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Cooperative WebLab in chemical engineering between France and Brazil: Validation of the methodology

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A B S T R A C T

A WebLab is an experiment operated remotely via Internet. Besides the strictly technical aspects of such an experiment, which may contribute to the learning of Chemical Engineering fundamentals, there is also important feedback when teams of students of two different countries are working together: the WebLab becomes an intercultural experience, enhancing the communication skills of the students. A WebLab between Universidade Federal de São Carlos (DEQ/UFSCar) and the Ecole Nationale Supérieure d'Ingénieurs en Arts Chimiques et Technologiques (ENSIACET) is presented in this work. A mass transfer experiment in a bench scale reactor (stirred and aerated) had to be studied by mixed teams, thus emulating challenges that will be common in future working environments. In order to perform the experiment, students in Brazil and in France were put into groups. The students had to make decisions about the procedure for executing the experiments. All the students were able to control the equipment, no matter where they were physically. Students communicated using video conference software. The students' and teachers' opinions of this experience were very positive. This methodology is an important contribution to the education of engineers in a world integrated by modern communication technologies.

Keywords: Cooperative WebLab; Internet experiment; Chemical engineering; iLabs

1. Introduction

Online laboratories ("WebLabs" or "iLabs") are experimental setups that can be accessed through the Internet from a regular web browser. iLab was born in microelectronics classes taught by the electrical engineering professor Jesus del Alamo of MIT, in 1998 (iLab project homepage, 2011). From time to time, this concept is used by other disciplines like chemical engineering (Henry and Knight, 2003; Klein et al., 2005; Shin et al., 2002).

In a workshop about WebLabs in Chemical Engineering that took place in Cambridge, UK (Selmer and Kraft, 2011; Moros, 2005), three main kinds of WebLab use were found to be the most promising:

1. Very small setups of a few centiliters (Moros, 2005; Selmer et al., 2005) that do not need to be locally supervised. Their main advantage is more convenient access to the labs. Experiments can be carried out from anywhere at any time.
2. Pilot-scale setups from a few liters to tens of liters, which

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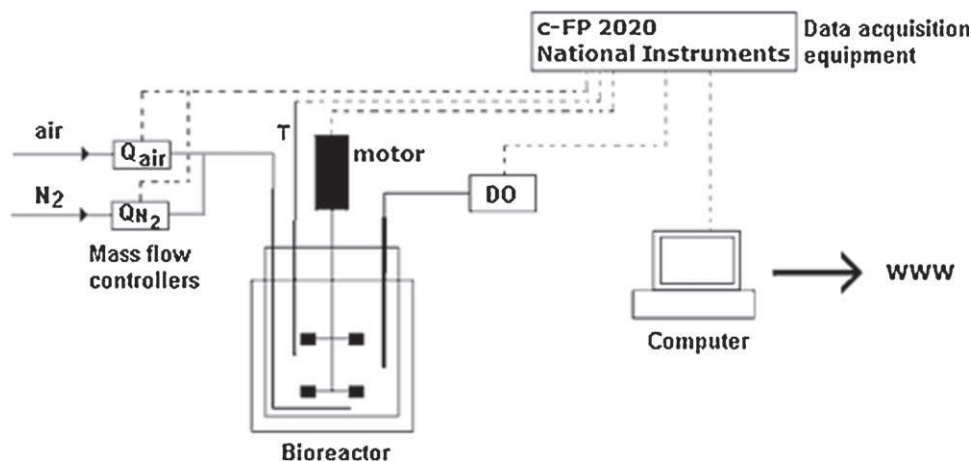


Fig. 1 – Experimental setup used for k_La determination.

are conducted by two groups of people: one group close to the equipment, the other anywhere in the world. Their main advantages are, first, to enable the plant to be operated from far away as is increasingly done in industry and, second, to promote intercultural exchanges.

3. Specific experiments that are used few times and are expensive. More people can access such equipment, thus contributing to its financial equilibrium.

An experimental setup for the determination of mass transfer coefficient was prepared for remote experiments at the Laboratory for Development and Automation of Biochemical Processes (LaDABio) of the Chemical Engineering Department of the Universidade Federal de São Carlos (DEQ/UFSCar) with the support of the Kyatera program. This program was established by the São Paulo State Agency for Research Development (FAPESP) to study and develop the use of technology and applications in advanced Internet for research and educational purposes (KyaTera). One of the projects that originated in Kyatera is the “Cluster of WebLabs for Chemical and Biochemical Process Engineering”, which aims to develop a set of real experiments, available through the Internet, for chemical engineering students at undergraduate level. Other KyaTera projects and the annual report can be found at <http://www.kyatera.fapesp.br>.

In order to validate the methodology, a WebLab was implemented between LaDABio and the Process Engineering Department of the Ecole Nationale Supérieure d’Ingénieurs en Arts Chimiques et Technologiques (ENSIACET).

One of the main objectives of this WebLab experiment is to offer students intercultural experience while enhancing their communication skills. At the same time, a technical problem has to be solved by heterogeneous teams, thus emulating challenges that will be common in their future work environment. And, last but not least, even though the objective of this WebLab is not to replace actual experiments, it helps in the assimilation of concepts concerning Chemical Engineering fundamentals. To achieve these goals, the students of both countries are required to work in synergy.

During 4 different sessions, 14 students from ENSIACET and 8 students from DEQ/UFSCar were invited to study a system physically located at LaDABio using remote access. The WebLab consisted of a mass transfer experiment in a bench-scale reactor (stirred and aerated). The experiment applied the gassing-out dynamic method to determine the volumetric

oxygen mass transfer coefficient (k_La) for different conditions of stirring and aeration.

In order to perform the experiment, two students in Brazil and three or four in France worked as a group, supervised by teachers of each country. The students had to decide on the measurements that were to be made and on the experimental protocols (who controls what). As only the students in Brazil were able to interact physically with the system, web-cameras were installed in order to allow the students in France to follow the experiment visually. Students communicated using conventional video conference software.

Each student was invited to answer a questionnaire intended to assess his/her expectations before the experiment, and another one after the final report was returned. This work compiles the opinions of the students and teachers in order to sketch a portrait of the pedagogical impact of this type of experiment.

2. Determination of mass transfer coefficient (k_La): theory

During the aerobic growth of microorganisms or cells in tank bioreactors, the level of dissolved oxygen must be kept high enough for the organisms to thrive. It is important for future (bio-)chemical engineers to master the fundamentals of mass transfer involved, and also to become acquainted with techniques for assessing rates of oxygen transfer from the gas phase into the liquid culture medium.

The method used in the WebLab to determine k_La was the unsteady state method (“Gassing-out Method”). In this method, the dissolved oxygen is removed from the liquid phase by sparging nitrogen into the medium. When the dissolved oxygen concentration (DO) reaches a value of zero, the nitrogen feed is interrupted and the air flow is restarted. DO is monitored until the solution is nearly saturated. Assuming ideal mixing in the liquid phase, the mass balance for DO in the liquid phase during the re-aeration can be expressed by Eq. (1).

$$\frac{dC}{dt} = k_La \cdot (C^* - C) \quad (1)$$

where C^* is the DO saturation concentration and C is the DO concentration

Eq. (1) is suitable when fast probes are employed. If a fast probe is not available, the dynamics of the electrode should



Fig. 2 – Photograph of the hardware used for implementing the WebLab in LaDABio.

be considered. The response of modern electrodes can be described as a first-order system, given by Eq. (2).

$$\frac{dC_e}{dt} = \frac{1}{\tau_E} (C - C_e) \quad (2)$$

where C_e is the DO measured by the electrode and τ_E is its time constant.

Combining Eqs. (1) and (2) and solving for C_e , gives Eq. (3).

$$C_e = C_{e0} \cdot e^{-((t-t_0)/\tau_E)} + C_{es} \cdot (1 - e^{-((t-t_0)/\tau_E)}) + \frac{(1/\tau_E) \cdot (C_{es} - C_0)}{(1/\tau_E) - k_L a} \cdot (e^{-((t-t_0)/\tau_E)} - e^{-k_L a \cdot (t-t_0)}) \quad (3)$$

where C_0 is the DO concentration (at time t_0), C_{e0} is the DO measured by the electrode at re-aeration (at time t_0), C_{es} is the DO concentration at steady-state.

The parameter $k_L a$ is estimated by fitting Eq. (3) to the experimental data by means of a nonlinear least-squares algorithm. For accurate results, the criterion $\tau_E \ll 1/k_L a$ is recommended (Badino Jr. et al., 2000).

3. Experimental facilities

The WebLab system was implemented employing National Instruments hardware for data acquisition and LabVIEW® as the supervisory system. A sketch of the implemented WebLab is shown in Fig. 1 and a picture of the experimental setup is shown in Fig. 2. In Table 1, the resources available for this WebLab are presented.

The user interface was developed using LabVIEW 7.0 and was hosted in a framed web page. This approach allowed the user to access information about the experiment (theory, recorded data, etc.) without leaving the LabVIEW interface.

Fig. 3 shows a screenshot of the principal web page and Fig. 4 depicts the main interface of the experiment. At the end of each experimental session, the students saved the collected data for further off-line analysis, in order to determine $k_L a$.

4. The exercise

“Gas-Liquid Agitated Tank” is a second year experiment of Chemical Engineering at Ecole Nationale d’Ingénieurs en Arts Chimiques et Technologiques. Its aim is to give the students indispensable knowledge on stirred tanks. At the present time, there are no classes dedicated to this specific topic but

the students borrow the concept from various other courses (transport phenomena, mass transfer...).

The activity was divided into three parts:

1. Preparatory experimental work was done, in France, in order to enable the students to identify and calculate specific parameters (power number N_p , $k_L a$) from experimental data acquired from a 100 L stirred tank. This experiment was performed only in France because the setup differed from that in Brazil. Students in Brazil did not have to do the experiment beforehand.
2. An experimental WebLab session, with access and control, in France, of the system physically located in Brazil.
3. Processing of the data obtained during the experiments, analysis of the results obtained and further discussion about the importance of the parameters calculated.

For the first part, groups of four French students spent two half-days studying the general behavior of a stirred tank located at AIGEP (Atelier Interuniversitaire de Génie des Procédés: <http://www.inp-toulouse.fr/fr/aussi-sur-le-campus/aigep.html>). Part of their work was devoted to the determination of the power number (N_p) of a Rushton Turbine. They studied the evolution of N_p for different stirring speeds and for different fluids (air, water, and water + air). The second objective of the practical exercise was the determination of the overall volumetric oxygen mass transfer coefficient ($k_L a$) according to Eq. (3), for the various experimental conditions tested. During all these experiments, special attention was paid to the gas hold up (ϵ), the size of the bubbles and the dispersion regime. From the data, the students critically compared their experimental results to empirical correlations found in the literature. Before the WebLab session, the students received the main guidelines from the teacher and discussed the differences between the two systems and how to choose new experimental conditions in order to obtain comparable results.

For the second part, the French tutor logged on to the WebLab at <http://ladabio.deq.ufscar.br> and the use of the Graphical User Interface (developed in LabVIEW®) was explained to the students. In order to facilitate the communication between the groups, Skype® chat via webcam was used. First, the students of each country introduced themselves and then, as part of the WebLab experiment, the French students stated the precise experimental conditions they wanted to test and explained why they had chosen them.

During the French access, the Brazilian students acted as a supporting group, providing information about the system physical characteristics (e.g., size, volume) and conditions (e.g., temperature before and after the experiment). After the end of the French session, they saved the same log file (for further analysis) and, when necessary, accessed the experiment to test new conditions and to clarify any remaining doubts.

Throughout the experiments, the students exchanged information and opinions about the phenomena that took place in the stirred tank. Their main concerns were about the quality of the mixing, the size of the bubbles and the various problems that arise during such experiments (bubbles blocking the tip of the probe, high coalescence phenomena, conditions of inefficient mixing...). Modeling the dynamical system was part of the work, but it was not addressed in the case of the French experiment. When the system did not respond as they expected, the students decided collectively which parameter they should modify using their theoretical

Table 1 – WebLab resources.

Resource	Description
Bioreactor and motor	(Bio)reactor with jacket (Applikon BV, Switzerland), 2L working volume, motor/impeller (0–1200 rpm)
Module for stirrer control	Used to manipulate the stirrer speed, 4–20 mA signal (Applikon BV, Switzerland)
Thermostatized bath	With recirculation (Nova Etica, Brazil); water is pumped through the bioreactor jacket
Mass flow controller	Controls and measures air flow rates into the bioreactor, 4–20 mA signal (Aalborg, USA)
DO transmitter	Amplifies DO probe signal (Mettler-Toledo, Switzerland)
DO probe	Measures DO in the medium (Mettler-Toledo, Switzerland)
Thermoresistance/transmitter	Measures the temperature in the medium (Pt-100, Exacta, Brazil)
Data acquisition	Compact Field Point, c-FP 2020, with AI, AO, DI and DO modules (National Instruments, USA)

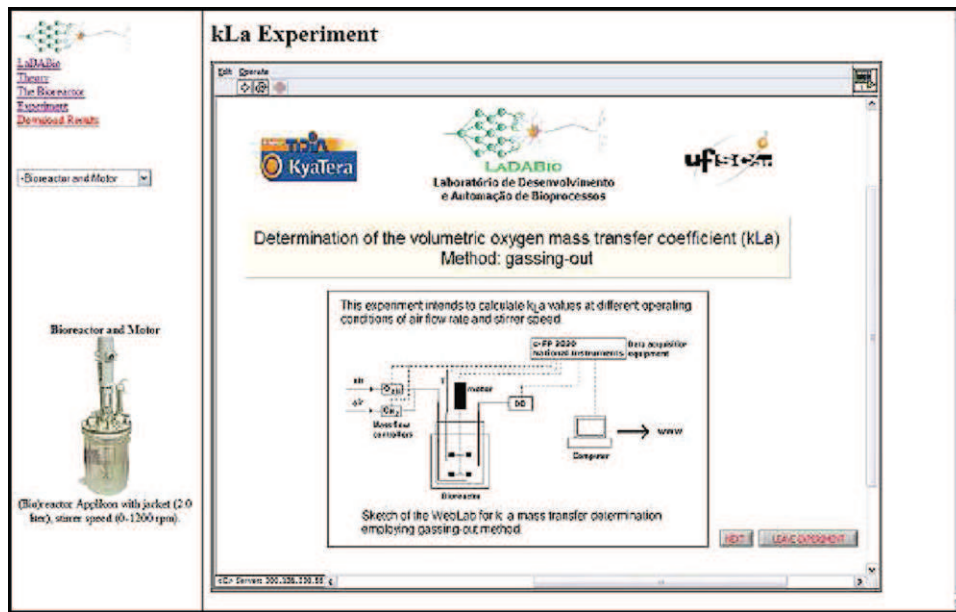


Fig. 3 – Screenshot of the web page accessed by the students.

background. Once they had set the chosen conditions, the data were loaded through the interface and recorded in a log file. During the activity, it was clear that a high level of interaction occurred among the students, who talked and discussed throughout their work.

After the experimental session, the students processed the data collected in order to calculate $k_L a$ and wrote generic reports. Knowing the value of the time constant of the electrode and assuming that the response time could be described using a first-order equation, the students estimated

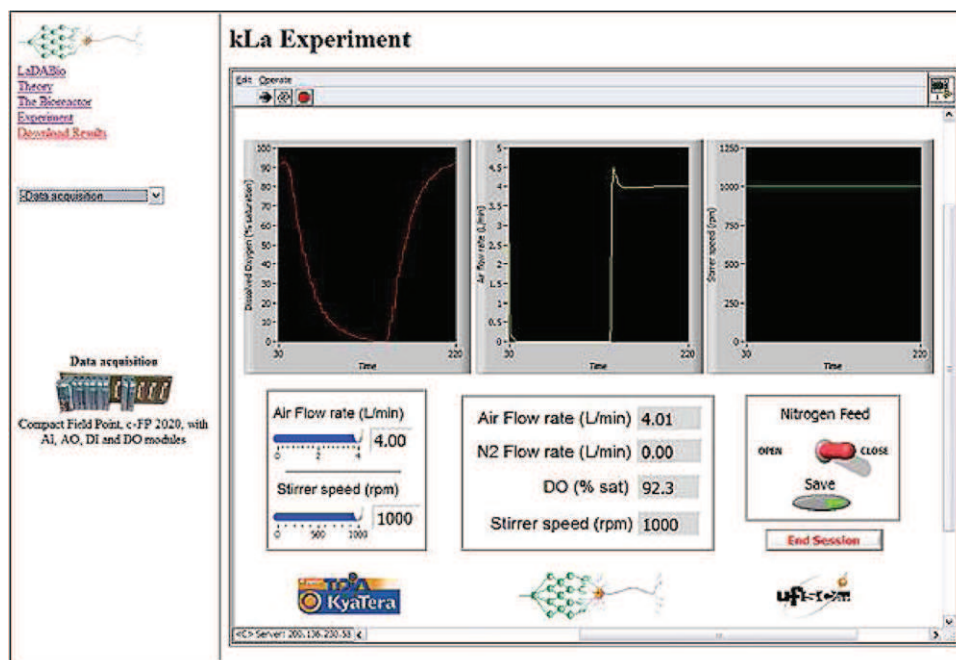


Fig. 4 – Main screen of the gassing out method.

the parameter $k_1 a$ by fitting a theoretical equation to the experimental data using a nonlinear least squares algorithm (MS-Excel solver). After this experiment, the students were expected to be able to give explanations for the discrepancies between the model and the experimental data, to realize that, for tanks of different sizes, relevant parameters do not have the same importance, and to explain why $k_1 a$ values obtained from the Brazilian and French systems were different.

5. Practical considerations

The organization of the timetable was the first challenge to be faced. The WebLab experiment could only be held between the months of March and April due to AIGEP's busy schedule. As the Brazilian academic year begins in February, the Brazilian students did not have time to become as familiar with the experiment as the French students, whose academic year had begun 7 months earlier and who had done a related experiment a few days before. This did not seem to impact the experiment too much but the Brazilian teachers may have had to give more explanations.

The time delay between France and Brazil was another challenge. First, it forced the groups to work at different times of day: afternoon in France and morning in Brazil. In addition, the WebLab experiments were carried out during the period of change for daylight saving time. The change in time-difference from five hours to three hours complicated the organization.

Another challenge concerned the software adjustments. Although the interface developed by the Brazilian group operates extremely well, a few problems related to the data transfer rate of the Internet connection occurred. For example, if the video of the experiment was enabled, it was difficult to visualize what happened in the stirred tank in real time because of the delay between frames.

These three points show that some improvements need to be implemented and that very good "practical" organization is crucial in order to run a WebLab experiment at such a distance.

There was a second, more subjective kind of challenge. One of the main objectives of WebLab is to offer intercultural experience to students. It is interesting to observe that there was a high level of interaction among them during the activity: they chatted and discussed all the time. However, the chat was not exclusively about technical aspects of the experiment!

These experiments also offered the teachers intercultural experience on their teaching context. A general and previous agreement needed to be found between the two teachers in order to supervise the students correctly during the class. From a pedagogical point of view, it was also highly instructive to see how the other supervisor explained the same phenomena to his/her students. It was noticed that the French teachers gave rather more importance to the theory whereas Brazilian teachers were more concrete. Moreover the relationship between teachers and students seemed more familiar in Brazil and more formal in France.

Communication between teachers, although pleasant, was not always obvious. For example, the questionnaire submitted to the students contained different questions for the two sides of the Atlantic Ocean because cultural differences implied time for adjustment, which was not planned. For example, the choices in the answers were different for cultural reasons: French teachers wanted their students to agree or disagree (avoiding neutral statements) but have the opportunity to not have any opinion, whereas Brazilian instructors wanted their

Table 2 – Questions presented to the French students.

Q_F1	I enjoy doing this
Q_F2	Being in touch with students 8000 km away is interesting
Q_F3	This laboratory is interesting
Q_F4	This laboratory is well situated in my education program
Q_F5	This laboratory is relevant to my program
Q_F6	This laboratory will be done again next year
Q_F7	WebLab will develop

students have the opportunity to partly agree, partly disagree, but to express an opinion.

6. Students' opinions

French students answered questionnaires before and after doing the experiment. These questionnaires contained questions about the previous relationships of students with foreigners and their opinions about the WebLab experiment. These last questions are presented in Table 2 and the related synthetic answers are shown in Fig. 5. A similar questionnaire was answered by the Brazilian students after the experiment. Table 3 presents the questions in the questionnaires. Fig. 6 shows the answers of the Brazilian students.

First, French students had already been abroad, 86% for short periods and 14% for long stays. 71% thought that they spoke a foreign language correctly and 29% that they did it

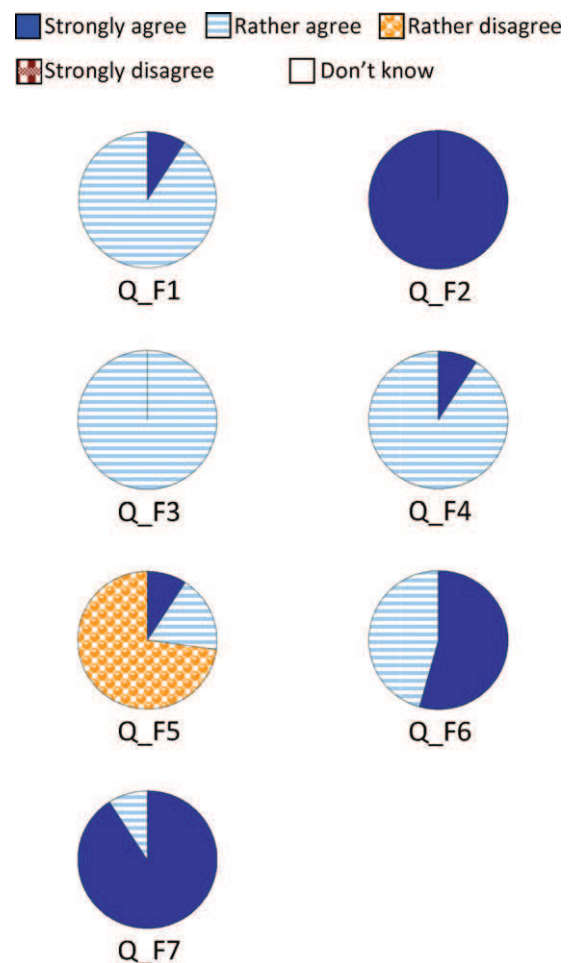


Fig. 5 – French students' answers.

Table 3 – Questions presented to the Brazilian students.

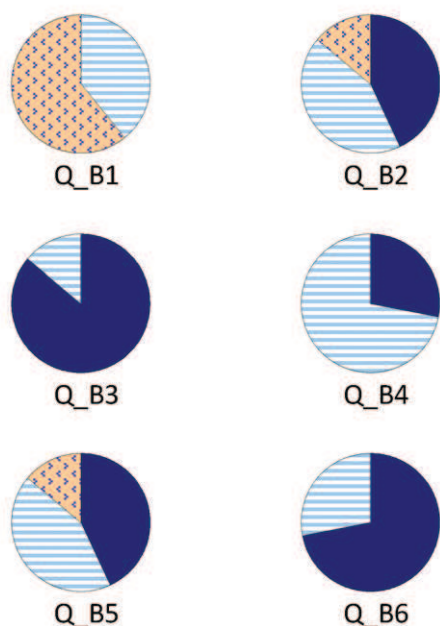
Q_B1	The activity helped me to consolidate the concepts exposed in the classroom
Q_B2	The interface used to control the experiment was appropriate
Q_B3	The use of English facilitated the exchange of information between the groups
Q_B4	This kind of activity had a positive impact on my academic education
Q_B5	The use of remote experiments increases students' motivation
Q_B6	The participation of the professor/tutor during the experiment is important

poorly. 64% had had no working experience with foreigners, 29% had had a few meetings and 7% long training periods.

For their opinion about the WebLab experiment, although the questions were not asked in this order, we have grouped them in three sets: the first concerning what they thought about this new type of teaching (Q_F1, Q_F2 and Q_F3), the second how they considered this teaching experience in the context of their whole education program (Q_F4 and Q_F5), and the last what they thought about the future of WebLab (Q_F6 and Q_F7). As can be seen on Fig. 5, they consistently liked the concept of WebLab. They were divided about the adequacy of WebLab to their education program (this could be because these students were from Industrial Engineering and they may have preferred controlled experiments to a typical chemical engineering experiment. Finally, they thought that WebLab should be continued and would develop. Moreover, two groups of French students reported that this experience had encouraged them to think about a long training period in a foreign country and most of them thought that it helped them to demystify the concept of working with people overseas.

The understanding of technical and scientific concepts was evaluated through a report for the French students (as usual for practical works). There was no significant difference in

Strongly agree
 Agree
 Partly agree/disagree
 Disagree
 Strongly disagree

**Fig. 6 – Brazilian students' answers.**

learning between the students which performed the WebLab and those who faced actual experiment twice more time.

Among the Brazilian students, none chose the options “Disagree” or “Strongly disagree” for any question. Most of them thought that this kind of activity had a positive impact on their education (Q_B4) and, despite English not being their mother tongue, they thought they were able to communicate properly (Q_B3). It is interesting to note that none of the Brazilian students chose “Strongly agree” for Q_B1. As a complement, they reinforced the importance of a teacher to guide them (Q_B6). They agreed that the motivational aspect of the WebLab is appealing, but a few students did not enjoy the experiment that much (Q_B5). Despite some concerns, the students approved the user interface used to control the WebLab (Q_B2).

The interpretation of these answers led to the conclusion that the use of WebLabs fosters interest in students, but that care must be taken when preparing the theoretical content of the class and when implementing the experiment and the user interface to control it.

7. Conclusions

The implementation of WebLabs is not very expensive and offers intercultural experience to students, in a variety that could not be obtained without the new communication technologies. It emulates challenges that will be common in students' future working environment. The understanding of technical and scientific concepts was evaluated through a report for the French students (as usual for practical work). There was no significant difference in learning between the students who participated in WebLab and those who did not. And, last but not least, without replacing an actual experiment, the interactive WebLab helps the assimilation of concepts concerning Chemical Engineering fundamentals. As the students of both countries work in synergy this methodology is an important contribution to the development of engineers in a world integrated by modern communication technologies. Even if it is difficult to evaluate the long-term benefits (for example on the internationalization of student careers), the questionnaires showed that students' opinion on this experience was very positive. This involvement corresponds to an additional motivation for the further use of this technology in teaching activities.

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