness of countries, is decreasing in the U.S. In this country, less than 40% of persons pursuing a career are interested in *STEM* areas. Of these, only 20% obtain the degree [1]. Reasons for the latter are varied, including: (a) that the student is not academically prepared for the entry level; (b) the misleading idea that specialized, innate talent is needed for studying the area; (c) a lack of a sense of community with classmates, and (d) unattractive teaching practices [2]. One tactic that can improve the attraction and retention of *STEM* students to those fields is the use of effective and proven pedagogical strategies such as those that belong to *Active Learning* (*AL*).

The U.S. President's Council of Advisors on Science and Technology recommended the adoption of "empirically validated teaching practices" to increase per year the number of *STEM* degrees by 33%. Previous studies argue that *AL* can aid in achieving this set goal [1]. *AL* is promoted by international agencies and countries such as the European Commission and the Finnish government as a useful approach to develop a base population who are educated and who are lifelong learners. The reason is that *AL* improves the development of specific and useful competencies such as collaboration, autonomy, logic, creative thinking and problem-solving. These capabilities are essential for having a globally competitive workforce [3].

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Universities are considering the benefits that *AL* offers, and they are implementing innovative *AL* activities in proper environments that are conducive to educating their students. To describe these, this work presents a review of the activities performed by some leading universities with the focus being to present their concepts and practices that are central to Active Learning. Also, a case from the experience of the professors in using *AL* techniques in specific areas of engineering education at *Tecnologico de Monterrey* is described. Therefore, this research paper is a useful guide related to *AL* practices. It can support engineering professors and people interested in knowing/adopting this approach for in order to improve their students' results. The outline of the work is as follows: Sect. 2 offers an overview of *AL* concepts. Section 3 focuses on the utilization of *AL* specifically in engineering education. Additionally, the approaches of leading universities are presented. Section 4 describes a case study related to the use of *AL* for teaching engineering at *Tecnologico de Monterrey*. Section 5 ends the paper with conclusions.

2 Active learning (*AL*) overview

AL is an interactive teaching method, its main characteristics include [4]: (a) a student-centered approach that puts the learner directly in the center of the process, (b) let students be the main protagonists of their learning process by performing meaningful activities and critically thinking about what they are doing, (c) is a highly engaging method of education [5], (d) encourages the learner to participate actively by developing hands-on activities, (e) students work based on learning objectives, (f) increases retention and understanding of knowledge because all the learning effort is exerted by the student himself [6], (g) professors assume the roles of mentors and evaluators of the progress of the students [7] and (h) take advantage of a vast array of aids in order to capture and maintain attention of learners. In the specific case of engineering, an interactive teaching approach can be supported by the use of technology. Such advances allow engineering students to interact with processes and methods in vivid ways. This offer to them a better understanding of the parts and functionality of a given system, which allow to have a better acquisition and understanding of knowledge.

AL is the result of a combination of various elements such as planning well, engaging participants, creating an effective infrastructure and using *Information and Communication Technologies* (*ICT*) effectively. Of these, the latter could be considered one of the most significant factors in transforming the traditional way of learning, particularly in engineering education [7]. Examples of ICT tools are projection technologies, microphones, monitors, in-class access to internet [8], laptops, clickers, cameras and the use of diverse software [9]. From the side of infrastructure, there are specific classroom designs that support the development of *AL* activities. These include open spaces, correct acoustics and lighting in the learning space, air temperature [10] and movable seats and tables with whiteboards. It is arguable that *AL* spaces enable the development of conceptual understanding and improve the achievement of learning outcomes [8]. In *AL* classes, lectures are minimal (10–20 min maximum) and are integrated with labs; the most important topics are taught in depth; professors become only supporters of the learning process and formative assessment is performed. Additionally, competencies such as teamwork, communication, critical thinking and effective presentation are developed [9].

2.1 Active learning techniques

AL comprises a wide range of techniques ranging from the simplest to the most complex. These can be incorporated in a class as sporadic activities or can be used for radically redesigning the entire course [11]. The simplest or easiest AL activities to implement include interactive questions and answers, pause technique, the one-minute paper, Think-Pair-Share [12], debates, Half-and-Half, concept mapping [7], group discussions, internet searches, Socratic dialogs [9] commitment-generating exercises and roleplay [13]. On the other hand, examples of the most complex *AL* techniques are:

- *Project-based learning* The rationale of this approach lies in the idea that people construct new knowledge based on what they already know and have experienced. Students combine the knowledge acquired or generated in previous courses with the knowledge gained through developing the project [14].
- *Cooperative-based learning* Effective learning is a social task. Students can have better results when working together and understanding team dynamics [10]. With this technique, students learn in groups of three or more. Performed activities are highly complex, such as research projects or multiple-step exercises [6].
- *Problem-based learning* Students first analyze and discuss a real problem in small groups without the opportunity of searching for new concepts. The goal is that they recall their previous knowledge. Then, questions are posed so that each participant answers them individually and then, a few days later, in conjunction with group members, the students discuss and agree upon a solution [15].
- *Team-based learning* This is a case-based-teaching-and-learning method. Course knowledge is acquired independently before class. Students are examined at the beginning of the session through an individual quiz and, immediately after, they take the same test in groups. The

results of both exams compose the final grade. Finally, class time is used to develop applied exercises [11].

- *Competence-based learning* This refers to systems of instruction, assessment, grading, and academic reporting that are based on students demonstrating that they have learned the knowledge and skills they are expected to learn as they progress through their education. The general goal is to ensure that students are acquiring the knowledge and skills that are deemed to be essential to success in school, higher education, careers and adult life [16]
- *Challenge-based learning* Actively engages the student in a relevant and challenging situation connected with a context in the real world. It involves knowledge acquisition, problem definition and the implementation of a solution(s) [17].

2.2 Active learning assessments

As with traditional teaching activities, *AL* tasks need to be measured to determine their effectiveness and to establish whether students are acquiring the necessary knowledge and competencies. *AL* assessment is formative, i.e., it is used to identify comprehension gaps, to understand students' learning needs and to adapt teaching strategies accordingly and immediately [18]. Some easy-to-implement *AL* techniques are both skills promoters and performance evaluators of the students. *AL* assessment tools include those listed in Table 1.

3 Active learning in engineering education

STEM education has been characterized by using the *AL* approach in the form of *studio* classrooms. In these, lectures and laboratory activities are combined, technology is highly used and physical spaces are designed to promote active interactions among students and professors. *AL* improves performance of the students, promotes problem-solving [9], reasoning and writing skills, aids in the retention of concepts [25] and reduces failure rates in *STEM* fields [1]. These results are better with small classes, but good outcomes can be achieved in a variety of course designs. Increase in students' motivation and positive attitudes are also important benefits of *AL* [5].

AL is highly recommended for those areas of study in which the development of *Higher Order Thinking Skills* (*HOTS*) are essential, such as in engineering [6]. Among the most complex *AL* activities implemented in the engineering area are collaborative-based learning, cooperative-based learning and problem-based learning [24]. On the other hand, some of the low risk *AL* activities used during class and useful for developing *HOTS* include those in Table 2 [6, 11, 26–28]:

From Table 2, it can be said that the main purpose of *AL* activities in engineering is to give the opportunity to students to have deep reflections on the topics being taught and also to interact with classmates. This improves the learning process and helps in developing important competencies such as teamwork and interpersonal skills.

Table 1 *AL* assessment tools

Tool	Description
Observation	The teacher registers comments related to student performance and progress regarding a learning objective. This is done during the performance of the class activities through the use of anecdotal notes, notebooks, notecards, formats and labels. The final goal is to analyze the results and meet students learning needs [19, 20]
Lesson learning log	The student records his learning during the whole semester. Different formats can be used, but in any case, the main goal is that the learner specifies in his own words what he understood about the lesson and how it can be applied. This can be done after each exercise is completed. At the end, the professor use a rubric to determine a general grade from the records analyzed of each student [7]
Questioning	During the class, teachers ask meaningful questions related to the topic, i.e. questions that let students reason what they are learning. With this method, professors can determine the level of understanding of the learners [19, 20]
Self/Peer assessment	Self-assessment is useful for students to understand their own learning processes and determine their strengths/weaknesses. Peer assessment teaches students to look to external sources to understand the quality of their work. Professors analyze results and determine students' success or areas of improvement [18, 20]
Rubrics	Rubric formats depend on the *AL* activity performed. For example, in problem-based learning, the Research Skills Development (RSD) Framework and the Inquiry and Analysis VALUE rubric can be used [21]
Immediate Feedback Assessment Technique (IF-AT)	Multiple choice test that gives students the opportunity to acquire concepts and gives teachers the chance to assess whether students are learning. It can be used individually or collaboratively. The main advantage is that it gives instant feedback to the learner [22]
Concept tests	Conceptual multiple choice questions which are focused on a single concept. Questions are short and can be used to assess students' comprehension of a topic before or after class [22, 23]
Concept maps	Graphical tools for representing or structuring knowledge. They exhibit relationships among concepts. These are useful for assessing students' understanding of a topic and identifying misconceptions [24]

Table 2 Low risk *AL* activities for developing *HOTS*

AL Activity	Description	Benefits
Think—pair—share	Students are given a problem and are asked to analyze it individually (Think). Then, they compare their results with those of their nearest neighbor (Pair). Finally, the pairs present their conclusions to the whole class (Share)	Enables the professor to determine students' understanding of a topic and to clarify misconceptions. Classes are more interactive and dynamic, enhancing involvement. Also, this promotes student reflection about concepts and problems
Circular questioning	Small groups are organized, and a student of one group asks a question to a student of other groups until all participants answer one. At the end, the professor summarizes all the responses generated	Promotes new forms of thinking, and the professor can understand the ideas students have about a specific topic
One-minute-paper	The professor asks a question related to the course, and students must write an answer in no more than 2 min. Responses are read anonymously, and feedback is given to participants	Permits tracking student progress regarding the understanding of the course materials
Jig-saw method	Students are divided in groups of 5–6 members. The theme that is going to be taught is also divided in these equal parts. Each part is then assigned to each student in all the groups to be analyzed. Finally, students must present their parts to their team members. At the end, an individual quiz is taken	Improves test performance and teamwork among class members because students are dependent upon each other. Improves learning
Group assignments	Students perform specific assignments collaboratively	Promotes team and interpersonal skills
Roleplay	Students adopt a character to make a performance related to a determined situation. Then, participants switch characters so all of them have the opportunity to assume all the roles	The understanding of concepts and theories is improved

Any professor can implement *AL* strategy in his/her classes. To start from a base, the first task is to determine which activities are already being used in the courses. The idea is to change the dynamics of the class gradually. The teacher has to plan the transition and resolve some issues. First, begin with one single *AL* activity so that students adapt to the new approach progressively. Second, link the activity with its intended benefits and be sure that the learning outcomes are well defined. Third, plan how activities will be deployed in the course days/hours. Fourth, request students' feedback regarding the overall implementation and then modify strategy based on results [29]. There are a variety of easy-to-implement *AL* activities for those who start; for example, request the student to read assigned texts and subsequently ask related and relevant concepts in a dynamic manner; allow students to teach partners; post questions and ask students to answer them within 2 min; make group assignments and games and give prizes [30].

Some of the benefits of implementing the *AL* approach include the development of competencies such as critical thinking and problem-solving, an increase in engagement by both students and professors [31] and the possibility of teachers obtaining real-time feedback regarding students' understanding of concepts [30]. To support the *AL* implementation process, organizations have to invest resources in training professors and adapting the infrastructure accordingly. However, some challenges need to be considered regarding the faculty: (a) Experienced teachers whose traditional activities have been proven to offer great learning results may be unwilling to take on the approach; (b) Time is needed to prepare the activities, and the teachers, who have various responsibilities in the university, might not have this resource (time) for implementing something new in their classes, and (c) Resistance to change on the part of the professors and even the students [32]. To benefit from the results offered by *AL*, it is necessary to have institutional support so that *AL* becomes a key approach of the educational model.

3.1 Active learning practices of leading universities

There are pioneer universities in developing *AL* environments and activities. Major organizations that have successfully adopted this approach for education in engineering are described below with their experiences and successful results.

3.1.1 Massachusetts Institute of Technology (MIT)

In 1990, *MIT* developed the *Technology Enabled Active Learning* (*TEAL*) project, which consisted of using advanced technology in an *AL* environment for improving the teaching of physics. The objective of the initiative has been to promote effective interactions and development of problem-solving skills in students [33]. The classrooms' physical spaces are specially designed, including a central workstation for the professor, roundtables and whiteboards. Among the technologies used are screen projectors, computers, animated simulations, polling systems and wireless microphones. The dynamics of the class are based on collaborative and experiential learning. Groups are comprised of different levels of students. Activities include practical experiments, lectures, discussions, exercises [34], demonstrations and advanced visualizations. Results show that the *TEAL* project is helpful to reduce failure rates and to improve conceptual understanding of learners [33]. Students who participated in a study aimed at determining the effects of this project indicated that it was an appealing way of taking a course and that they would recommend it to their peers. The most liked features were the interactivity, the development of practical activities and the opportunity to visualize concepts in a more vivid way [35].

3.1.2 North Carolina State University (NCSU)

This organization developed 27 years ago the *Student-Centered Activities for Large Enrollment Undergraduate Programs* (*SCALE-UP*) to change the teaching of introductory physics courses. Since then, many universities have adopted this approach. At *NCSU*, *AL* spaces were developed and new pedagogical strategies were implemented. In the classrooms, roundtables, laptops with internet access, projectors and microphones are used for students to share their work and ideas [33]. Also, a website of the course, specialized software and systems to perform polling are utilized. In most of the class time, students work in groups developing activities that include practical observations, discussions, solving real-world problems, conducting in-depth internet searches, doing laboratory tasks and having Socratic dialogs [36]. *AL* adoption at *NCSU* courses has enhanced conceptual understanding of students and the development of competencies such as problem-solving [33], communication and technological literacy. Also, the attitude of learners has improved and failure rates have been reduced significantly [36].

3.1.3 University of Minnesota

The University of Minnesota's effort to change the way its students learn began in 2006. The initiative was primordially focused in developing two *AL* classrooms for professors to experiment with new pedagogies. By 2010, the organization built an innovative edifice that included ten *AL* classrooms. The spaces are equipped with large round tables for nine students working in groups of three, laptop connections, screens, projectors, a 350° glass marker board and internet access. A variety of subjects are taught in these classrooms including biology, chemistry, environmental sciences and calculus [37]. Activities such as discussions, hands-on tasks and problem-solving are performed. Research results related to the initiative indicate that this approach is useful to promote teamwork and collaboration skills. In addition, learning results are improved and the behavior of students and professors is enhanced—students become highly motivated and professors interact with them more in discussions [38].

3.1.4 University of Alabama

In 2002, the Department of Physics and Astronomy of the University of Alabama designed a non-traditional introductory physics course. Two classrooms were built with *AL* environments and having capacity for 54–60 students. Work stations were available so that students could work in groups of three. Learners, professors and assistants meet with each other 5 h per week, and the class format mixes lectures and labs in a coordinated manner [39]. Technology used in the classroom includes computers, electronic data-collecting equipment, video cameras, projectors, internet and a variety of software. Activities performed are diverse. The class begins with a quiz on the material that is going to be analyzed and a short presentation by the professor. Then activities such as written exercises, computer simulations and calculations and experiments are performed. Results indicate that class attendance, learning outcomes and motivation are increased [40]. Also, problem solving skills and conceptual learning are improved [41].

3.1.5 Rensselaer Polytechnic Institute (RPI)

The Studio Physics model was first introduced by *RPI* in 1994. The aim was to attract the attention of the students and to enhance their performance in physics courses. The main characteristics of this approach are the integration of lectures and laboratory activities, the use of advance technology, the development of meaningful and practical tasks and a better interaction among students and professors. One of the main benefits is that students are in touch with the professors both in lecture time and during laboratory activities, allowing for a better understanding of topics and taking the most advantage of the teacher's knowledge [42]. Courses taught in this format include those related to engineering, chemistry, genetics and economics. Infrastructure is specifically designed for developing *AL* activities. There are long tables for students to work in pairs or groups of four, open spaces and a central work station. Educational technology consists of lab equipment, projectors, screens, computers, software, video cameras for recording experiments and simulations, among others. Performed activities include short lectures, group assignments, experiments, discussions, presentations, hands-on-problem-solving and laboratory activities. Results indicate that this teaching format engages students in the learning process. Student performance results are varied; in some courses, these are equal to the results of traditional classes and, in others, these are superior [43].

3.1.6 University of Iowa

The *Transform*, *Interact*, *Learn*, *Engage* (*TILE*) program of the University of Iowa was created with the objective to transform all aspects of education to increase the recruitment and retention of students. It is founded on an approach that incorporates *AL* pedagogies and a redesign of the classrooms [44]. The *TILE* teaching spaces are prepared for teaching various disciplines, from physics and astronomy to business and social sciences. Classrooms are equipped with round tables with capacity for nine students, a control station, glass boards and white boards. In regard to technology, three laptops and an *LCD* screen per table are assigned, and also a wireless mouse is available so that users have more freedom when presenting a topic or task results. Performed activities depend on the field of study, but they include discussions, problem-solving and in-class exercises. Results indicate that the grades of the students are improved. The students like the interaction with partners that these kinds of courses enable. Also, learners participate more in classes, and a sense of responsibility develops. Collaboration is also enhanced [45, 46].

3.1.7 Aalborg University

Aalborg University has more than 30 years of experience developing engineers with the aid of *AL* strategies, mainly through Problem-and-Project-Based Learning. Since the institution's foundation, the goal has been to respond to the demands of the industries, which have required specified profiles for engineers [47]. Physical spaces such as group rooms that enable the implementation of *AL* strategies have been built since the beginning. Nowadays, the University has 1200 of these facilities principally designed so that students work together. These are like engineering offices with internet access and blackboards. There are also laboratories available for students to perform experiments that complement the project tasks [48]. In addition, the university offers information systems, virtual spaces, computers, research equipment and diverse software [49]. Activities performed focus on the *AL* strategies mentioned above. Students analyze and resolve interdisciplinary problems, work in groups and develop technical reports. As a matter of fact, almost half of student time is spent in developing projects in teams, and the other half is dedicated to lectures. They also read related literature, perform group studies, study tutorials, do field studies and experiments [50], attend workshops and seminars and solve exercises [49]. They are graded both individually and in groups [50] with the focus on determining whether they have acquired the expected knowledge, skills and competencies. They are supported by a supervisor and external partners such as business experts [49]. Project-Based-Learning (PBL), the main *AL* strategy applied at Aalborg University, develops competencies such as teamwork, cooperation, responsibility, problem-solving, analysis, time and project management and written and oral communication. It also helps students to obtain real work experience [48].

3.1.8 Roskilde University

This organization was founded in 1972 with the main objective of transforming Danish higher education. Its educational model is focused on Project-Based-Learning. The aim is to develop professionals with an academic profile heavy in research activities. Half of student time is spent in real-life, theoretical or methodological project activities. Other activities include lectures, reading groups, report writing, seminars, analytical workshops and participation in colloquiums. Under this model, professors assume the role of mentors [51]. The university offers students areas for working according to the learning strategy. It offers group study rooms [52], open spaces and reading rooms [53] Technology includes computers, a wide range of data bases and intelligent-technology labs [54]. The Roskilde University model develops in students competencies such as independent analysis, problem-solving, cooperation, critical attitude, political awareness, responsibility and professional commitment [51].

3.1.9 Maastricht University

Founded in 1976, Maastricht University was the first educational organization in the Netherlands that applied successfully the PBL technique in all educational levels [55]. Under this model, students work in small groups tutored by the teacher or older students to solve a real problem. They also have practical training and attend a few lectures. Among other activities performed are reading scientific literature, studying tutorials, having discussions, debating, writing reports [56], doing assignments, making oral presentations [57] and analyzing cases [55]. Technology used depends on the program and includes lab equipment, high-quality digital facilities and large computer screens. It offers work stations of different sizes to accommodate students working individually or in groups. Movable seats are available [58]. Regarding infrastructure, the university has invested a lot of resources in a library that aids in implementing the *PBL* model. The Maastricht University model develops in students competencies such as collaboration, problem solving, critical thinking, independent working, analysis and oral communication [56].

3.1.10 The University of Queensland, Australia

The University of Queensland was founded in 1910. Since then, it has become a leading Australian institution in research and teaching. In engineering, *PBL* and the flipped classroom are the *AL* strategies mainly promoted by the institution [59]. Students work on projects and are tutored by professors [60]. Technology used includes Blackboard LMS, Web PA, Drupal, Khan Academy style videos, Skype, podcasts [59], blogs, discussion boards, wikis, virtual spaces, advanced audio-visual equipment, data projectors, 40 inch LCD screens, immersive 3D visualization technology and internet access. The university offers various spaces for students to interact, collaborate and socialize. These consist of theatre-style-lecture classrooms with ergonomic seats, booth chairs, whiteboards and open places. The goal is that students have areas in which they can interact and be creative [60]. As a result of the application of the mentioned *AL* techniques, students develop competencies including teamwork, critical thinking and project management [59].

3.2 State of the art on active learning practices

The main goal of organizations when implementing *AL* is to adapt to global changes and educate their students accordingly so that they become highly competitive. To achieve this objective, universities combine different elements like those which were elaborated in each of the cases described above; namely, technology, physical spaces and activities. According to the organizations that we analyzed, the implementation of *AL* strategies offers interesting results with respect to students' education. All these common elements are shown graphically in Fig. 1 and are described below.

3.2.1 Physical spaces design

Some of the organizations analyzed designed their physical spaces with an *AL* approach since their foundation; others have been adapting them in a gradual manner. Any organization that wants to fulfill the educational needs of society can invest time and resources in implementing *AL* strategy and achieve good results.

AL spaces are unstructured, providing a sense freedom that is conducive to professors and students to take risks and be more creative and innovative. These environments permit more meaningful and engaging interactions and learning activities among students and professors owed also to a principle focus on collaboration. Besides the characteristic infrastructure of *AL* environments, the spaces are also fitted with the type of furniture that allows deployment of the strategy. These ensure a comfortable interaction among students and allow activities to take place more efficiently and engagingly. In this educational AL environment and atmosphere, specific competencies can be developed and nurtured.

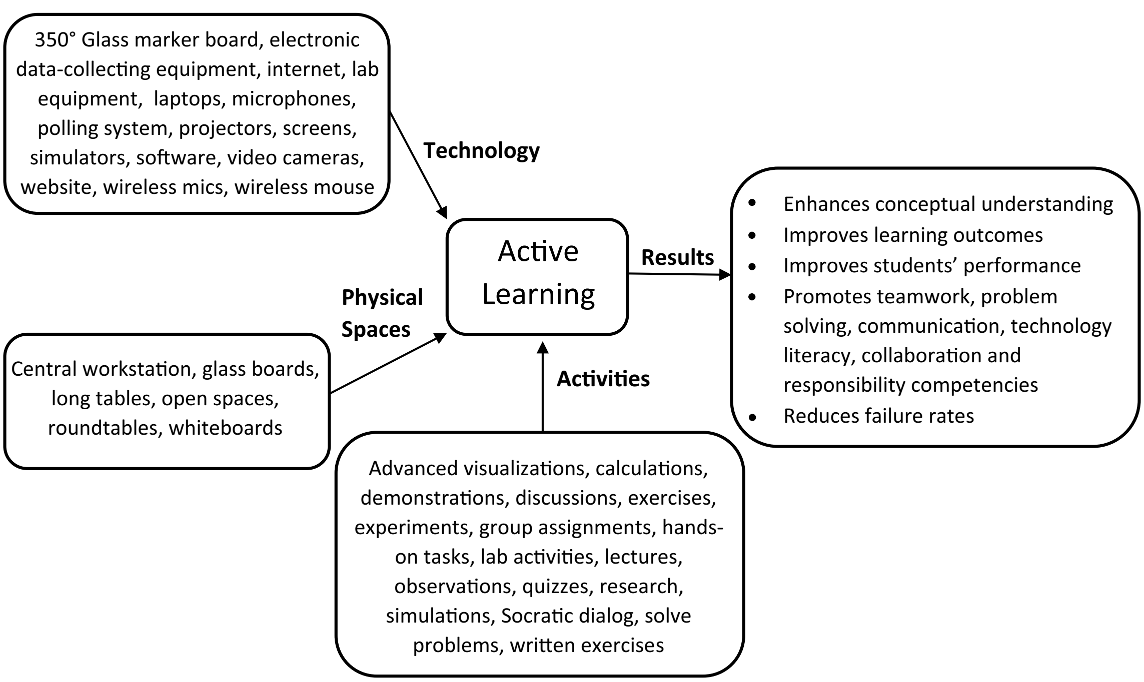

Fig. 1 State of de Art on *AL* Practices

3.2.2 Technology

Organizations also rely on technology to deploy *AL* strategies, increase engagement and magnify the educational effects. It helps students and professors to present their ideas more effectively, to understand better and to apply concepts as well as to practice competencies. Technology ranges from specialized equipment such as electronic data collectors and the ones used in scientific laboratories to tools useful to develop more attractive classes and support the learning process. Technological ideas such as learning management systems, polling systems, podcast, *Skype* and discussion boards foster collaborative activities, help to shape students' understanding and attention, help them to study independently, to communicate and to share knowledge. It has to be clear that technology is only an element that may improve learning when it accompanies suitable pedagogical strategies and meaningful activities.

3.2.3 Activities

AL activities are engaging and focus the student to be responsible for his learning and the creation of his own knowledge. Special emphasis is placed on collaboration, because knowledge is better acquired and understood in groups. *AL* tasks allow participants to do things in a practical way and have opportunity for deep analysis and understanding of what they are doing. The identified activities are varied and combined so that students might experience different approaches to learning. *AL* activities can be mixed with traditional ones; they can be experienced in a way to extract the best from them. However, less time is spent on more traditional activities such as lectures, which are used only for transmitting the concepts behind a subject. In this research, activities such as simulations, Socratic dialog, hands-on tasks, problem-solving and field work were identified as being used by the organizations selected.

Some of the organizations analyzed (for example, The University of Queensland in Australia) offer *AL* programs that help professors learn how to incorporate this strategy in their daily classes. This shows the great importance AL has for their pedagogical success and for students' satisfaction.

3.2.4 Results

AL offers important benefits for education. It was identified that this strategy aids in improving the performance of the learners. It also encourages them and, as a result, reductions in failure rates are achieved. An important aspect to be considered is that *AL* helps to promote a great variety of competencies including Teamwork, Problem solving, Analysis, Communication, Collaboration and Critical Thinking. The success in building competencies will depend on the activities, technology and physical spaces offered.

4 Implementation at *Tecnologico de Monterrey*

Tecnologico de Monterrey (TEC) is a Mexican higher education institution with an educational model that has been updated in response to global changes. At the end of the '90 s, learning became student-centered, and new teaching techniques became incorporated, such as collaborative learning, problem-based learning, project-based learning, case studies and services-learning. Since then, new and innovative didactic approaches have been integrated. Nowadays, a new, radically changed approach to Active Learning [61] with focus on educational technologies [62] has been presented through the development of the educational model named the Tec21 Model, currently in the process of implementation [61].

The Tec21 Model is an educational model that will develop abilities of students to become leaders who embrace the challenges and opportunities of the 21st century. This model considers disciplinary and transversal competencies as essential for developing leaders with an entrepreneurial spirit, a humanistic outlook and an international competitiveness. Learning under the Tec21 Model is challenge-based-learning, flexible, aiming to provide a memorable college experience and to inspire faculty with four main enablers: academic communities, innovation in teaching and learning, learning spaces and interaction with industry and organizations [17]

The Tec21 Model actively engages the student in a relevant, challenging situation connected with a real-life context. It involves knowledge acquisition, problem definition and an implementation of a solution. It includes activities such as "i week" and "i semester" in which students face real-life challenges and intensive experiential learning during 1 week or one semester (16–20 weeks).

Flexibility, under the Tec21 Model, relates to how, when and where the students learn. Instead of a linear approach per academic program (chemical engineer, mechanical engineer, etc.), students follow pathways, exploring to understand possibilities during the first three semesters, focusing in one semester and specializing during the last four semesters.

Memorable college experiences imply performing or attending cultural activities, practicing sports (intramural and representative), participating in student group activities, and developing an international experience. Based on academic achievement, students are elected to participate in an honors international exchange program or international excellence programs.

Faculty members who are energized to inspire others is one of the key elements of the TEC21 Model. Professors should inspire students in all their activities (teaching classes, advising students, tutoring students, etc.). They should be leaders in their fields of knowledge with experience in their professions or research, using technology in the learning process with innovative activities.

There are many examples of *AL* applications at *Tecnologico de Monterrey*, some of them with international awards or recognitions such as the Reimagine Education Conference & Awards (www.reimage-education.com). One case study of the *School of Engineering and Sciences* (*SES*) in which the *AL* approach was incorporated is described. The key issue in this case was the development of educational technology for the professors in the controlled systems approach.

4.1 Case study: a quarter of vehicle (QoV) model

An experimental platform of a *Quarter of Vehicle* (*QoV*) model was developed to improve the teaching–learning system in the Vehicle Dynamics course; specifically, regarding the suspension control systems topic [63, 64]. A fully-instrumented 1:5 scale prototype was connected with a dSpace™ card to a *Human Machine Interface* (*HMI*) that was implemented in *Matlab Simulink*™. The *HMI* follows the *plug and play* philosophy that facilitates the design, implementation and validation of several control algorithms under different conditions.

Vehicle dynamics is the study of vehicle-whole-body-motion. It encompasses ride, handling and braking behavior, although in practice, it is focused on ride and handling behavior. The fundamental goals of a car suspension are the isolation of the vehicle from the road and the improvement of road holding. The inherent limitations of classical suspensions have motivated the investigation of controlled suspension systems, both *Semi-Active* (*SA*) and active. Due to their higher reliability, lower cost and comparable performance, *SA* suspensions have gained wide acceptance throughout the automotive engineering community.

A *QoV* model is the most basic automotive suspension (see Fig. 2—left picture). Its use assumes an equivalent load distribution among the four corners and a linear dependency with respect to the translational and rotational chassis motions. The lateral and longitudinal wheel dynamics are neglected, while the wheel road contact is ensured. This very simple one-dimensional model consists

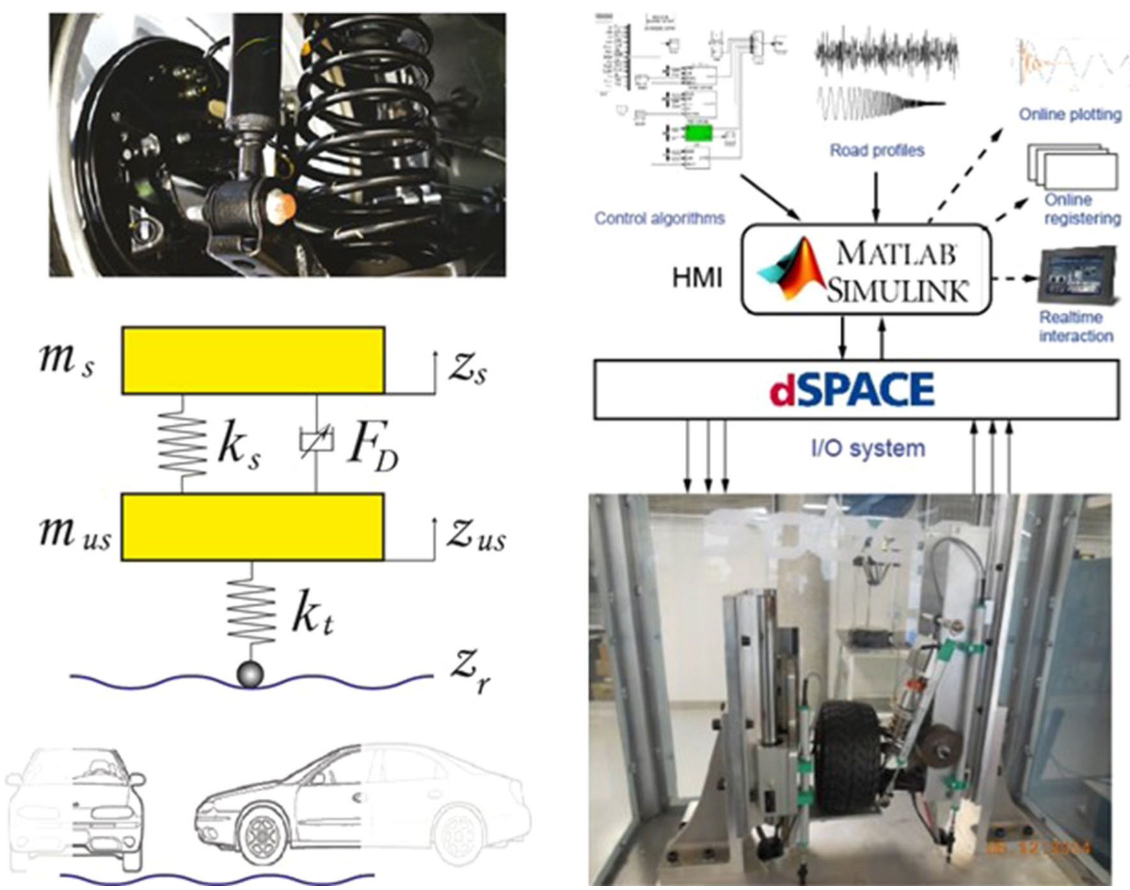

Fig. 2 Left Quarter of Vehicle (*QoV*) model, Right real *QoV* prototype and *HMI*

of a spring-damper-system representing the suspension strut and a single spring replacing the tire. The damper contributes the drive safety and the drive quality to the same extent. Its tasks are the prevention of an amplification of the chassis motion and the prevention of a skidding wheel. A non-skidding wheel is the condition for a good tire-road contact. The task of the spring is to carry the body-mass and to isolate the body from road disturbances maximally.

The dynamical behavior of a *QoV* model with a *SA* suspension is described by the Newton law where z_s, z_{us} and z_r are the sprung mass, un-sprung mass and road profile vertical positions, respectively; m_s is the sprung mass which represents the chassis; m_{us} is the un-sprung mass which represents the wheel, tire, etc.; k_s and k_t are the suspension and the tire stiffness, respectively; and F_D represents the damping force.

Comfort is measured by the vertical-chassis-acceleration ($\ddot{z}s$) response to road disturbances (z_r), between 0 and 20 Hz. This is the acceleration felt by the passengers. Road holding is measured with the vertical-wheel-deflection ($z_{us} - z_r$) response to road disturbances (z_r), between 0 and 30 Hz. It represents the ability of the wheel to stay in contact with the road. The common goal is the minimization of either the energy transfer from z_r to $\ddot{z}s$ (comfort) or the energy transfer from z_r to ($z_{us} - z_r$) (road holding) or a tradeoff of these two energy transfers over the aforementioned frequencies bands.

The experimental *QoV* model has an Electro-Rheological shock absorber that is adjusted using a manipulation voltage. Below the wheel lies a linear servomotor that mimics the desired road profile. The servomotor has a bandwidth of 0–20 Hz; it has a servo-driver that is operated from a computer through a *Dspace*™ card. An *HMI* was developed to easily interact with the *QoV* model. Figure 2 (right picture) shows how a *Dspace* card communicates with the experimental platform and *Matlab/Simulink* in real time. The *HMI* running on *Matlab* has a general control strategy with different options for each block/signal. Based on this flexibility, it allows one to: (1) design a control system as if you were drawing a block diagram (*Drag and Drop*) [65]; (2) reuse software such as road profile and control algorithms, etc.; (3) do online plotting and data recording, and (4) have online access to the *Matlab* and a toolboxes platform. Although the control algorithms and road profiles are already in the *HMI*, students are allowed to implement any proposal (limited to the actual I/O system).

Changing the damping ratio represents a very interesting challenge for a suspension designer; however, the selection of the best damping ratio is a very complex task, especially if a control system based on vehicle sensors is used. The problem becomes the design of the control algorithm. This problem was used to design a challenge:

Challenge: Working in teams of three students, implement in the *QoV* model a data-based controller for both ride-comfort and road-holding. Write a conference-paper-style report (6 pages), and prepare an oral presentation using PPT/PDF slides (20 min, including 5 min for questions/answers).
Deadline: Two weeks (12 h each student per week). Given the assigned time in the Vehicle Dynamics course, special support was given: (1) Papers (approximately 10) with the correct information; (2) Matlab/Simulink code (*Plug & Play*) of the data-based algorithms and sequences for test and post-processing data toolboxes; (3) *QoV* model operating manual and, (4) A full-time *TA* student for support. The professor plays a consulting role for the working teams. A road map of the main concepts and activities that students must complete to get knowledge and solve this challenge are briefly described:
Data-based controller: Students have to answer several questions. First of all, students must know the operating range of the vehicle in terms of the variables of control (comfort and road holding). Second, they must investigate through several papers the different data-based algorithms so they will learn the different principles of design. Third, the stability of the control system must be considered; it is a key issue in the control engineering community.
Ride-comfort: Students have to research the meaning of ride-comfort, the cause-effect relationship, the possible sensor/actuators for direct/indirect measurements, the different control algorithms, and the acceptable set points and stability conditions.
Road-holding: Same as ride-comfort, but, additionally, the interaction and degree of interdependence among these variables must be analyzed to decide the control strategy. Considering the right solution as a hybrid control algorithm, an optimization procedure is needed.
QoV model: Equipped with a detailed manual and the support of a *TA* student, students must learn by themselves how to operate the experimental *QoV* model. There are two specific areas; namely, hardware and software. Even the startup and shut down sequences have many steps, but these procedures are simple recipes. Special effort was dedicated to the software side. The *HMI* is very simple and easy-to-use under the *plug and play* concept. Students have a repository of several elements to design (i.e. to draw) a control system and to try different road profiles, standard tests, data-based algorithms, etc. However, the most important and motivating issue is that their design/drawings are translated into physical implementations that can be heard, seen and, eventually, understood and assessed; all of this facilitating the active learning.

A survey shows some open questions and answers [frequency of the comment] that validate our discussions:

1. What do you like best? “Applying theoretical concepts in a real process.” [5], “Experimenting with physical equipment.” [4], and “Understanding some concepts.” [3].
2. What do you like least? “Errors occurred several times in the Arduino Due microcontroller.” [3], “The prototype is very small.” [2], “No sync-data reading, and the spring requires more strength.”
3. What are the advantages of the interface? “Excellent.” [5], “There are great possibilities using *Matlab/Simulink*.” [5], “Very simple and easy to use.” [4], “Online plotting.” [3], and “You can easily test designs.” [3]
4. What are the disadvantages of the interface? “None.” [3], “Very difficult to detect programming errors in your code.” [3], “Many steps in the start-up/shutdown.” [3], “Software versions are obsolete.” [3], and “There is only one prototype and many students.” [3].
5. What suggestions do you have for improving this experimental prototype? “Do full-scale.” [5], “Design more experiments.” [4], “Integrate with *CarSim*™ “ [3], and “Replace the *Arduino Due* microcontroller.” [2]

As students commented in the survey, working with a 1:5 scale prototype with a high performance *HMI* was great. Certainly students improve the teaching–learning system; moreover, they developed some competencies and skills through the experiential sessions.

4.2 Discussion

The main academic contribution in this case study is the development of educational technology so that various *AL* strategies could be implemented in the teaching–learning process. The technological development behind this project has been of considerable effort and investment. Even though the *Tecnologico de Monterrey* has equipped manufacturing laboratories, it is not possible or practical to teach and train all the students through real systems, because the level of operation and maintenance would be unsustainable.

Regarding the prototype of a *QoV*—As its name indicates, it is a configuration that has two levels of scaling. The first one, that is widely accepted, is to study the vertical dynamics of the suspension of a car through a *QoV*, which utilizes a valid dynamic approach; however, this requires expensive equipment (real tires, shock absorbers, MTS test system) to simulate the road, compressions, etc. Therefore, the dimensions of the elements of the suspension were reduced to a scale of 1:5, which only provides a qualitative validity. In this case, the *HMI* interface was focused on developing a platform that would allow the students to assess very easily different strategies and/or control algorithms and appreciate the effect immediately. This could be very costly and complicated with a real vehicle, not even counting the complexity of implementing road tests to evaluate the automotive dynamics.

In addition to the partial results that were achieved, there are two integrating activities that are high-value for the competencies that they develop and, especially, for the global feedback that fortifies the use of the *AL* approaches; namely, the reports and the presentations.

For learning, the act of writing demands a chronology of thoughts, and then students can label, objectify, modify and build on ideas, thereby promoting awareness and reinforcing their learning. Writing-to-learn forms and extends thinking and deepens understanding. Writing a report requires a level of cognitive activities which maximizes the potential of the students to modify and restructure knowledge. Students improve their learning by constructing and evaluating the acquired knowledge. They gain ownership of knowledge by questioning existing knowledge on their own. Writing a report plays the key role in the process of student knowledge-construction. It includes conceptual understanding, procedural knowledge and logical thinking as means of acquiring concepts and skills. It demands students to actively express and explain meaning according to their own abilities. Writing a report working in teams can be complicated, but the resulting collaborative learning could be exponential.

Speaking is fundamentally different from writing because listening is fundamentally different from reading. Each working team has to prepare a slides presentation with four basic sections: (a) Introduction; (b) Main body (c) Conclusions and (d) Answers/Questions. The Main Body section includes four points required to be covered: (1) Signpost (Title) the point; (2) State the point clearly and succinctly; (3) Support the point with data, cases, description, relevant studies, etc. and (4) Summarize the point.

Communicating information clearly and effectively is a key skill to get students’ messages across. The ability to communicate is important to be able to operate effectively in the real world [66].

Early results can be discussed based on different points of view: (1) Academic, (2) Student Outcomes, and (3) Student motivation. The Academic objectives were successfully achieved because all students were able to solve the challenge with a reasonable level of mastery. Students demonstrated their understanding in different ways: validating results; identifying unexpected results; justifying wrong conditions, etc. Students learned through active and experimental procedures to understand the theoretical concepts, and they acquired some competencies through challenges. The following student outcomes of *ABET* criterion 3, Engineering Accreditation Commission (2014), were promoted or developed: (b) an ability to design and conduct experiments as well as to analyze and interpret data; (c) an ability to design a system, component or process to meet desired needs, (e) an ability to identify, formulate and solve engineering problems; (g) an ability to communicate effectively (written and oral); (j) a knowledge of contemporary issues; and (k) an ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

Several factors can influence the motivation of students. One important factor is the student's self-efficacy. They will put forth more effort to accomplish this task. They will work harder and persist longer with this learning task. As a result, they are more likely to be successful than students with lower self-efficacy. By engaging students in a discovery-learning environment, teachers come closer to ensuring that students will be inherently motivated to learn. For these reasons, these experimental platforms were developed as a part of institutional strategy. The motivation of students was one of the key points for the successful results.

5 Conclusions

Education has undoubtedly changed in response to the needs of society. Universities are investing important time and resources in transforming their educational models in order to prepare students to have the knowledge and competencies that will aid in solving the main problems of the different economic sectors. *AL* has proven to support this objective. This is an educational approach that places the student at the center of the learning process, allowing him to be a dynamic learner who will become a competitive collaborator or entrepreneur. Any organization can incorporate *AL* as part of its educational strategy. This is a very flexible approach that can be integrated in a gradual manner. It offers palpable results in a relatively fast way, because there are a variety of activities that are attractive and easy to implement. However, to implement the full approach, significant investments must be made in technology and infrastructure. This could be a significant restriction for some organizations. The correct integration of three components (i.e., activities, technology and physical spaces) augurs a successful *AL* implementation.

AL has proven to offer important benefits for educational organizations. By analyzing leading universities such as Aalborg University, North Carolina State University and Massachusetts Institute of Technology, it was determined that this approach supports the development of demanded competencies such as Teamwork, Problem-solving, Analysis, Communication, Collaboration and Critical Thinking. In addition, performance and retention of students are improved by the appealing activities and, as a result, more learners successfully complete the programs.

From the implementation of *AL* in an engineering course led by the authors of this paper, it can be said that the use of advanced technology in conjunction with the right *AL* activities lead to a superior training of students that is more real. As a result, learners can acquire and practice different technical skills in a controlled manner, analyze how a system works, see different responses and have a deeper understanding of the elements' interactions. They can also make mistakes without assuming the economical responsibility for fixing a given equipment. All of this benefits the academic performance of students, because understanding of the topics is enhanced, and student engagement and motivation are improved.

AL is not new. It has several decades of implementation by leading universities presented in this research. Nowadays, there is an interest in adopting this strategy because it has proven to offer important benefits, both academic and practical. Students are educated facing quasi- real situations. This allows them to be better prepared to face the challenges that they will find in a real working environment.

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