Weblab in Chemical Engineering between France and Brazil: validation of the methodology

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

Index Terms – Internet, Weblab, intercultural, synergy.

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 from MIT, in 1998 [1]. From time to time this concept is used by other disciplines like chemical engineering [2]. In the workshop about WebLab in Chemical Engineering that took place in Cambridge [3], three kinds of WebLab uses seemed interesting:

1- Very small setups of few centiliters [4] [5] that have no need to be locally supervised. Their main advantage is a more convenient access to labs. Experiments can be carried out from anywhere at any time.
2- Pilot scale setup from few liters to tens of liters, which are conduced by two groups of persons: one group close to the setup, another anywhere in the world. Their main advantages are, first, to operate a plant from far away like it is more and more done in industry and, second, to promote intercultural experiences.
3- Specific experiments, used few times and expensive. More people can access these equipments which can be economically better balanced.

A WebLab between the Laboratory of Development and Automation of Biochemical Process (LaDABio) of the Chemical Engineering Department of the Universidade Federal de São Carlos (DEQ/UFSCar) and the Process Engineering Department of the Ecole Nationale Supérieurs d'Ingénieurs en Arts Chimiques et Technologiques (ENSIACET) was assembled. It is within the scope of the second type of Chemical Engineering Weblabs, quoted above.

One of the main objectives of this Weblab is to offer intercultural experiences to students, 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, the Weblab helps the assimilation of concepts concerning Chemical Engineering fundamentals. To achieve these goals, the students of both countries are required to work in synergy.

In this experience 14 students from ENSIACET and 8 students from DEQ/UFSCar were invited to study, through remote access, a system which is physically located at LaDaBio during 4 different sessions. The WebLab consists of a mass transfer experiment in a bench scale reactor (agitated and aerated). The experiment applies the gassing-out dynamic method to determine the volumetric oxygen

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

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

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

k_La DETERMINATION: THEORY

During the aerobic cultivation of microorganisms or cells in tank bioreactors, the level of dissolved oxygen must be kept high enough for the organisms to thrive. Thus, its is important for the formation of (bio-)chemical engineers to dominate the fundamentals of mass transfer herein involved, and to get acquainted with techniques that assess rates of oxygen transfer from the gas phase into the liquid culture medium as well.

The method used within the Weblab to determine k_La was the "Gassing-out Method". In this method, the dissolved oxygen is removed from the liquid phase by bubbling 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. Assuming ideal mixing in the liquid phase, the mass balance for dissolved oxygen in the liquid phase during the re-aeration can be expressed by (1).

$$\frac{dC}{dt} = k_L a \cdot \left(C^* - C\right) \qquad (1)$$

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

This equation is appropriate when fast probes are employed. If a fast probe is not available, the dynamics of the electrode should be considered. The response of modern electrodes can be described as a first-order equation, given by (2).

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

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

Combining (1) and (2) and solving for C_e, one obtains:

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

Where C_{es} is the DO concentration at steady-state.

The parameter k_La is estimated by fitting (3) to the experimental data by means of a nonlinear least-square algorithm. For accurate results, the criterion $\tau_E << 1/k_L a$ is recommended [61].

EXPERIMENTAL FACILITIES

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

FIGURE 1
HARDWARE USED FOR IMPLEMENTING THE WEBLAB IN LADABIO.

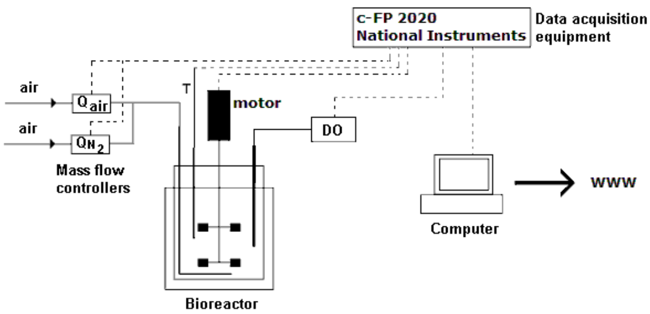

FIGURE 2
EXPERIMENTAL SETUP USED FOR K_LA DETERMINATION.

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

Figure 3 shows a screenshot of the web page and Figure 4 depicts the main interface of the experiment. At the end of each experimental session, the students should save the collected data for further off-line analysis, in order to determine k_La.

TABLE I
WEBLAB RESOURCES

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

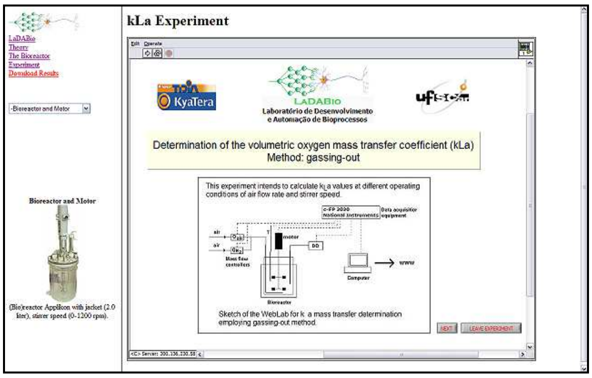

FIGURE 3
SCREENSHOT OF THE WEB PAGE ACCESSED BY THE STUDENTS.

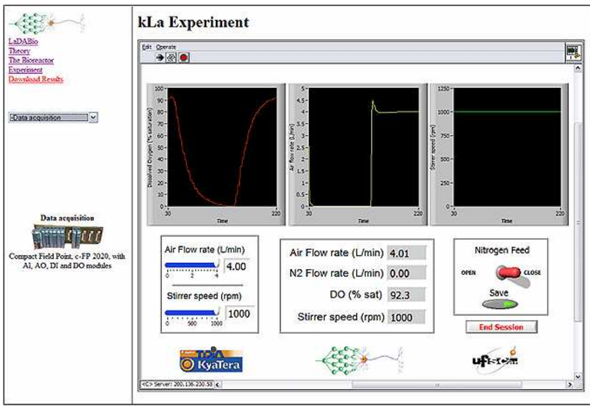

FIGURE 4
MAIN SCREEN OF THE GASSING OUT METHOD.

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 the indispensable knowledge on stirred tanks. At the present time, there are no dedicated classes on this specific topic, but the students borrow the concept from different other courses (Transport phenomena; Mass transfer….).
The activity was divided into three parts:

1. A preparatory experimental work was done, in France, in order to enable the students to identify and calculate specific parameters (Np, kLa) from experimental data acquired from a 100L stirred tank.
2. An experimental WebLab session, with access and control of a similar, but smaller, system physically located in Brazil.
3. Processing of the data obtained during the experiments, analysis of the obtained results and further discussion about the importance of the calculated parameters.

For the first part, groups of four French students spent two half days studying the general behavior of a stirred tank located at the AIGEP (Atelier Interuniversitaire de Génie des Procédés: http://www.aigep.inp-toulouse.fr/). Part of their work was dedicated 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_La) 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 compared critically their experimental results to empirical correlations found in the literature. Before the WebLab session, the students received the main guidelines from the teacher, discussed about the differences of the two systems and how to choose new experimental conditions in order to obtain comparable results.
For the second part, the French tutor logged in to the WebLab at http://ladabio.deq.ufscar.br/english and an explanation about the use of the Graphical User Interface (developed in LabVIEW®) was made to the students. In order to facilitate the communication between the groups, the Skype® chat via webcam was used. In a first moment, students of each country introduced themselves and then, as part of the WebLab experiment, the French students informed the precise experimental conditions they wanted to test and explained why they had chosen them.
During the French access, the Brazilian students acted as 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. Figures 5 and 6 show a group of students during a WebLab session.
All along the experiments, the students exchanged information and opinions about the phenomena that took place into 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 background. Once they set the chosen conditions, the data

were loaded through the interface and recorded in a log file. During the activity, it was patent that a high level of interaction occurred among the students, who kept talking and discussing all along the assay.

After the experimental session, the students processed the data collected in order to calculate k_La and wrote generic reports. Knowing the value of the time constant of the electrode and assuming that the response time can be described using a first-order equation, the students estimate the parameter k_La by fitting a theoretical equation to the experimental data using a nonlinear least squares algorithm, (MS-Excel solver). We expect that after this experiment the students would be able to give explanations about 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_La values obtained from the Brazilian and French systems were different.

FIGURE 5
BRAZILIAN STUDENTS DURING EXPERIMENTS

FIGURE 6
FRENCH STUDENTS DURING EXPERIMENTS

PRACTICAL CONSIDERATIONS

The organization of the timetable was the first challenge to face. The Weblab experiment could only be held between the months of March and April due to the AIGEP busy schedule. As the Brazilian school year begins in February, the Brazilian students did not have time to become as familiar with the experiment as the French students, whose school year had begun 7 months earlier and who had done a related experiment a few days before. In addition, the time delay between France and Brazil forced the groups to work at different day times: afternoon in France and morning in Brazil. Besides, Weblab experiments were carried out during the period of change of daylight saving time, time delay changing from five hour to three hour which complicated the organisation. Another challenge concerns the software adjustments. Although the interface developed by the Brazilian group had operated extremely well, a few problems related to the internet connection data transfer rate occurred. For example, if the video of the experiment was enabled it was difficult to visualize in real time what happened in the stirred tank because of the delay between frames. These three points show that some improvements need to be implemented and that a very good “material” organisation is crucial in order to run a Weblab experiment at such a distance.

There is a second kind of challenge, which is more subjective. If one of the main objectives of Weblab is to offer intercultural experiences to students, it also offers an intercultural experience to the teachers. A general and previous agreement needed to be found between both teachers in order to supervise correctly the students during the class. From a pedagogical point of view, it was also highly instructive to perceive how the other supervisor explained the same phenomena to his students. It was interesting to observe the high level of interaction among the students during the activity, who kept talking and discussing, however, the subject of the chat was not exclusively the technical content of the experiment!! At the end of each session, teachers discussed about how the session took place and how to improve it for the further occasions. Besides, some parts of the explanations given to the students were adjusted during the sessions.

STUDENTS OPINIONS

A questionnaire was answered by French students before and after doing the experiment. It contains questions about the previous relations of students with foreigners and opinion about the WebLab experiment. The questions are presented with the synthesis of the answers, in Figures 7 to 13.

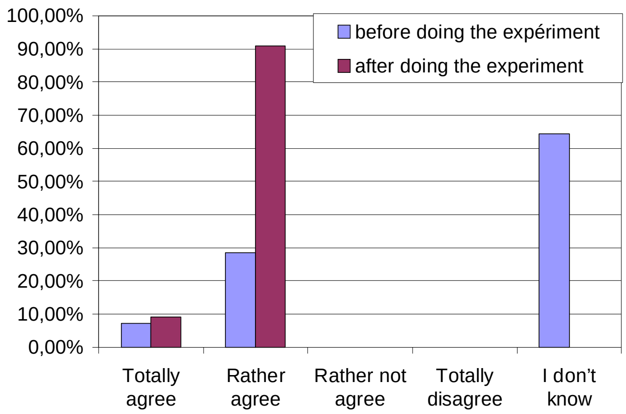

FIGURE 7
ANSWERS TO THE QUESTION: I ENJOY DOING THIS

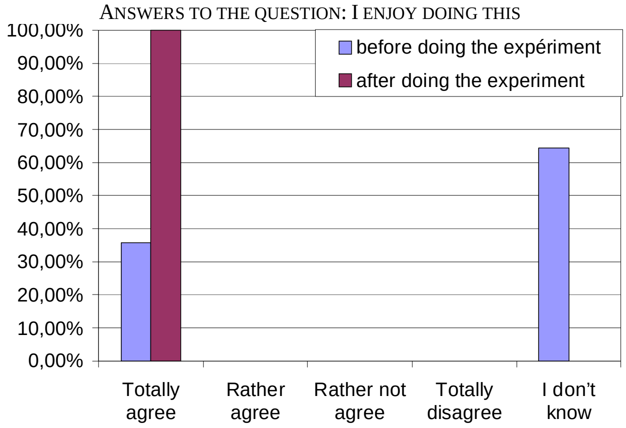

FIGURE 8
ANSWERS TO THE QUESTION: BEING IN TOUCH WITH STUDENTS AT 8000 KM IS INTERESTING

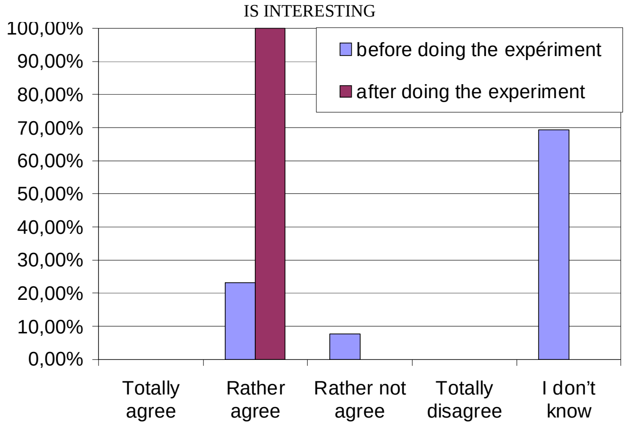

FIGURE 9
ANSWERS TO THE QUESTION: THIS LABORATORY IS INTERESTING

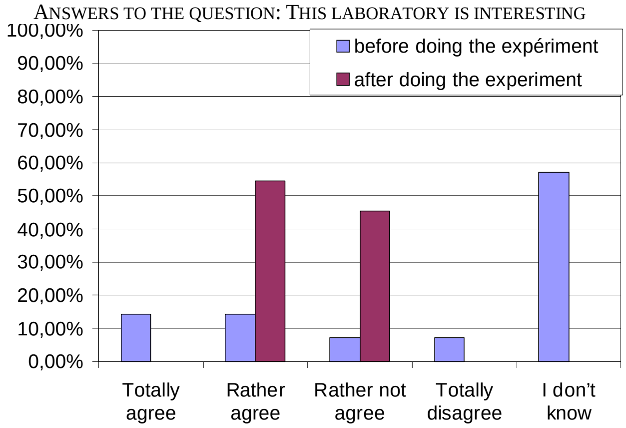

FIGURE 10
ANSWERS TO THE QUESTION: THIS LABORATORY IS WELL INSERTED IN MY EDUCATION PROGRAM

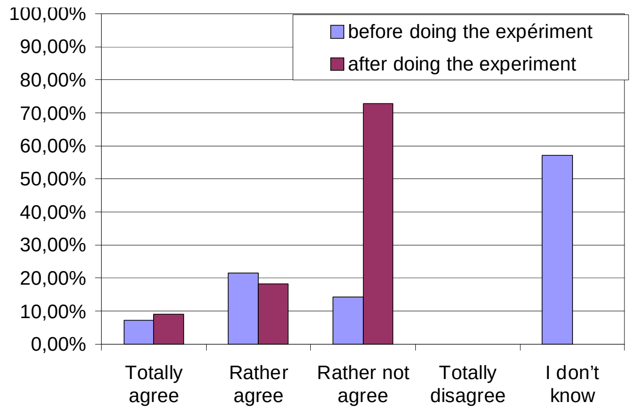

FIGURE 11
ANSWERS TO THE QUESTION: THIS LABORATORY IS RELEVANT TO MY PROGRAM

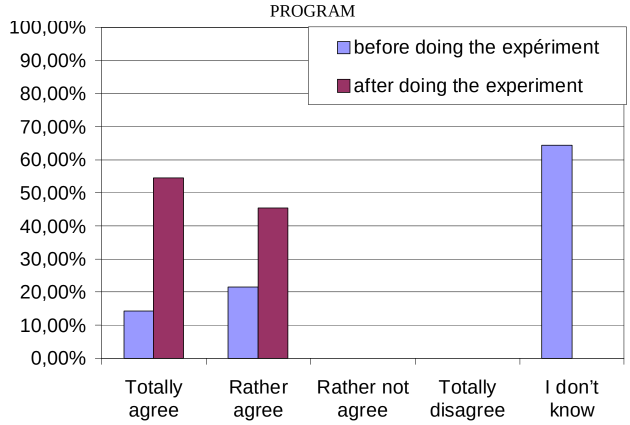

FIGURE 12
ANSWERS TO THE QUESTION: THIS LABORATORY WILL BE DONE AGAIN NEXT YEAR

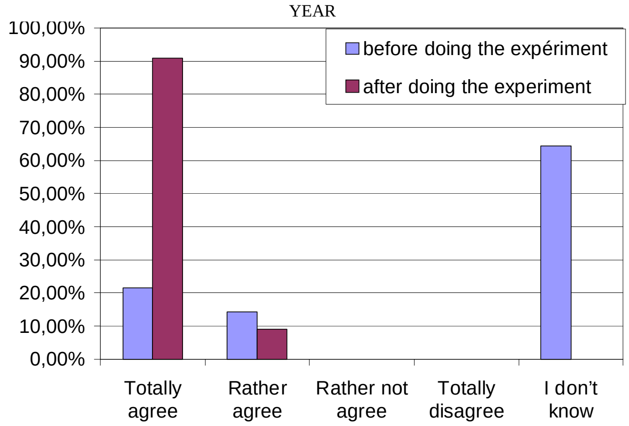

FIGURE 13
ANSWERS TO THE QUESTION: WEBLAB WILL DEVELOP

First, French students have ever been abroad few times for 86% and for long stays at 14%. They think that they speak correctly a foreign language for 71% and that that they do it poorly for 29%. They have had no working experience with foreigners for 64%, few meetings for 29% and long training periods for 7%.
For their opinion about the WebLab experiment, even if they were not asked in this order, we group the questions in three

parts. First, what do they think about this new type of teaching, second, how they consider it with other parts of their education program, and last what do they think about the future of WebLab. As can be seen on Figures 7 to 9, they mainly like the concept of WebLab. They are divided about the good relation of this WebLab with their education program; it could be because these students are from industrial engineering and they would have preferred a control experiment to a typical chemical engineering experiment. Lastly, they think that WebLab has to be continued and will develop. Two groups of French student reported us that this experience has encouraged them to think about a long training period in a foreign country and most of all think that it helped us to deconsecrate the work with foreign people.

A similar questionnaire was answered by Brazilian students after the experiment. Table II presents the questions in the questionnaire.

TABLE II
QUESTIONS PRESENTED TO THE BRAZILIAN STUDENTS

Q_01	The activity help you to consolidate the concepts exposed in the classroom.
Q_02	The interface used to control the experiment was appropriate.
Q_03	The use of English facilitates the exchange of information between the groups.
Q_04	This kind of activity has positive impact in my academic formation.
Q_05	The use of remote experiments increases the students' motivation.
Q_06	The participation of the professor/tutor during the experiment is important.

Figure 14 shows the answers of the Brazilian students. None of them choose the options “Disagree” or “Strongly disagree”. Most of them think that this kind of activity has a positive impact in their formation (Q_04) and, despite English is not their mother language, they were able to communicate properly (Q_03). It is interesting to notice that none of the Brazilian students choose “Strongly agree” to Q_01. As a complement, they reinforced the importance of a teacher to guide them (Q_06). They agreed that the motivational aspect of the WebLab is appealing, but a few students did not enjoy the experiment so much (Q_05). Despite of some concerns, the students approved the user interface used to control the WebLab (Q_.02).

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

CONCLUSIONS

The implementation of Weblabs is not expensive and offers intercultural experiences to students, in a variety that could not be obtained without new communication technologies. It emulates challenges that will be common in the students’ future working environment. And, last but not least, the 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. The questionnaires showed that students’ opinion on this experience was very positive which corresponds to an additional motivation for further use of this teaching tool.

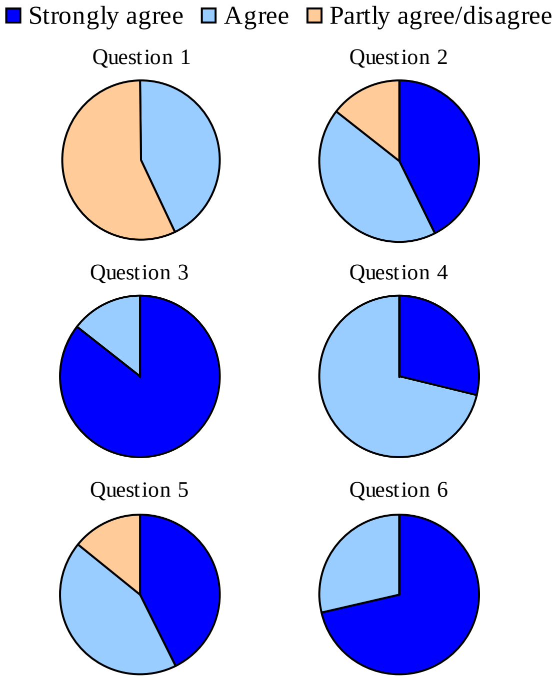

FIGURE 14
BRAZILIAN STUDENTS’ ANSWERS.

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REFERENCES

[1] http://icampus.mit.edu/spotlights/iLab.shtml

[2] Klein A., C. Hausmanns, G. Wozny,“Web-based remote experiments with a real technical plant in chemical engineering education”, *AIChE 2005 Annual Conference*

[3] http://como.cheng.cam.ac.uk/conf.workshop.html

[4] http://como.cheng.cam.ac.uk/pdfs/workshop/ralf_moros_ws.pdf

[5] Selmer A., Goodson M., Kraft M. ,Sen S., McNeill V., Johnston B.S., and Colton C.K.. "Performing Process Control Experiments Across the Atlantic." Chemical Engineering Education 9 (2005): 232-237.

[6] Ruchti, G., Dunn, I. J., Bourne, J. R, “Comparison of dynamic oxygen electrode methods for the measurements of kLa.”, *Biotechnol. Bioeng*., 23. (1990), 277