Educational Robotic Simulators:
A Systematic Literature Review

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ABSTRACT

The possibility to model many physical events through the use of computers turned simulators into a widely used tool in research, teaching and training. The use of simulators in teaching-learning robotics gives students complementary ways for practicing theoretical concepts learnt in the classroom. Many simulators have been developed, but only a few papers have investigated the effects of using simulators in the teaching-learning process. In this paper a Systematic Literature Review (SLR) was performed aiming to investigate which methods are used to evaluate simulators educational impact and what are the educational features present in such systems. Based on the SLR data analysis, a set of most frequent educational features were found which include Foward Kinematics, Tasks, Scenes with various objects, Programming language, Modeling/Designing and, Inverse Kinematics. This SLR found that the most popular assessment method is questionnaires of usability and motivation and only a few researchers based their assessment on the students performance while programming and operating real robots. It was made clear that more extensive research on the impacts of using robot simulators is needed in order to better understand the relationship between learning issues and simulators features.

Categories and Subject Descriptors

J.2 [**Computer Applications**]: Language Constructs and Features – *abstract data types, polymorphism, control structures.*

General Terms

Algorithms, Measurement**,** Performance, Design, Experimentation, Human Factors, Languages, Theory, Verification.

Keywords

Education, Industrial Manipulators, Virtual Reality, Robotics, Simulation, Simulator, Training.

1. INTRODUCTION

Simulators are a viable and cheaper way to provide practical lessons. The practices carried out in the laboratory help in understanding the contents taught in lectures. Nevertheless, only a few robotic physical laboratories are available for the students at universities and schools. Simulators have been consolidated as a

popular tool for training, teaching and research. The possibility to model many physical events using computers turned simulators into a widely used tool in research, teaching and training. An advantage of using simulators is the possibility of several students to perform a given task at the same time. Other advantages are more flexible timetable practices according to the student's availability.

Amid the growing number of applications of simulators in education and training arises the need for validating these tools. A possible validation methodology is to use a given teaching methodology in virtual and real robotic systems in different groups of students, and conduct a research on performance, acceptance and satisfaction of students [16].

Some studies on the impact of simulators in the teaching-learning process achieved good results: Koh et. al. [1] carried a research based on the Self-Determined Theory (STD) to investigate the impact of using simulators in teaching how to operate a turning machine. It was concluded that basic psychological needs are met through the use of simulators, enhancing the intrinsic motivation and encouraging learning in general. The study developed by Corter at. al. [2] compared the learning outcomes obtained through remote labs, simulated and hands-on laboratory. They demonstrate that simulated Labs have learning results very similar to those obtained through remote laboratories or hands-on laboratories. Similar results were obtained by Tzafestas et. al. [3] when comparing the results of simulated, remote and real laboratories, giving evidences regarding the validity of using simulators in teaching robotics.

Validating a simulator as a learning tool, however, is a very length process and not all studies perform such rigorous assessment. This systematic literature research (SLR) intended to map robotics education-related studies about simulators and to identify methods used for assessing their educational impact and main features.

2. RESEARCH METHODOLOGY

The methodology of a systematic literature research (SLR) used in this paper differs from conventional literature research by making use of a systematization [4]. SLR has the goal of making possible the replication of results obtained by those who have access to a research protocol. The research can be divided into three phases, that is, planning, processing and analysis, and synthesis [5].

During the planning stage, from April to May 2015, a systematic research protocol was developed whose items will be presented below. After the protocol was well defined, searches were carried out in seven Academic Search Engines (ASE) for journals and conferences. The papers were then filtered by exclusion and inclusion criteria previously defined in the research protocol. The remaining items were then used as the basis to develop of a SLR.

2.1 Objective

The primary research question (PRQ) of this SLR is: What are the best practices and impacts on the teaching-learning process of using industrial robotics simulators?

2.2 Secondary Objectives

To answer PRQ the following secondary questions (SQ) were defined:

- Q1. What are the learning assessment practices used for validating robotic simulators?

- Q2. What are the technological capabilities offered by educational robotic simulators?

2.3 Inclusion Criteria (IC)

Studies included in this SLR must contain the following elements:

- IC1. Application of a simulator in teaching industrial robotics;

- IC2. Use of simulators or virtual reality for robotic laboratories;

- IC3. Studies on the educational and motivational impact of the use of simulators in training courses.

2.4 Exclusion Criteria (EC)

Will not be included in this SLR studies that have the following characteristics:

- EC1. Application of simulators in teaching mobile robotics or surgical training or any other application of non fixed industrial robotics.

- EC2. Works that do not show any kind of learning evaluation.

- EC3. Work with no access to the full text.

2.5 Search and Selection Strategies of Primary Studies

In this research only works published in English will be considered. The selection criteria will be applied in three filtering stages:

- F1. The first filter applied the EC for considering only the title, the abstract and the key words of the articles.

- F2. The second filtering applied the EC considering the introduction and conclusion of the remaining papers of the first filter.

- F3. In the last step of filtering a complete reading on the remaining papers of the previous steps in order to make sure that they conformed to selection criteria. Selected papers were used as the basis for a SLR data collection and analysis.

2.6 Search String Development and Sources

The search string was obtained grouping some keywords extracted from the research questions and from the IC and EC. The extracted keywords are:

Robot, Industrial Manipulator, Simulator, Simulation, Virtual Reality, Education, Training, Teaching, Learning, Evaluation, Assessment, Mobile, Vehicle, Surgical, Surgery, Medic.

These keywords were grouped using Boolean operator ORs , ANDs and parentheses to form a search expression. The first part of the string is (Robot* OR "Industrial Manipulator") is meant to return paper related with robotic applications. The second group

(Simulator OR Simulation OR "Virtual Reality") is intended to restrict the research in terms of virtual reality or simulated applications. The third group (Education* OR Training OR Teaching OR Learning OR Evaluation OR Assessment) is meant to restrict the search to papers which the authors discuss the educational application or educational assessment of robotic simulator. All the three first groups where inspired by the research questions and inclusion criteria, the last group (Mobile OR Vehicle OR Surgical OR Surgery OR Chirurgical OR Medic*) was inspired in the EC and targets to exclude from the retrieved papers those whom discuss about medical and mobile applications and others not related to industrial robotics. The resulting research expression can be seen below:

(Robot* OR "Industrial Manipulator")
AND
(Simulator OR Simulation OR "Virtual Reality")
AND
(Education* OR Training OR Teaching OR Learning OR Evaluation OR Assessment)
AND NOT
(Mobile OR Vehicle OR Surgical OR Surgery OR Chirurgical OR Medic*)

Some of the keywords used the wildcard character asterisk (*), this wildcard is used to replace zero or more characters in a word producing a shorter search string, the words "robot" and "robotics" were replaced by a single word with a wildcard "robot*", the same logic applies for "medic*" and "education*" cases. After the first search string development it was applied in some ASE and it was noticed that some other terms could be added to the EC keywords group due to its repetition on several medical and mobile application papers. The final string has the follow general form:

(Robot* OR "Industrial Manipulator")
AND
(Simulator OR Simulation OR "Virtual Reality")
AND
(Education* OR Training OR Teaching OR Learning OR Evaluation OR Assessment)
AND NOT
(Mobile OR Vehicle OR Surgical OR Surgery OR Chirurgical OR Medic* OR Rehabilitation OR Vinci OR "DV Trainer" OR Gait)

This string was applied to different ASEs but some of those did not support Boolean operators and parentheses when searching for titles, others had differences on implementing of parentheses and title searching, all these particularities required adaptations on the string for each ASE, however, its semantic semantic were maintained as equal as possible. For the purposes of this research the following ASES: ACM Digital Library (ADL), Google Scholar (GS); IEEE Explore (IEEE), Science Direct (SD), Scopus, Springer Link (SL) and Web of Knowledge (WOS).

2.7 Summary and Results

After filtering the papers retrieved by each of the ASE it was conducted a data extraction on the remaining studies. The obtained data collection was analyzed and organized in Tables and charts, a discussion on results was conducted to answer the PRQ and SQ.

3. RESULTS OF FILTERING PROCESS

The execution of searches, organization of results and selection process was carried out from May to June 2015. The Search

String was used in a search for titles only, this strategy has been used to reduce the amount of spurious results returned by search engines if considering full texts. However some of the ASE do not supported the use of strings when performing search for titles, thus a gross sum 794 papers were obtained from the seven search engines used. Excel™ Tables were used to filter the results retrieved by WOS and the Mendeley™ search tools to filter the results retrieved by SL. This process used (Robot * or "Industrial Manipulator") for filtering the titles thus reducing the total from 794 to 413 articles.

3.1 First Filtering Step
During this step, the reading of the title, abstract and key words in order to identify papers that could be deleted based on the first two criteria for deletion. At the end of this stage were eliminated 334 papers based on the first criterion of exclusion.

3.2 Second Filtering Step
The reading of the introduction and conclusion was performed for the application of the EC over the remaining papers from the previous step. A total of 69 were eliminated, 30 due to the first criterion, 26 due to second, and 13 due to the EC3. It is worth noticing however that this gross quantity does not consider duplicated papers. In the case of the third search criterion, for example, the 13 papers excluded result in only 6 papers after considering duplicated papers.

3.3 Third Filtering Step
A complete reading was performed on the ten remaining papers in order to certify their eligibility with respect to the EC, which eliminated two papers based on EC1 and EC2. At the end of the last filtering step, only eight papers remaining were selected.

3.4 Results Analysis
The next Figures illustrates several details of the filtering process. It can be observed that most of the papers were excluded in first filtering step based on the EC1 (Fig. 1a). As expected, about of 80% of the papers were excluded at F1 (Fig. 1b). The relevant number of excluded papers shows the importance of performing a filtering process, the ASE are not capable of returning only the wanted papers. The Springer Link, for example, at the time of this research could not support the use of strings in the search for titles only (Fig. 1c). The Web of Science, despite allowing the use of strings, returned many results that were excluded in the first step of filtering, for example, many studies were able to attend the search string expression for titles however were medical applications.

3.5 Selected papers
Six of eight papers were computed by the IC1, which discuss the development of simulators for robotics courses. Only two of the selected papers discusses the implementation of a simulator for training, namely the work developed by Matsas et. al. [6-7]. Table 1 lists the selected works indicating the reference, year of publication and the inclusion criterion adopted.

3.6 Ad Hoc Inclusions
In order to extend the coverage of the survey, a conventional literature research on Google Scholar and intuitive in Science Direct was conducted. Search were made using the strings "Educational Robotics", "Virtual Laboratory", "Simulated Laboratories" and "Learning Outcomes" the first ten pages of the results ordered by relevance where read. This process resulted in the inclusion of five articles. Table 2 lists the characteristics of the ad hoc selected papers such as Table 1.
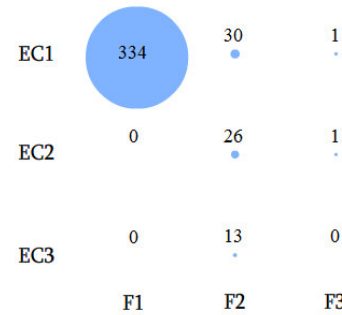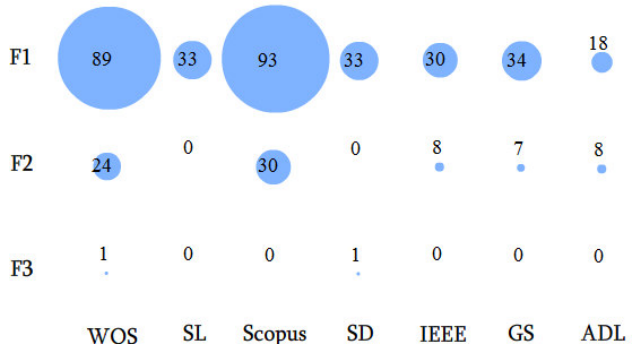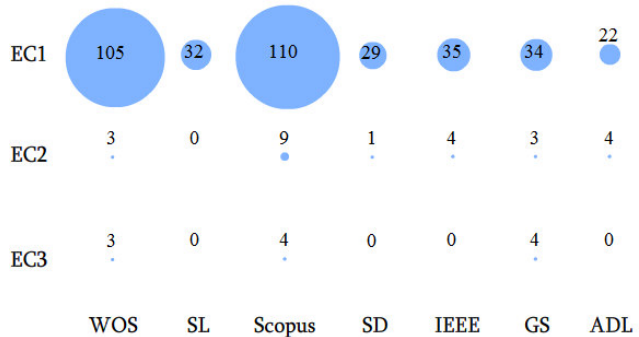

Figure 1 a. Excluded papers by exclusion criteria and filtering step.

b. Excluded papers by filtering step and ASE;

c. Excluded papers by exclusion criteria and ASE;

Table 1. Papers Selected via SLR

Ref.	ASE	IC	Year
[10-11]	GS IEEE Scopus WOS	1	2009
	ADL Scopus WOS	1	2014
[8]	Scopus	1	2011
[12-13]	Scopus WOS	1	2011
	Scopus WOS	1	2012
[9]	Scopus WOS	1	2013
[6-7]	GS Scopus	2	2013
	Scopus	2	2015

Table 2. Ad hoc papers selected

Ref.	ASE	IC	Year
[3]	GS	1	2006
[14]	GS	1	2011
[19]	GS	1	2011
[16-17]	SD	1	2011
	GS	1	2012

4. CONTRIBUTIONS REVIEW

To answer the PRQ an analysis of selected works was performed to investigate the educational features provided by simulators and which evaluation methodologies were used to measure the effects of the use of simulators on the teaching-learning process. The results of this analysis are and discussed in the the next sections.

4.1 Virtual and Remote Robotic Laboratory

Tzafestas et. al. [3] researched the differences in the mean scores obtained in a final test with a real robot by three distinct groups: group I was trained with a hands-on robotic station; group II used a remote station and; group III received training through a simulated laboratory (Fig. 3).

Each group was divided into six groups of three to five students, each team received about 1 hour and 30 minutes training. All students received the same training and educational material differing only in the laboratory nature. The final test was conducted in a real robotic station and the students were told to program a pick-and-place task. During the test, an examiner took notes about students performances, quantity and type of mistakes they made (from pressing a wrong button to failing on programming or, even failing to implement the task correctly).

The simple and operational mistakes were scored with 2 points and the conceptual mistakes with 5 points. The time taken to solve the test was also considered and scored in minutes. The lower the final score the better the performance since it is based on the time elapsed and taken mistakes (Fig. 4).

The average total score for the groups I, II and III were 19.14, 25.0 and 18.83 respectively, which means that the group trained with the simulated got an overall better result than the others. The only aspect that the real station training was superior to the simulated was the time, students that were trained with real

Figure 3. Virtual laboratory user interface [3].
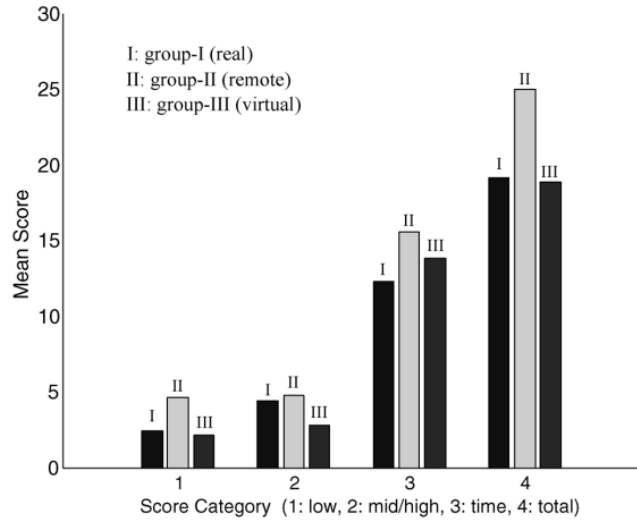
Figure 4. Mean scores in the final test [3].

devices were faster, however that difference is not statistically relevant.

The remote station training students achieved the highest score at all the categories indicating a bigger difficulties to transfer the knowledge from the remote training to the real station if compared to the other groups. The author concludes that more studies are needed to understand the reasons for this difference but that can be partially explained by the greater motivation the simulator trained students showed leading them to have a better comprehension and performance in the final test.

4.2 3D-RAS

Sanguino & Márquez [12-13] developed an educational simulator called 3D-RAS (3D Robotic Arm Simulator) with the objective to help making more attractive and practical the teaching-learning process of serial robotic arms kinematics. The simulator was programmed using LabView, the main contribution of 3D-RAS is the possibility to simulate the forward and inverse work space volume of generic robotic arms (Fig. 5).

The system was first applied between the years 2008 and 2009 to 32 students and 14 teachers from the Robotics course of the Computer Engineering and Electronic Engineering degrees at the University of Huelva. A survey consisting of 17 questions using Likert scale was used to evaluate the contributions and capabilities of the system. The survey found that the initial knowledge level on Robotics was low (question 1). Teaching and learning of robotics was favored by the use of the system (questions 2-7). Graphical interface and easy of using it fostered the quick learning (questions 8-12). A high degree of satisfaction (questions13-16) and a high score in the general assessment (question 17).

Another data brought by this research is the possibility the students had to choose between executing the tasks in a university lab or at home, 57.15% of the students opted for counting on the teaching support of professionals and the help of their classmates at the university, but 42.85% of the students used the system at home. After the first application the authors added a new educational feature to the system that made it possible to simulate surface and volume trajectories, the surface trajectories correspond to open curvilinear paths applied to robotic arms of 5 DOF, the volume trajectories correspond to closed curvilinear
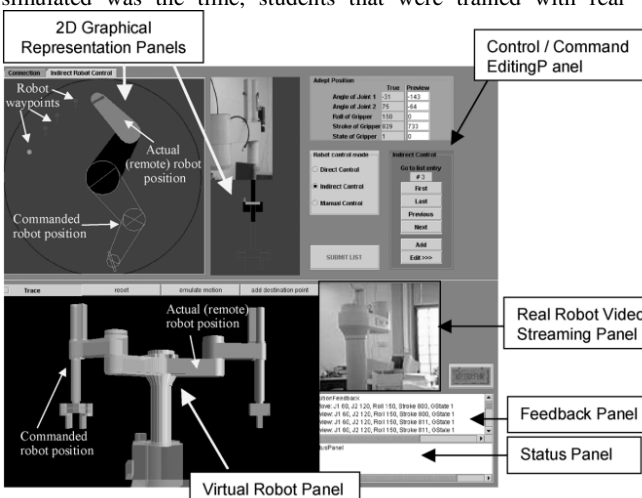
paths. The system was applied again between the years 2008 and 2009, this time the survey counted with 38 students and 14 teachers. The same 17 questions using Likert scale to evaluate the system. The Figure 5 shows a comparison of the students' perception was applied in both the applications, the authors conclude that it follows the same tendency with slightly variations. On the second test 56.52% of the students opted for doing the exercises at the university laboratory and 43.47% used the system at home. From the research the authors concludes that the developed system achieved the objective of making it easier and more interesting to teach and learn robotic anthropomorphic arms kinematics.

4.3 Beware of the Robot

Matsas & Vosniaskos [6-7] that developed a training immersive simulator for collaborative works between a human and a robotic arm in industrial environments. The main objective of this system called beWare of the Robot (BOR) is to train operators in human-robot interactions thus preventing accidents and increasing production.

The system is based in the Kinetic™ technology allied to a virtual reality stereoscopic glasses apparatus, making the system immersive and highly interactive, the system creates an avatar to represent the user inside the virtual environment (Fig. 6). The authors applied the system in a group of 30 senior mechanical engineering students (between 21 and 31 years), sufficiently familiar with theoretical robotics and manufacturing systems. After ten minutes of an introductory exercise and six to eight minutes of tasks execution the users were submitted to a 42 questions survey.

Fourteen questions about participant's personal information, level and experience, ten questions about immersion (I), presence and
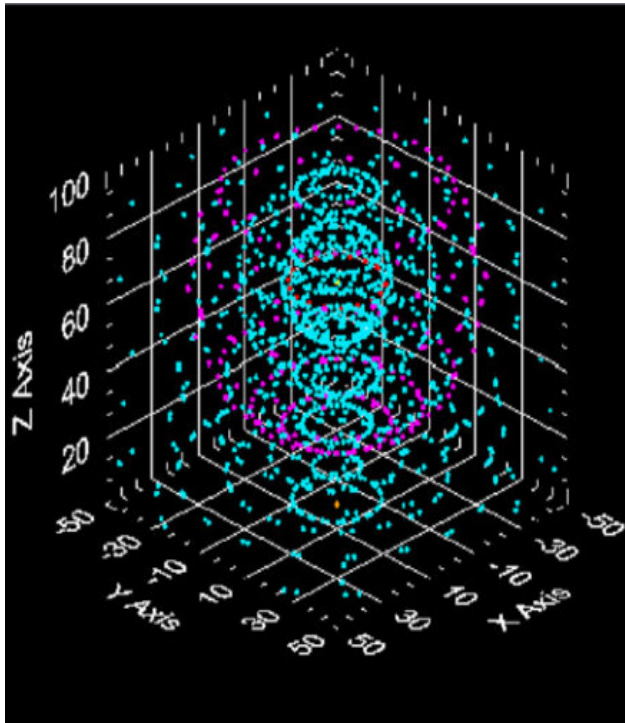

Figure 5. First 5-Axis Puma560 forward workspace simulation, base in orange, shoulder in yellow, elbow in red, wrist in magenta, and gripper in cyan [12].

Figure 6. View of avatar trying to take a board from the robot gripper [6].

realism perceptions and eighteen questions about usability, effectiveness, tracking and interaction quality. A task execution video recording for posterior observation, and discussions with each participant was conducted to complement the system evaluation. About the immersion perception, the survey found that 93% of the participants did not lose their concentration at all during the test. Large number of subjects felt like they were really moving an object with their hands, despite the fact that the object did not have physical mass, video observations confirm the above finding, although subjects were told that they should use one hand, 20% of them used both hands to grasp and carry the work pieces.

It was also noticed that some users (17%) spontaneously closed their hands and/or fingers in order to grasp the parts (as they would have reacted in the real world); although they were told that, our system does not support fingers tracking. Concerning the system usability and effectiveness 76% of the participants replied that during the experiment they were feeling more as if they were participating in an amusing game. Only 10% of them encountered some difficulties during the initial detection and calibration process and 70% of subjects managed not to enter into the workspace (which was the potentially hazardous area).

4.4 Simulator Development as Learning Methodology

Cao et. al. [8] proposed that the development of robotic simulators is the solution for some educational robotics problems like, for example, the difficulty most students have to understand the complexity of the robotic systems and the lack in quantity of hands-on robotic laboratories. The author proposed a course for undergraduate electrical and mechanical engineering students composed of three phases, that is, modeling, developing a graphical interface and a PID (proportional integral and differential) controller for each robot joint. The students could choose a CAD software to model the links and joints of a PUMA 6-DOF robot to be later imported in MATLAB™.

In the second phase, the imported patch object must be used to develop the graphical user interface containing inverse kinematics (IK) and forward kinematics (FK) controllers. The final phase consists on designing a PID motion controller for each robotic joint using the robot dynamic model using MAPLE™ or
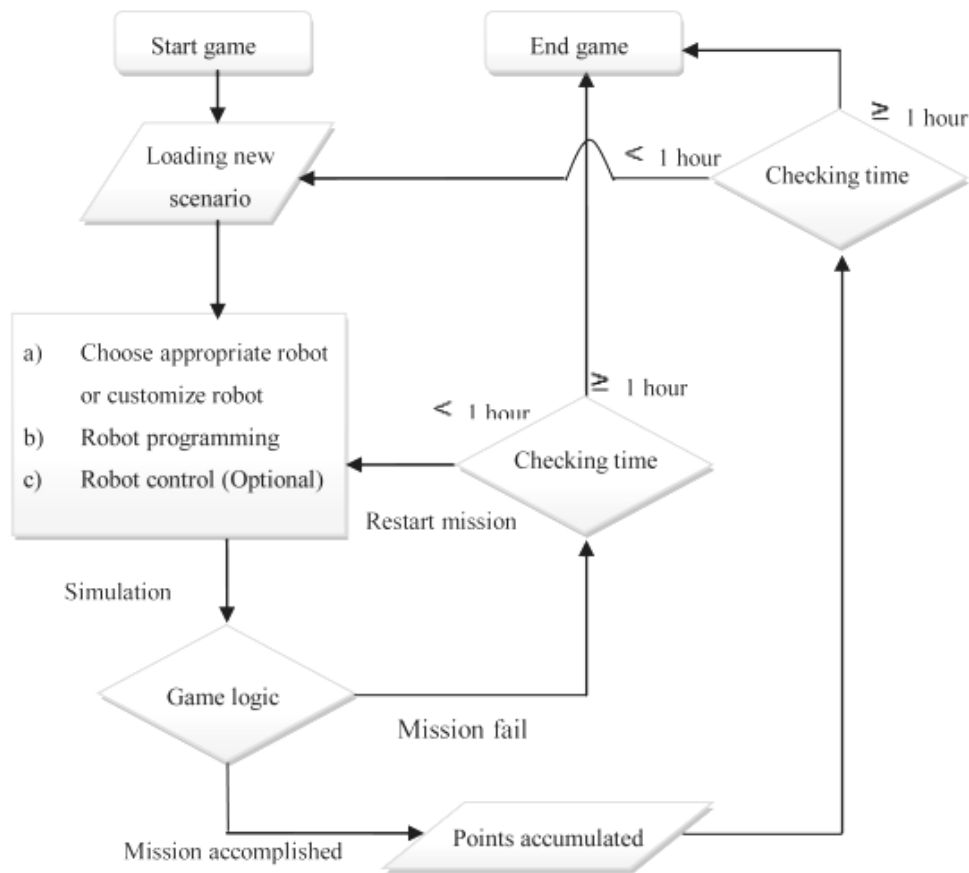
Figure 7. Game based simulator task flow [9].

MATLAB™. In the presented work the authors did not perform an formal survey to evaluate the impact of his educational methodology but offered to the students assistance in presence for helping the students and also evaluate their performance and difficulties on fly. It reported a great enjoyment by the students during the development of the robotic simulators, also reported that helping the students to overcome their frustration on trying to implement the IK algorithms and controllers design is a key component for the success of the course methodology proposed.

4.5 G-IRSTS versus IRSTS

Lee et. al. [9] researched about students' perception of using constructivist game-based simulator (G-IRSTS) compared to a conventional robotic simulator (IRSTS). The research was applied on undergraduate students, age 22 to 25, who had attended a formal course of automation and robotics.

The same basic collections of educational features are present in both simulators. The difference is that G-IRSTS have a set of predefined work cells with interactive objects and manipulators composing missions that need to be accomplished by the student in order to progress, at Figure 7 shows G-IRSTS game dynamics. IRSTS allows a complete customization of the layout, using predefined machines, robots and objects available on it's library or by using user-defined robotic model. After modeling the work cell the user develop a program and then simulate a given manufacturing process.

The authors divided 120 students in two experimental groups, and each group was again divided in 6 classes of 10 students. The first group attended to the a course using the G-IRSTS system and the second used the conventional simulator. Each student was provided with a computer and unlimited time to complete the challenge/assignment and the survey administered after it. The author adapted an evaluation method of students' attitudes toward science (TOSRA) to be applied to robotics courses (TORRA). The applied survey consisted of 38 Likert scale questions divided into computer simulation-based learning environment criteria and an attitude criteria based on TORRA. The criteria are negotiation, inquiry learning, reflective thinking, relevance, ease of use and challenge, each criteria had about 5 questions to assess the attitude of the students towards the simulation tool used.

This survey found that the G-IRSTS was more effective as a learning environment than the IRSTS based on the attitude scores. The students who used the game based robotic simulator got higher scores in terms of negotiation, inquiry learning, reflective thinking and challenge and the same score the second group have got higher scores in terms of relevance, ease to use and attitude towards robotics.

4.6 VCIMLAB

Hashemipour et. al. [14] states that most comercial industrial robotics simulators are too sophisticated for educational purposes and require high computer knowledge raising the need for educational simulators development. A Virtual Computer

Integrated Manufacturing Laboratory (VCIMLAB) module was developed to integrate other engineering virtual modules. VCIMLAB contains programmable industrial robots, Computer Numerical Control machines, quality control systems and other industrial automated machines (Fig. 8).

A set of experiments to evaluate the educational impact of the VCIMLAB was designed and applied once a semester between the years 2003 and 2007 with a total of 80 undergraduate students participants from the Mechanical Engineering course of the Eastern Mediterranean University. The evaluation happened in two stages, at the first stage, students were asked to use VCIMLAB to complete a given task. Typical tasks were, for example, operating robot arms, picking parts, recording positions and writing robot programs for automated manufacturing operations.

At the second stage, the students were taken to a real laboratory asked to do the same tasks using the real hardware. At the end, the students are given a lab quiz in order to test their understanding of the experiment and a usability evaluation survey. This survey was based in the Software Usability Measurement Inventory (SUMI) [15], consisting in 50 questions divided into five subscales, namely, efficiency, affect, helpfulness, control, and learn ability. According to these scales, a system that achieves a score in the range of 40 to 60 is comparable in usability to most of successful commercial software products. VCIMLAB got was well evaluated in all the scales, with a global score of 48, with the minimum score of 46 at control and maximum of 60 in learn ability, which indicates a great quality in the system.

Figure 9 shows some selected results that indicates a positive impact over the learning process by motivating the students and presenting a relevant knowledge transfer from virtual to real laboratories.

4.7 SGRobot

López et al. [10-11] applied simulators to Industrial Engineering Masters degree students. The system is composed of two software, the first: RobotScene (Fig. 10) is an environment for
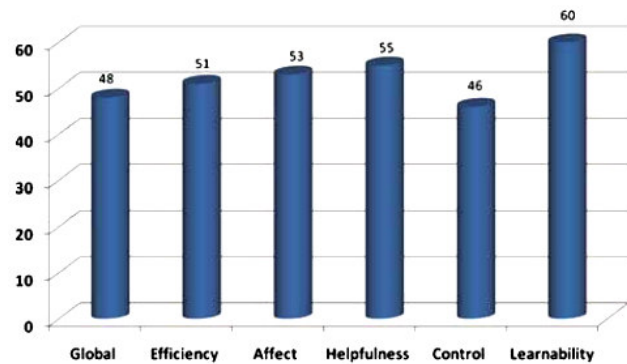

Figure 8. VCIMLAB training module [14].

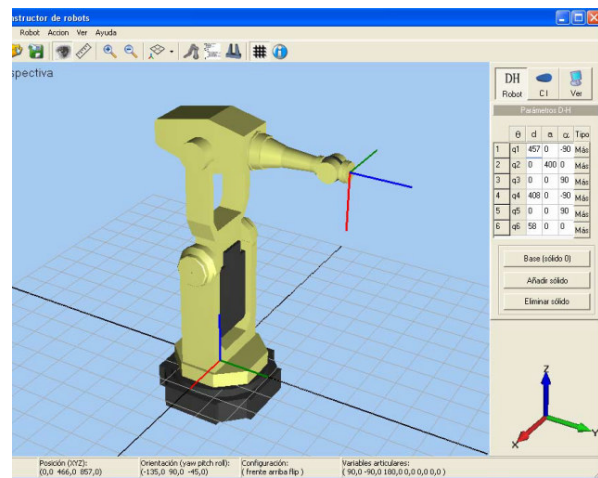**Figure 9. VCIMLAB usability evaluation [14].**

Figure 10. Example of robot modeling using RobotScene [10].

designing work cells and; the second SGRobot is a simulator of the previously designed work cell.

Authors argue that students should read, write, discuss, or be engaged in solving problems, do more than just listening. According to authors the use of simulators gives students the possibility to autonomously explore the system and thus, learn more effectively. Authors also defend the use of simulators to help model robots, design its control system, and practice to obtain programming skills.

Final test was applied to the students at the end of the course and mean scores obtained was a measure of success on the application of his educational methodology. The mean final test score of students between the years 2003 and 2009 was taken. Students could choose not to take the exam in case one felt not comfortable to, which brought uncertainties over the results obtained.

The survey found that 23% of the students from Control and Programming of Robots course got an A grade, 34% got B, 18% got C, 24% opted not to take the exam, and 1% of the students got a D grade. Similar results were obtained at the Industrial Robotics course with 16% of the students getting an A grade, 44% got B, 30% got C and 10% opted not to take the exam.
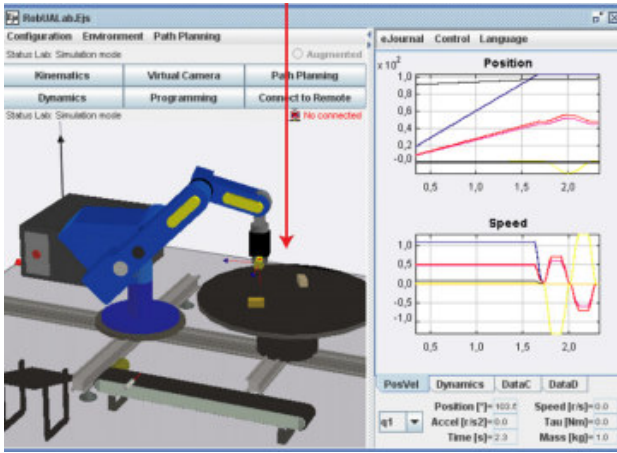
Figure 11. RobUALab - Programming the virtual environment of a pick-and place operation [16].

A survey on 50% of the students about the time they expended on practical, theoretical and project activities was performed. The survey found that the students expended 35% of their time (50h) studying theory, 30% (43h) using simulators for practical activities and 35% of the time working of their final project. These results stress the importance of the simulators in the leaning process.

4.8 RobUALab

Jara et. al. [16-17] states that simulated laboratories should be used as an initial experimentation and a first contact with the robotic systems and propose the integrated use of simulated and tele-operated laboratories. The authors developed RobUALab and used it in a blended-learning method between the years 2009 and 2010 in the Automatics and Robotics subjects of Computer Science Engineering degree at the University of Alicante (UA). RobUALab has virtual, remote and augmented reality (AR) capabilities to simulate an anthropomorphic robot arm with 6-DOF to pick and place tasks with a turning table (Fig. 11).

The blended method use different resources for the face-to-face interaction as theoretical lectures and problems, textbooks, seminars, conventional tutorial classes, and practical exercises where students experiment with the real plant in-situ. Exercises are based on both supervised remote and simulated hands-on experiments using RobUALab and real laboratory setups. The practical exercises were organized in four virtual and remote experiences. The first three had several theoretical concepts such as kinematics, path planning, dynamics and programming. A total of 50 students used the system and were asked to answer a satisfaction survey composed of 19 questions using Likert scale.

The research found that 36% of the students were completely satisfied and 46% were satisfied with the system, 52% found it better than the traditional learning methods, 90% found the system easy to use, 38% and 30% considered the system's quality good and very good respectively. 80% thought the system is suitable for the learning of relevant concepts. 44% consider questions to teacher the most important learning source, 22% consider it's the simulation, 20% consider the documentation and 14% found to be present at a real laboratory to be more important learning source.

Using the Easy Java Simulations, an open-source tool developed in Java [18], RobUALab was extended to add remote synchronous collaboration (RSC) between teacher and students (Fig.12). The system was also applied in the Computer Science Engineering

degree at UA, in Computer Process Control and Robots and Sensorial Systems subjects and was applied 25 students. The application methodology was divided at Practical lessons at the University and Practical lessons through the Internet. The first phase give students opportunity to learn how to use the collaborative system and solve any doubts they could have. During the remote lessons, teachers helped students using the collaborative system to operate the robot and Skype for video conference.

After the lessons the students answered a survey of nine questions divided into three issues: three questions about the suitability of the system for learning relevant control and robotic concepts; three questions about the collaborative system functionality and; three questions about the effectiveness of the synchronous collaboration in the learning process.

The survey found that 64%, 52% and 48% of the students strongly agreed with the three survey issues, a comparison with the average marks obtained by the students using no collaborative systems in past years found an increase of 13% in the number of students which got an A mark, and a 9% increase in the B marks.

4.9 AutomatL@bs

Vargas et. al. [19] developed a framework for a complete network of automatic control web-based laboratories called AUTOMATL@BS (Fig. 13), it was used to integrate under the same system the virtual and remote laboratories from the University of Alicante and the University for Distance Education (UNED). The system grouped the tank, motor (Fig. 14) and heat flow control virtual and remote laboratories developed at UNED and RobUALab from UA.

Other universities can submit a request to join the virtual and remote laboratories consortium, to join the consortium the requesting must develop a remote and a virtual laboratory in LabView or C code and a client framework in EJS, the only requirement is a Java-compatible web browser to access the system.

A total of 120 students from seven different universities, which participated in the project, used the system. The test was divided
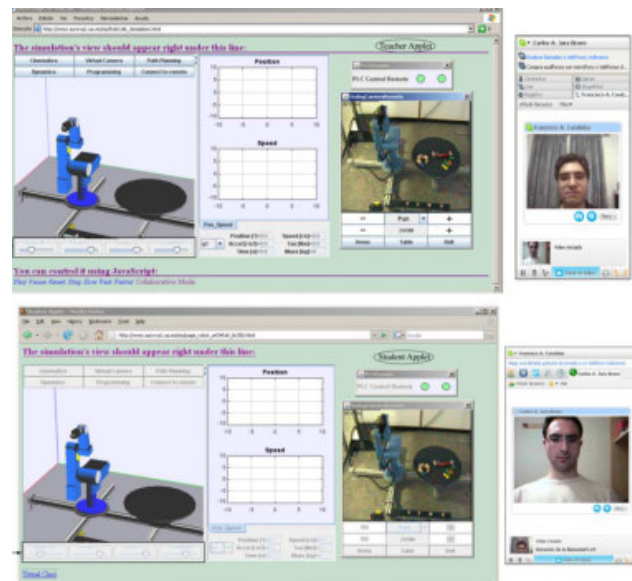

Figure 12. RobUALab.EJS - View of a collaborative operation between teacher (up) and student (bottom) on a virtual and remote laboratory [17].

in two phases, in first phase, called PRE-Labs, the students were given lessons on how to use the system until they could operate it fluently, in the second phase, called Labs, students received access to execute programming tasks in the virtual laboratory.

Once the students performance in the simulator is evaluated as satisfactory by the teachers it is allowed to access the remote laboratory. To get a feedback on student's perception of their learning experience it was applied a survey very similar to the one applied by Jara et. al. [17] compounded of five questions about the system technical and structure quality and five questions about the learning experience and usability. The survey found that 19% of the students where satisfied and 69% very satisfied towards the system, 33% think the simulated laboratory is very good, 48% think it is good and 15% think its acceptable.

About the remote laboratory 25% think it is very good, 38% think it is good, 25% think is accepTable, 10% think it is bad, and 2% think it is very bad. In the students opinion the most important learning resources are the documentation for 18%, questions to the teacher for 44%, the simulation for 27% and the remote access to the plant for 11% of the students.

Bad results obtained in the satisfaction of some itens was found to be due to the fact the students did not an opportunity to work directly with the actual equipment, to solve this a blended learning methodology should be applied giving the students a first contact with the control and robotic stations before the virtual and remote sessions. The authors points that a probable reason for bad evaluation of the remote laboratories was the internet connection quality, some of the students had their experiences using old dial up connection causing the system to respond slowly, a 512kbps/128kbps connection returned satisfactory results. The authors conclude also that the system documentation and the teachers instructions are essential for a good learning experience.

5. DISCUSSION

In the next subsections, systems educational features and educational assessment methods are summarized and discussed from hypothesis are formulated to answer primary and secondary research questions.

5.1 Educational Impact Assessment

This research found essentially two assessment methods, namely, the satisfaction or usability survey and the performance

Figure 13. AutomatL@bs project homepage [19].

Figure 14. View of UNED DC motor remote control laboratory [19].

assessment. Most of the usability or satisfaction surveys did not follow a survey design methodology, or else, the methodology applied was not reported in the paper.

There are, nonetheless, two exceptions, the Test of Robotics-Related Attitudes (TORRA) applied by Lee et. al. [9] and the Software Usability Measurement Inventory (SUMI) developed by Kirakowski & Corbett [15] applied by Hashemipour et. al. [14]. The survey design used in TORRA was adapted from the early developed Test of Science-Related Attitudes (TOSRA) a 70 questions using Likert scales survey published by Fraser [10] in 1978 aiming to assess attitudes like enjoyment of science lessons, leisure interest in science, and career Interest in Science. TORRA is intended to measure negotiation, inquiry learning, reflective thinking, relevance, ease of use and challenge through 38 questions using Likert scales.

SUMI was published in 1993, it was developed on the basis of CUSI (The Computer User Satisfaction Inventory) [20] by examining it and extracting further subscales, resulting in 50 questions using likert scale that aims to measure affect, efficiency, helpfulness, control and learnability.

Both TORRA and SUMI have validity studies published. All the other authors designed their surveys based on their own know-how and past experiences on assessing usability and satisfaction. From the authors whom used a knowledge test to evaluate the educational impact of using the proposed simulators only Tzafestas et. al. [3] designed a practical test to systematically score the students performance based on the mistakes they took during the test. The other two authors based theirs assessment on the students marks and informal feedback during the courses [8][10-11].

Nonetheless, out of 13 selected papers, ten used surveys thus it can be conclude that the Likert scale survey is certainly the most popular assessment method among the studied authors.

5.2 Educational Features

Table 3 presents educational features of each simulator and the educational assessment method used in order to understand how these characteristics are distributed among the different systems. Simulator are ordered by feature quantities and EF are ordered by importance, based on the repetition they show among the systems.

The only feature present in all simulators was FK. Predefined tasks like, for example, pick-and-place or welding tasks (T), the

Table 3 - Educational resources and educational impact evaluation methods

Ref.	Simulator	FK	T	Scene	P	M/D	IK	D	C	RCS	AR	I	TWS	Assessment	TEF
[3]	VRRL	x	x		x									Mean Scores	3
[12-13]	3D-RAS	x				x	x						x	Survey	4
[6-7]	BOR	x	x	x					x			x		Survey	5
[8]	-	x			x	x	x	x						Performance	5
[9]	IRSTS	x	x	x	x	x								TORRA	5
[14]	VCIMLAB	x	x	x	x			x						SUMI	5
[10-11]	SGRobot	x	x	x	x	x	x							Mean Scores	6
[17]	RobUALab.EJS	x	x	x		x	x			x				Survey	6
[16]	RobUALab	x	x	x	x	x		x	x		x			Survey	8
[19]	AutomatL@BS	x	x	x	x			x	x	x	x			Survey	8
	Total	10	8	7	7	6	5	4	2	2	2	1	1		

existence of interaction between the robotic arm and different objects in the environment (Scene), the possibility of programming the robotic arm (P) were present in most systems. Other educational features found are the immersive environment (IE) with use of virtual reality glasses, IK, the employment of body dynamics for a more realistic robot model (D), collision detection (C), the trajectory and workspace volume simulation (TWS), the remote collaboration system (RCS), the use of augmented reality on remote robot operations (AR), the possibility to model or design the robot and the work the cell (M/D), the educational assessment methodology used (Assessment) and the total of educational features present (TEF).

From the information presented in the Table 3, one can see that there are some features that can be considered essential due to the frequency that these features are present among the simulators. Important resources are forward kinematics, predefined tasks, existence of interaction between the robotic arm and different object, possibility of programming the robotic arm, possibility to model or design the robot and the work the cell, inverse kinematics and body dynamics, this group can be considered as a essential set of features for an educational robotic simulator. However none of the presented simulators has all these six features indicating a possibility for a future simulator development. Some features are unique to a few simulators such as the TWS developed by Sanguino et. al. [12-13] and the immersive environment developed by Matsas et. al. [6-7].

6. CONCLUSIONS
This paper performed a SLR on seven academic search engines and found 794 papers in the context of educational robotic simulators. After filtering and the inclusion of papers found ad hoc, 10 simulators were selected. These simulators were actually use as an educational tool. Features regarding simulator functions and assessments were mapped from these papers.

It was found that 3D environments and Forward Kinematics are the always present features. There are six most used simulation features: Tasks; Scenes; with various objects; Programming language; Modeling/Designing and; Inverse Kinematics. Nevertheless, most complete of simulators offer only two thirds all features found.

Most papers performed assessment over simulators use in the educational setup and the use of questionnaires were the most frequent instrument. These questionnaires however, measured a variety of aspects including satisfaction and usability, for instance. Performance on the real robot, suitability of the simulators as educational aid, knowledge scores, learnability and amusement, were also assessed.

Nevertheless, there is a consensus among reviewed authors that simulators should be favored against conventional classes or remote labs or, at least, be presented as an optional complementary material.

It was also found that assessments have not been done extensively in order to gather statistically relevant findings. In addition, no pedagogical approach seemed to be of concern to authors. Therefore, more research and assessment should be performed in comparison to teaching-learning theories. In doing so, a more clear understanding of the impacts of robot simulators as an educational aid will be achieved.

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