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VISIR's Usage as an Educational Resource: a Review of the Empirical Research

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ABSTRACT

Laboratory experiments are one of the backbones of engineering teaching, as they help students learning in a unique way, providing better understanding of scientific theories, clarifying concepts and principles as well as improving their technical skills. Nevertheless, with the Bologna Process reforms and the economic constraints most Higher Education Institutions face nowadays, caused a significant decline in the amount of time devoted to hands-on lab. Researchers are seeking complementary ways to teach these practical skills and recently, with the explosive popularity of computer-based learning, remote labs are being used as an option. This review paper presents a first attempt to compile empirical studies that directly report the use of the remote laboratory VISIR (Virtual Instrument Systems in Reality). These practices of engineering classes/courses, used VISIR individually or as a complement to traditional hands on laboratory. Concerning these different approaches of how VISIR is used, the authors draw several conclusions - findings suggest that VISIR is a useful learning instrument, having been used, so far, by more than 4400 students. It contributes to improve students' competences and knowledge, their confidence in lab and their enthusiasm and motivation. Some factors, such as teacher's supervision and attention to the VISIR component play a crucial role in students' engagement. Finally, the results achieved through this review raise several important and still non-studied issues to be addressed by future research.

CCS Concepts

• **Applied computing → Physical sciences and engineering → education**

Keywords

Remote Laboratory; VISIR; Learning Outcomes; Engineering Education.

1. INTRODUCTION

Engineering education has solid needs of experimental competences, regardless the area [1]. Students need to perform experiments in order to gain better understanding of theory, to collaborate and interact efficiently with instruments and equipment, consolidating knowledge and skills, which will be of a vital role after their graduation. As Gustavsson states [2], in order to become experts when dealing with more complex problems, as it will be the case in their future professional life, students have to become *fluent in the language of nature and a successful designer, and for that engineering students must perform numerous experiments practice laboratory work* These competences, were traditionally developed in laboratories, along their education

Until quite recently, hands on lab experiments were the only existing experiences from which these conclusions could be settled [3]. In the last decades, there was a general growth of the number of students attending higher education and has a consequence the physical resources available were no longer sufficient. Simultaneously, with the Bologna Process, the laboratory time was reduced in most European Engineering Schools and the number of students per class increased, due to economic restrictions.

About the same time, along with the rapid pace of evolution of Information Technologies (IT), scientists started developing computer simulations and remote laboratories, allowing students to practice some experimental skills differently – giving them freedom to organize their own learning activities according to their perception of their learning needs and extended access to the learning resources (access many times and from different places), potentiating students' autonomous learning activities and even supporting life-long learning [2], [3], [4]. On the other hand, online learning is becoming critical to institutional long term strategy – online education is strengthening, and it is expected to proceed this way in the next years [5]. In fact; web-based computer-assisted learning exhibits several advantages, being quite efficient and covering up a demographically and geographically wider student population [3]. However, for engineering and/or science courses, mostly this is accomplished at the expense of students' physical presence at lab, and there is clearly a need for developing competences with physical objects at some point [3].

Nowadays there is still some controversy about web-based laboratories efficacy [6] - some researchers consider them educational hindrances while others conclude that they are a useful complement to hands-on labs [7]. In spite of this, teachers are often using these resources either as replacement of or as a complement to the traditional hands-on lab. Remote labs are becoming a popular learning tool, emerging as one of the main instructional technologies adopted and valued in engineering education, corresponding to one of the major shifts in engineering education in the last 100 years [8].

Students need to understand the major differences in the type of experimental results that can be obtained from these different resources: computation model results from simulations and real experimental results from hands-on or remote labs. In this sense, remote labs give the advantages of simulations and the advantages of working with real things. Still, remote labs are not the perfect solution – the underlying technology of the laboratory (as the interface of the equipment) may influence learning effectiveness [4].Very recently (2015), J. R. Brinson [3] presented a study – an extensive literature review on comparative studies that present empirical measures of students´ achievement of learning outcomes in hands on traditional labs (TL) versus non-traditional simulation and remote labs (NTL) – the main conclusion is that student learning outcome achievement is equal or higher in NTL versus TL, regardless of the outcome category being measured (quizzes and tests/exams being the most common assessment instrument). A “blended” or “hybrid” approach to laboratory learning is being advanced – a combination of TL and NTL procedures, taking advantage on the benefits of both: knowledge and understanding outcomes from NTL and technical skills acquisition from TL [3]. “Blended” Labs seem to be more effective than NTL alone and the sequence of TL and NTL component in the laboratory procedure seems to make little difference [3].

This poses new trends regarding pedagogical and didactical issues, as the educational objectives associated with each of these resources may differ [9]. Each method allows developing different competences, so teachers should be aware of this fact, when deciding which method or combination of methods/resources to use. The use of these new resources, on their own (without an appropriate didactical design), may even be prejudicial – some of these tools are quite complex and not immediately understandable by students, potentially leading them to frustration and dropping out the task [10].

As is well known, teachers can reach more students, if they diversify the methods and techniques used in classroom, due to students' different learning style [11], [12]. On the other hand, it is crucial to design the course curriculum based on the learning outcomes teachers want their students to develop [12], [13], and for this planning teachers must take into account not only the teaching methods but also the resources they will be using and design students' activities accordingly.

A remote laboratory can be defined as an educational resource, in which the user and the experimental apparatus are physically apart. For the experiment execution there is a need of a communication mean (e.g. Internet) between user and remote equipment and usually also requires a particular user interface [14]- the user has the possibility to configure, control and/or monitor the physical parameters of a real experiment. Most of its advantages have already been enumerated but it´s worthwhile to remember it also enables education and research collaboration between individuals and institutions all around the world.

Among the most used labs in Engineering Education lies VISIR (Virtual Instrument Systems in Reality). This work is based upon a literature review on published papers about VISIR usage from 2004 to May 2016.

This work presents an effort of systematizing the results of using VISIR reported in literature and better understand common grounds and the need of future research. First VISIR will be presented in section 2 and the correspondent literature review methodology in section 3. In section 4 and 5 the results, discussion and conclusions will be presented. And finally, we will address the implications for future research.

2. VISIR REMOTE LAB

Since 2000, a large number of remote laboratories, in many different scientific and technological areas, were implemented and set up over the world [9], [14]. Considering engineering and scientific disciplines, the most widespread use of these is in electrical and mechanical engineering [15].

The remote laboratory VISIR emerged from a feasibility study started in 1999, at the Blekinge Institute of Technology (BTH) in Sweden although it was launched just on 10 March 2004. VISIR is a combination of open source software packages and commercial equipment from National Instruments (NI), released under a GNU General Public License (GPL), for creating, wiring and measuring electronics circuits on a breadboard remotely, supporting a wide range of electronic circuit components [16]. Nonetheless the platform is not limited to electrical experiments - VISIR laboratories for acoustics and mechanical vibration experiments are on line in BTH [17], [18]. BTH, together with NI in the USA and Axiom EduTECH in Sweden launched the VISIR Project at the end of 2006, the project being financially supported by BTH and the Swedish Governmental Agency for Innovation Systems (VINNOVA) [18] .

So far, and after BTH, VISIR was installed in seven different Higher Education Institutions (HEI), in five different countries: Austria (Carinthia University of Applied Sciences and FH Campus Wien for Applied Sciences), Portugal (School of Engineering of Polytechnic of Porto (ISEP)), Spain (University of Deusto and the Spanish University for Distance Education), Georgia (Shota Rustaveli State University) and India (Madras Institute of Technology) and it has served well several thousands of students [14], [18], [19], [20]. BTH research group is still responsible for maintaining and updating the VISIR distribution that is available as open source. The International Association of Online Engineering (IAOE) created a Special Interest Group of VISIR (SIG VISIR) to foster the collaboration within the community and to foment the project dissemination [18], [20]. The existence of this community, which is quite wide and active is a major advantage: VISIR users, both teachers and students, frequently come up with different requirements and/or identify constraints and problems that were not predicted by VISIR developers. This feedback is often used to add new features and introduce improvements to the system interface and operation, promoting VISIR's evolution and improvement [21]. In fact, in 2015, VISIR was recognized as the best remote controlled laboratory by the Executive Committee of Global Online Laboratory Consortium [22]. VISIR is also the first remote lab in the world serving a Massive Open Online Course (MOOC) on industrial electronics [23], [24].

VISIR may be considered as a remote workbench, equipped with the same instruments that exist in a hands-on laboratory for conducting experiments with electric and electronic circuits; these workbenches are similar to each other, every place in the world: usually in each, there is a breadboard and components, provided by the instructor, and the student uses them to mount the circuits and to connect the test probes, as determined in the lab instruction procedure. Using VISIR, an identical simulation of the real equipment and instruments appears (a virtual breadboard and photographs of the components) on the student PC screen. Students use the mouse, instead of their fingers, to adjust the instruments, to position components on the breadboard and to do the wiring to assemble the circuits. The corresponding real components are mounted in sockets in a switching matrix and the measurement results, through the instruments virtual front panels, are displayed in students´ PC screen. So, as long as the student as a PC or more recently a handheld device, such as a smartphone or tablet, he has the ability to access to this real electronic lab (which mimics a traditional workbench), at any location, by using the internet and a web-based user-interface using any web browser [25], [26].

Figure 1.VISIR at ISEP.

One can briefly describe VISIR architecture (figure 1) as a set of four different, mostly independent components:

- Equipment server: deals with the hardware and the circuit-wiring robot;
- Measurement server: works with the equipment server, in order to provide the real time measurements to the client;
- Flash Client: is connected to the measurement server and provides the experiment user-interface, accessible through any browser;
- Openlabs Web layer: provides the basic remote experimentation layers, including the initial web-pages, user authentication and authorization, etc., as well as a database, used to store users, circuit and other information [27].

VISIR has its own Learning Management System (LMS) and four different user account types: administration account, teacher account, student/instructor account and guest account. Each user account has its own features, privileges and limits, setting the availability of the lab contents. The account associated to the lab organizer and distributor is the administrator account with privileges of designing the lab web pages, uploading files, creating courses, assigning teacher and instructor accounts and modifying user accounts. The teacher account is linked to the course(s) for which the teacher is responsible and its' main privileges are: adding and removing experiments as well as student accounts and making schedule reservations. The student/instructor account allows to access the experiments of a specific course. Finally the guest account is a public trail account, that can be accessed by anybody to try VISIR [19].

3. VISIR LITERATURE REVIEW METHODOLOGY

The purpose of this work is to understand and systematize the scientific research using VISIR's approach, done so far. The tackled research questions is: *Considering VISIR implementation and usage reported in literature until May 2016, which common outcomes and indicators of consistent results can be found in the different didactical approaches?*

This question will be tackled through a systematic analysis of these former research. In the next sections we will start t discuss how this analysis was conducted and the methodology used.

3.1 Research Methodology

A systematic literature review, or systematic review as it is often referred, *is a means of identifying, evaluating and interpreting all available research relevant to a particular research question, a topic area or phenomena of interest* [28]. Literature research can be arduous and very time consuming and one must be aware that many publications can be, somehow, concealed for instance in conference proceedings and not immediately available. So, an extra care is crucial to avoid the possibility of leaving aside relevant studies.

A search on the B-on Electronic data base, confined to the terms "VISIR", "Remote Laboratory", "Learning Outcomes", "Engineering Education" and "Curricular Integration" was first performed. Because VISIR is restricted to a yet small community [20], a second search was performed considering known researchers, working with VISIR. Afterwards we had also searched the two major conferences in the online/remote labs field: Remote Engineering and Virtual Instrumentation (REV) and the IEEE Global Engineering Education Conference (EDUCON). Finally, the references cited in each of these papers were also checked. The final resulting titles were than manually filtered, by title and by abstract resulting in a total of 86 papers (from which 7 were book chapters and 2 were webpages) for consideration. These 86 papers were then more detailedly analyzed and 32 of them were rejected as although VISIR was mentioned or shortly described, the paper focus was not VISIR. So, in the end, a total of 54 papers were full-text reviewed and coded.

3.2 Materials and Analysis Description

A total of 54 papers, from conference proceedings, journal articles and book chapters were thoroughly read and analyzed. Two main lines of research were found, which will be named as Technical Issues (TI) and Didactical Issues (DI). There are 6 papers that focus both items: Technical and Didactical. The papers distribution, per area, is displayed in figure 2.

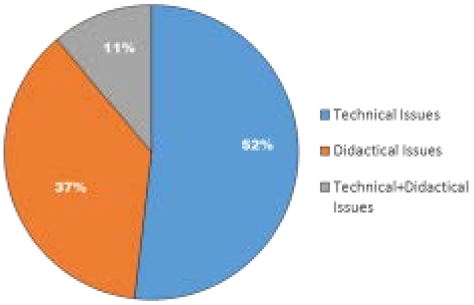


Figure 2.Frequency of articles per research line.

Papers were considered in Technical Issues line of research when their main focus was the software/hardware VISIR components description and other technical items such as, for instance, integration with other labs and/or with a Learning Management System (LMS). All the papers that describe VISIR implementation and usage in a specific course and the resulting outcomes were considered in Didactical Issues line of research.

Technical Issues are briefly addressed, as this topic in not the main focus of this work. However, it is listed the most relevant topic, that the various institutions within the VISIR community have identified that should be developed.

Considering Didactical Issues, it was used a multicase study approach. Each case represents a different course where VISIR was used/implemented. A total of 22 courses, covering more than 4400 students, from different educational levels (Secondary (Sec), Vocational (Voc) and Higher (Hig)) are summarized in Table 1. The courses were also categorized accordingly to the knowledge level (Basic (B) Scientific (S)) and the type of intervention during the semester. Table 1 also includes the academic year in which the implementation occurred and the number of students involved. These courses represent quite different student educational backgrounds, knowledge and levels of competence development carried out in different academic years.

Table 1. Identified Cases

Course type	Academic Year	Students	Educ. Level	Interventions /Semester	Papers
B	2010/11	561	Hig	6 weeks	[14]; [52]; [7]; [19]; [56]; [68]; [22]
S	2010/11	49	Hig	All semester	[7]; [21]; [20]
B	2010/11	574	Hig	All semester	[8]; [21]; [20]
S	2010/11	47	Hig	All semester	[7]; [21]; [20]
S	2010/11	68	Hig	All semester	[7]; [21];[20]
S	2010/11	345	Hig	All semester	[7]; [21]; [20]
B	2010/11	189	Hig	3 weeks	[7]; [21]; [20]
S	2013/14	79	Hig	All semester	[64]; [65]; [66]
S	2013	15	Voc	NI	[61]; [20]
S	2013/14	71	Hig	NI	[57]; [62]; [20]
B	2009/10; 2010/11	94	Sec	7-8 weeks	[16]; [20]
S	2014/15	35	Hig	NI	[69]
S	2008/09; 2009/10	NI	Hig	NI	[19]; [53]; [68]; [20]
S	2008/09; 2010/11	NI	Hig	3 Pratical Sessions	[19]; [53]; [67]; [68]; [20]
S	2010/11	NI	Hig	NI	[19]; [53]; [68]; [20]
S	2009/10	40	Voc	2 days	[19]; [63]; [68]
S	Since 2010	NI	Voc	NI	[19]; [68]
B	2013/14	53	Hig	NI	[53]; [55]; [58]; [60]
B/S	Since 2003	NI	Hig	NI	[67]
S	2013/14	NI	Hig	NI	[23]
S	2013	2200	Voc	NI	[23]; [24]
NI	2012/13	NI	Hig	NI	[59]

NI No Information

The reported results for each case were analyzed in four dimensions: intervention description, research analysis, educational goals and reached conclusions.

The categorization in the first three dimensions was previously established: In the first dimension the defined categories were the type of VISIR usage, considering the implementation intervention description: no description of the intervention, a brief description and a detailed description. In the dimension research analysis, it was taken in consideration the type of collected data: no reported data, qualitative data, qualitative and quantitative data. In the third dimension the categories examined were the type of educational goals, if any. Considering the fourth dimension the main conclusions were nominally listed.

4. ANALYSIS AND RESULTS

4.1 Technical Issues

As shown in figure 2, the research line Technical Issues is the one with more published works [2], [17], [18], [25], [27], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45] , [46], [47], [48], [49], [50], [51]. All the papers start by doing a detailed description of the VISIR system, including in some cases, the installation procedure. The hardware and software components, the operation cycle, including types of accounts and its' privileges are also carefully introduced. In different ways, they describe their experience using VISIR, in different students/courses/institutions and report the feedback that has been gathered from administrators, teachers and students within the VISIR community. Although all types of users, students and teachers from the diverse institutions, have a positive perception of VISIR, some drawbacks and limits were identified and reported in some of the works. The most common are:

1) When a student accesses VISIR, the system only registers his login and doesn´t allow the student designed circuits to be assessed afterwards by the teacher, for assessment and evaluation. A solution to this problem is to integrate VISIR with a Learning Management System (LMS). This solution is already being developed and implemented at several institutions (as WebLabDeusto).

2) The relay switching matrix (developed at BTH) is limited to 16 component boards, reducing VISIR flexibility and limiting its utilization. However, VISIR provides the possibility to choose another platform technology based on IVI (Interchangeable Virtual Instruments) drivers (instead of NI). A solution would be to replace this relay switching matrix with a commercial solution, such as a LXI equipment platform (instead of PXI). A VISIR LXI system is already being developed at University of Deusto.

3) Although VISIR contains the majority of the instruments used in electricity and electronic lab sessions in engineering courses, originally it didn't allow two prototypes of a single instrument. To overcome this limitation it must be added to the system several PXI modules. This solution, already implemented in one system, implies an increase cost and modifications in the software code.

4) Considering uniquely students' feedback it´s desirable to enhance the reality perception induced by the interface. If possible, it would be also interesting, to add or change some functionalities students reported, such as some changes in the environment layout.

Solutions to these identified issues are being developed and being implemented in some systems.

VISIR founders already proposed a solution to overcome these limitations and increase the flexibility of the system – interconnect all VISIR systems, installed in the diverse institutions, with each other, in order to create a grid laboratory shared and accessed by all participants within VISIR community. The application range of the system would be considerably extended as each institution would install certain circuits in its own VISIR and could use other type of circuits installed in any other VISIR and vice versa.

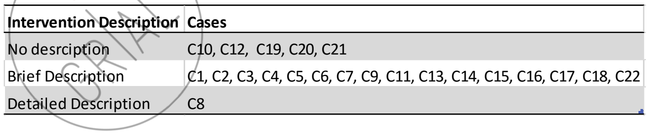
4.2 Didactical Issues

Overall, considering the twenty two identified cases, each reported in one or more papers ([7], [14], [16], [19], [20], [21], [23], [24] [52], [53], [54], [55] [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69]). They represent substantial differences in student contexts: different educational backgrounds, knowledge and level of competence development. Authors unanimously state that VISIR is a functional, effective and useful instrument for teaching and learning electricity and electronics, being well accepted by students.

Considering the four dimensions analyzed and the established categorization, the main results were:

1) Intervention Description: Cases' distribution, according to intervention description, is summarized in table 2.

Table 2. Intervention Description



Intervention Description	Cases
No desrciption	C10, C12, C19, C20, C21
Brief Description	C1, C2, C3, C4, C5, C6, C7, C9, C11, C13, C14, C15, C16, C17, C18, C22
Detailed Description	C8

Five cases (23%) were listed under the category No Description –meaning that although VISIR was used, it is not clear the intervention methodology used. VISIR was used mainly to test and evaluate its capacity for providing online remote experiments and to perceive students' opinion about it. In this category, students assembled one or two circuits, using a VISIR hosted in another institution (except for case C19). Case 19 describes VISIR usage in BTH, and although it's widely used since 2003, the implementation methodology was not described.

The majority of cases (73%) lies in the category Brief Description, in which we can find data such as: period of time of VISIR usage during the semester, where it was used (in class, autonomous, as complement or replacing some lab work), if it was mandatory or optional, its' contribution to final grade, used in groups or individually, type of teachers supervision. etc., although not all of these data simultaneously in all cases. Even though, there was an attempt to describe the methodology used in all of them, we could split this category mainly in two types of cases: the ones that take a special effort to describe the didactical approach (such as planned tasks, assessment, etc.) beneath this implementation and the ones that have a special interest in finding out the students' overall satisfaction about VISIR.

Just one case (C8) lies in the category Detailed Description – this course was developed based on the usage of four different resources: calculus, simulation, VISIR and hands on. The teacher imposed problem resolution, using an enquiry-based learning and teaching methodology, using these simultaneous resources, not only in the different type of class but also in assessment, with the main goal of developing better experimental skills and competences. The course classes were planned accordingly and somehow scaffold.

2) Research Analysis: the cases' distribution accordingly to type of research analysis can be observed in table 3.

Table 3. Type of Research Analysis

Research Analysis	Cases
Qualitative	C9, C10, C11, C12, C13, C14, C15, C16, C17
Qualitative and Quantitative	C1, C2, C3, C4, C5, C6, C7, C8, C18, C22
No reported Data	C19, C20, C21

Nine cases (41%) presents a qualitative analysis –collecting and analyzing qualitative data such as surveys/questionnaires and interviews/observations both to students and/or teachers. Laboratory reports, writing assignments and exams were also used in a lesser extent.

The majority of the cases (45%) presents qualitative and quantitative results. They used not only the qualitative data previously described but also some quantitative data such as the number of accesses to VISIR and other resources, presences in classes and students' grades.

There were three cases that did not collect any data: C20 and C21 describe on going experiences and so naturally there isn´t still no reliable data; C19 describes VISIR' usage in BTH since 2003 and although it´s known that this resource is widely used the work didn't present any data related to this dimension.

3) Educational Goals: As we can observe in table 4, only nine cases clearly specify the educational goals underlying the VISIR implementation. These were split in two subcategories: enfolding VISIR's usage into the learning goals (defining specific tasks using VISIR as a complement to lab work or individual study) or generally providing an extra resource to the course, as a mean to diversify ways of developing competences.

Table 4. Educational Goals

Educational Goals	Cases
Defined Centered	C2, C3, C7
Defined General	C1, C4, C5, C6, C8, C18
Not Defined	C9, C10, C11, C12, C13, C14, C15, C16, C17, C19, C20, C21, C22

Although we can infer the educational goals in the majority of the other cases, as they are implicit in the methodology description of VISIR's usage or in the results analysis and discussion or conclusion sections, they are not stated directly in most studies. The stated overall objective of those studies was more general, finding out if VISIR was a useful resource, noticing its weaknesses and strengths and exploring it to see users' satisfaction and not particularly concerned with didactical frameworks.

Table 5. Reached Conclusions

Reached Conclusions	Cases
Gains in development of competences	C1, C13, C14, C15, C19
Gains in students' learning and/or performance	C1, C2, C4, C5, C6, C13, C14, C15, C16, C17 C18, C22
Increment in students' skills problem solving	C3, C8
Increase in students' confidence in lab	C1, C4, C5, C6, C13, C14, C15
Development in critical thinking	C6, C8
Improvement of experimental competences	C1, C7
Increment in students' Motivation and enthusiasm	C1, C8, C16, C17
Useful tool as complement to hands on (and other resources)	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11 C13, C14, C15, C22
Useful tool for distance learning	C9, C20, C21
More appropriate to introductory courses	C4, C5
Students are satisfied with VISIR	C10, C11, C12, C13, C14, C15, C16, C17
Teacher experience and attention in VISIR plays a crucial role	C1, C2, C3, C4, C5, C6, C7, C13, C14, C15, C18
VISIR engagement is conditioned by the VISIR's contribution to final grade	C2
Students experience difficulties in their initial use of VISIR	C1, C7, C8
Students need time with the teacher (and/or) tutorials	C1, C8, C11

4) Reached Conclusions: Table 5 exhibits the main reached conclusions, for the overall 22 cases.

Considering VISIR's satisfaction, three main parameters were analyzed, through questionnaires: usefulness – VISIR's pedagogical and teaching issues, immersion – the extent to which VISIR replicates the feeling of a real lab and usability – technical and availability issues. All parameters were well evaluated.

VISIR is a useful resource that allows students to practice freely, from home or any other place, improving their freedom to organize their own learning activities according to their perception of their learning needs.

5. DISCUSSION AND CONCLUSION

The main research lines using VISIR's approach, done so far, are didactical issues and technical issues.

The results of this review contributes to the evaluation of the remote lab VISIR in terms of didactical implementations, including educational goals, learning achievements and competences and in to a less extent to some technical aspects that could be improved in VISIR itself and consequently improve its interaction with students.

To answer the research question - *Considering VISIR implementation and usage reported in literature until May 2016, which common outcomes and indicators of consistent results can be found in the different didactical approaches?* – VISIR system is a functional and useful learning instrument, well accepted by students, which should be used as a complement to hands on lab or as a tool for distance learning. It improves students' competences and knowledge as it is reported in 59 % of the analyzed cases.

The increase of students' confidence in lab and their enthusiasm and motivation are mentioned in 45, 5 % of the cases. The VISIR contribution to the final grade was also an important role in students' engagement and motivation.

Other conclusions of this work, even though not so much referenced in the analyzed cases, but very important to keep in mind is the teachers' continuous attention to the VISIR throughout the course teachers and their supervision in students first time with VISIR.

For the integration design it´s important to set up the VISIR tasks according to the leaning goals and students' knowledge. Nonetheless it´s very difficult to isolate VISIR's contribution to these results as several factors may compromise students' motivation and final results.

This work helped raised some important concerns and questions to be addressed by future research. Thousands of students have already used VISIR, but just in a (small scale) case (4,5 %) there was reported the course curriculum and the didactical implementation design indication. In this case, the designed based on the learning outcomes teachers want students to develop and the tasks used to it clearly specified. In this case VISIR was used with other resources (simulation, hands on and calculus) following an enquiry based methodology and it seems that this methodology enhanced students learning and the development of high order skills. This kind of work tends to be more helpful to other teachers who want to use VISIR. In this way, they can understand more accurately how it was incorporated in the curriculum and what kind of teacher' mediation was used. The obtained results may also be more clearly read.

In order to overcome some of the limitations of the actual VISIR system and to make the most of it, the BTH founders proposed to create a federation of VISIR laboratories that could be accessed by any partner and would include a free-access repository for sharing learning resources.

More recently (November 2015), it was launched the VISIR+ Project – a consortium between the European countries using VISIR and Brazil and Argentina which aims to define and develop a set of educational modules comprising hands-on, virtual and VISIR remote lab, together with calculus, following an enquiry-based teaching and learning technology. This will probably allow the conduction of a study in several different contexts to understand how and which student' learning outcomes are affected by the use of theses simultaneous resources. It will also allow exploring other factors that somehow may compromise students' engagement, motivation and learning outcomes.

Finally, a more recent project proposal for building the first European federation of VISIR nodes was approved and financed by the Spanish ERASMUS+ agency [70]. This result is expected to further nurture the research work around VISIR.

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