Laboratory Activities in Industrial Sequential Automation through a Virtual and Physical Environment

Noureddine Barka, Jean-Sébastien Deschênes, and Jean Brousseau

***Abstract*—The present project is intending as a new training approach based on the communication technology and the interaction between future engineers and technicians students. The first phase of the global project was consisted of developing of an automated mini-plant for containers recycling process and was realized by engineering students attending the project-based design courses. The second phase is consisting in development of the virtual environment allowing interactions between the students and between the students and the mini-plant. A laboratory activity has been conducted on the modules of the mini-plant. Future engineers and technicians have the mission to design, program and troubleshoot while they are working simultaneously. The obtained results demonstrate that the engineers and technicians students communicate effectively but they have different skills and competences. The training objectives have been achieved and the learned lessons will be exploited to enhance the training level and the competences in the future.**

***Index Terms*—Virtual environment, engineering education, sequential automation, communication.**

I. Introduction

In engineering education, it is very important to develop interaction with equipment in automation field using real systems and simulation environments. Such activities are generally necessary to consolidate the theoretical concepts learned in classroom [1]-[4]. In fact, the recent progresses of communication tools help the managerial staff, engineers and technicians to enhance productivity and optimize automated production systems without are physically present on the production floor. Moreover, actual automation technology can permit the remote control and often involves more complex situations implicating the real-time data exchange, video streams of different plant sections, and finally, the reception of process input commands and controller program modification. These methods have been introduced for the first time by service and equipment suppliers to allow the distance troubleshooting with clients. Moreover, in the globalization context of markets, the remote control methods and monitoring is the ultimate trend for manufacturers to stay ahead respective industry. Consequently, the business intelligence is becoming a significant advantage for the industries in the actually ever-changing business environment [5]-[7]. Furthermore, it is important to adapt the engineers and technician to rapid technological changes in automation systems. A relevant solution can be based on training by providing required skills to future engineers and technicians training. In fact, their academic contents also have to be constantly modernized to track current technologies and future trends. Aware to the training quality, the Université du Québec à Rimouski (UQAR), the Cégep de Rivière du-Loup (CEGEP) and the Premier Tech Company (PTS), a world leader in the bagging equipment field, have decided to join forces in order to improve the training of future engineers and technicians in Industrial Automation field.

Fig. 1. Mini-plant used in this experience.

The literature review demonstrates that it exists some related works involving distance learning or remote experiments [1], [5], [8], [9]. However, only virtual setup is treated and they don't imply real time monitoring with effective operators monitoring the equipment [2], [4], [8]. The present work is original because (1) it implies real time collaboration between distant teams of students on a common problem, (2) it assure an intensive interaction between future technicians and engineering students and (3) the students have the opportunity to use recent technologies in industrial automation field. Globally, the aim of this project is to allow the UQAR and CEGEP students to join forces and work together on practical problems while being in two separate sites. The first phase of this project consisted in the design of an automated mini-plant for recycling containers. This mini-plant (Fig. 1), designed and manufactured by engineering students at UQAR, was then installed in the CEGEP laboratories, located ~100 km away from the UQAR. The second phase consisted to build a virtual environment that would allow on-line process monitoring and real-time visualization of the mini-plant develop a training scenarios related to breakdown diagnostics, parameter adjustments,

Manuscript received January 22, 2013; revised March 27, 2013.

The authors are with the University of Quebec at Rimouski, 300 allee des Ursulines, Rimouski (Quebec) Canada (tel: 418-723-1986 ext 1949, 418-723-1986 ext 1997, 418-723-1986 ext 1541; e-mail: noureddine_barka@uqar.ca, jean-sebastien_deschenes@uqar.ca, jean_brousseau@uqar.ca).

DOI: 10.7763/IJEEEE.2013.V3.198

performance tests, security aspects, and process optimization. This paper presents first, this environment set up for interactions between the students themselves and towards the mini-plant located in Industrial Electronics Department at the CEGEP. Second, it also describes the experimented learning activities at the two remote sites. Third, it provides an assessment of the satisfaction level from students and an impact evaluation of the learning activities. Finally, it presents a few concluding remarks and proposes intended improvements to the learning activities during two consecutive years.

II. Setup Environment

During the activities, interaction process can be divided into two categories, namely "people-to-people," and "people-to-equipment". People-to-people interactions are to happen in real-time (synchronous) and off-line (asynchronous) mode. When present in the laboratory, UQAR students have access to a computer, a large videoconference screen, webcam, microphone, speakers and an Internet connection. CEGEP students, for their part, are physically present in close proximity to the mini-plant and they can communicate to the UQAR students using the same accessories. To allow people-to-equipment interactions, a Virtual Private Network bridge (VPN) was instated between UQAR and CEGEP LANs (Local Area Networks) via the Internet. The programming of the CEGEP controllers (Allen-Bradley CompactLogix series) was possible remotely at UQAR using RSLogix5000 software. Real-time visualization of the physical systems was possible through additional dedicated IP cameras placed to adequately cover all mini-plant units. Their video streams are accessible using any web browser software. A schematic representation of this environment between the UQAR and CEGEP sites is illustrated in Fig. 2. Since process control and automation applications require quick response times and high data throughput automation equipment, STRATIX 8000 switches were chosen at the core of the CEGEP Ethernet-IP network.

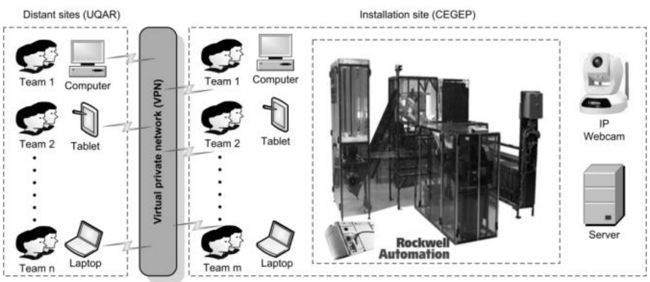

Fig. 2. Schematic representation of setup environment.

III. Automation Experience

During the winter semester 2010, the experience is programmed during automated production systems course (2010 and 2011). The students have challenge to make the mini-plant operational. Indeed, the engineering and technician students had the opportunity to design, program, and experiment and troubleshoot real industrial situations. During this activity, students are required to work together from the two sites and via the virtual environment presented early in this paper in order to automate the units operations of the mini plant used as recycling facility for containers. The experiment is based on the interactions between client and equipment suppliers and it is useful in order to develop expertise in the intervention and remote debugging. The situation considered a physical system has been delivered and installed by the UQAR team and finalized by the CEGEP team. The various units of the mini plant are completely installed including powers systems, actuators and sensors. However, the programming and debugging of the system operation remained. Objectives include the successful development and implementation of SFC (GRAFCET) and LADDER programs, complying with the specifications of logical and sequential operation of a given mini-plant unit. PLCs used for this application are the CompactLogix series from Allen Bradley. The mini-plant includes a variety of actuators such as AC motors, pneumatic and hydraulic cylinders, etc., and features sensors such as proximity, capacitive, inductive, limit switches, etc. It allows students to familiarize themselves with several instruments and technology employed widely in the industry.

A. Overview of the Physical Setup

Fig. 3 illustrates the various units of the mini-plant serving to recycle bottles and cans. This mini-plant includes principally the containers washer and dryer unit which are still under development by the UQAR engineering students, the storage unit, the sorting unit, the cans pressing-classification units and finally the bottle shredder unit. The washer and dryer unit allows cleaning adequately containers before transferring them to the storage unit. The storage unit can store several containers in two vertical carousels systems. These systems are connected to a conveyor that moves the containers to the sorting station where it's possible to identify consigned cans and plastic bottles using bare code detector, and rejects the other containers type. The cans are carried then to the hydraulic pressing unit and after to the classification unit. As for the bottles, they are transported to the shredder and immediately after to weighing unit [10], [11].

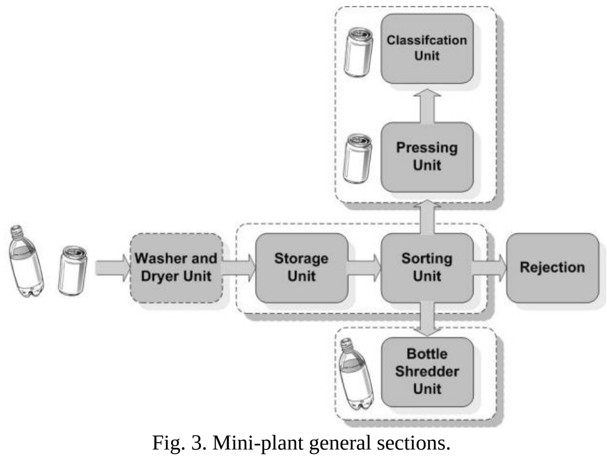

Fig. 3. Mini-plant general sections.

B. Learning Situation

The present experiment is done during 6 laboratory periods (3 hours) and it is realised through several stages. The first stage of this experiment was to accompany the engineering students to the CEGEP in order to meet and establish the first contact with technician students (3 hours). During this stage, the project is presented to the students by the coaching team. Thereafter, the student teams at each site were formed to cover the operational units of the mini-plant. The technician students, considered as clients, have carefully explained the various units operation to UQAR students and provide them all useful documentation for this project (electrical plan, sensor data, etc.). During the second stage, the UQAR students had the mission to establish functional specifications and validate them with the clients (CEGEP students). Using only off-line communication tools, the students have started to communicate and to exchange data and skills between them. Several iterations were necessary to converge towards to optimal specifications for the mini-plant operation that respect the clients need (1 hour and 30 minutes).

In parallel to this laboratory activity, the engineering students have received theory background related to sequential automation in class room. The PLC technologies and programming strategies are deeply presented and some cases studies about the subject have been resolved. It is very important to note that contrary to the technicians students, the engineering students had their first notions on the industrial automation only during this course. The third stage consisted in programming and establishing Grafcet (SFC) that meet adequately the actual specifications that express the real client needs. The SFC designs are sent to the clients for comments and final validation. The Ladder algorithms are developed then and implemented in the PLC's (Programmable logic controllers) that pilot each functional unit of the mini-plant (4 hours and 30 minutes). The fourth and final stage consisted to organize three virtual meeting between the two institutions. During this stage, the students have used online communication tools to exchange and interact between them. Moreover, they use VPN to access to the control program and IP webcam to visualize and monitor the unit operations. Based on this strong communication environment and using cutting-edges hardware and software materials, this experience seems very interesting because it permit to the students to exchanges expertise and skills in automation field and it provides them to develop a cordial relation before be inserting in industrial context. Three sessions (9 hours) are necessary to troubleshoot the units operation and complete this project.

Principally, the engineering students have to develop the specifications for each automation units constituting the mini-plant. They developed then SFC and Ladder programs and implanting them in PLC that drive the units. Technician's students, in turn, they have to validate and correct program and they ensure the compatibility of inputs and outputs with those given in the documentation. Moreover, they assist engineering students in the process of debugging and troubleshooting to converge towards to efficient and optimal industrial programs. The coaching team provides oversight activities throughout this experience by providing the logistics necessary for the success of this laboratory activity. The courses responsible provide to students the sufficient background in automation in classroom. These contents help them to develop appropriate applications and good knowledge and skills in this automation field. UQAR and CEGEP students are divided into three groups and each group mandated to work on one or two specific units. They have to design and program the PLCs and troubleshoot the function sensor while they are working simultaneously. Moreover, they must take in consideration the recent advances in PLCs and sensors technologies used in actual industrial context.

The first project is consisting to automate the storage and sorting units. In fact, the storage unit are composed of two carousels serving as cans and bottles tank, two chutes able to bring the containers to the conveyor. This conveyor can transport the containers to the sorting unit. The second project is consisting to develop program for the shredder and weighing unit. This unit is mainly composed of a chute leading the bottles to a swivel bottle holder in order to remove label using rotating steel brush. Finally, the bottles are moved to the shredder section to discard them. The third project is to automate the pressing and classification units. The pressing unit includes a conveyor to bring the cans to the pressing section, where a hydraulic cylinder is able to squeeze cans. The classification unit is used to classify cans depending on the registered trademark. The projects are based on development and implementation of SFC and Ladder programs which will respect the required sequences of mini-plant units operations. The PLCs used in this application is the RSLogics5000 from Allen Bradley Technologies. The actuators and sensors are chosen from different technologies and styles. Consequently, the mini-plant represents an interesting case study because it includes various types of actuators as AC motors, pneumatic and hydraulic cylinders and comprises sensors as proximity, capacitive, inductive, limit switches, etc. This actual configuration allows students to learn different types of technology employed in industry. A sample example of SFC and Ladder programs is presented in Fig. 4.

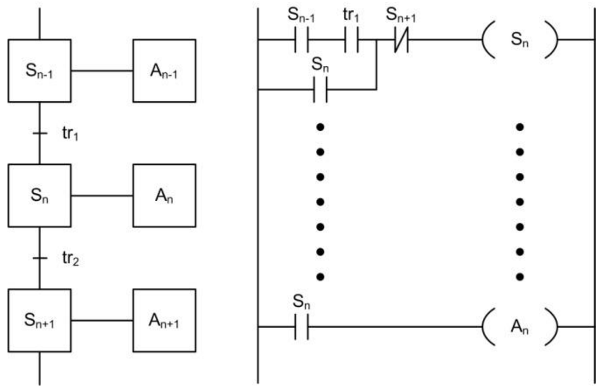

Fig. 4. Example of SFC and Ladder programs.

C. Results and Feedback from Students

The obtained results demonstrate that engineering students have developed strong knowledge and skills in the automation fields even the short duration of this experience. In fact, the learning in class room and the experience during laboratory are very useful for their training. They are able to establish specifications corresponding to the clients requirements in actual industrial context. Furthermore, they have mastered the SFC and Ladder techniques through PLCs programming and troubleshooting complex problems. The interaction with technicians students very specialized in industrial automation seems a great opportunity because it allows them to develop critical judgment related to their experience and create efficient exchange between them. Globally, the students have correctly provided programs respecting the required specifications and that, for the three units of the mini plant. However, the lacks of time and no complete documentation for some components have disrupted the experience. To improve the quality of these interventions and to allow students better learning and excellent training in the industrial automation field, it is necessary to set up a new approach proposing projects throughout the complete session. An appropriate approach should encourage a robust exchange between the two sites and a reformulation of roles among the students to converge towards a successful relationship between UQAR and CEGEP. Finally, to measure satisfaction with regard of the laboratory activity, a questionnaire was adapted to the hardware and software and used to evaluate this experiment and thus measure the overall interest and the level of student satisfaction (Table I). A total of 13 students participated in this activity, and 12 were available for the evaluation.

TABLE I: SURVEY QUESTIONS FOR UQAR STUDENTS

1. Communication tools: What is your general appreciation of the tools used for communication with the CEGEP teams?
2. Quality of the communication: Did you experience any communication problems?
3. Automation tools: How do you judge the automation tools used and their pertinence in your engineering formation?
4. Team interaction and cooperation: What is your general feedback on the interactions and pertinence of this activity in your formation?
5. General appreciation: What is your general impression of the activities?
6. General comments: Please state any pertinent comments regarding the activities, suggestions for ameliorations, etc.

The obtained results presented at Fig. 5-Fig. 8 show the students were satisfied with the communication tools used and the quality of communication throughout the experience (83%), in a similar fashion as the previous year (75%). It was however noticed that our students had a more limited knowledge of computer networks (25% felt they had major problems) than those of last year (0% felt so, even though problems were worse in the eyes of both teaching teams). The majority of students again agreed the activity helped improve their skills with the automation tools (92% in 2011 versus 87% in 2010). Interaction quality and cooperation between the teams was similarly good as the year before (50% versus 37% felt it was perfect, 42% versus 50% felt it was good, and 13% versus 8% felt it could be better) despite the modifications made to help improve comradeship. It is thus felt that there remains room for improvement. Finally, the students considered that this activity is a very good experience and should be kept as part of the course. Student satisfaction about the overall experience was either very high or high (~90%). All students once again considered this activity definitely has its place in their engineering formation.

Students and teachers at the CEGEP also evaluated the activity, again as part of a group discussion instead of survey questions. Observations from the teaching team were that communications effectively improved as compared to last year, and so did the collaboration between student teams. Good information exchanges were made between teams and most students felt they were well respected throughout the activity. One thing that was noted, however, is that there is sometimes an important difference between the teams regarding their skills with the tools. This could be attributed to the fact that UQAR students are often already qualified technicians before undertaking an engineering degree, or had at least one opportunity to work on controller programming as part of a summer internship, while the others had no prior experience or knowledge.

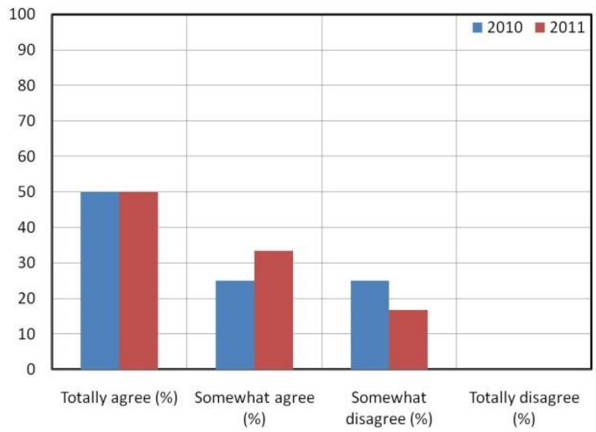

Fig. 5. Question 1 - Communication tools.

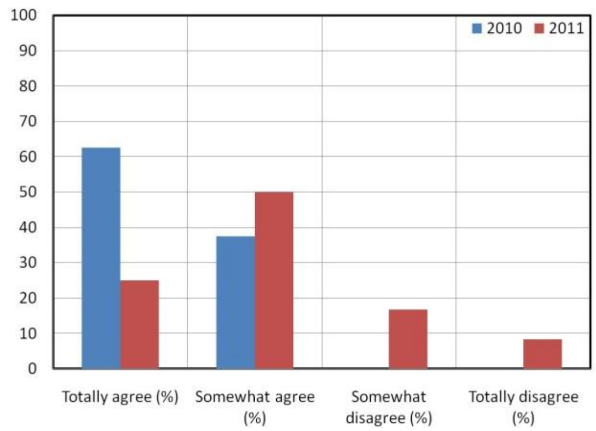

Fig. 6. Question 2 - Communication quality.

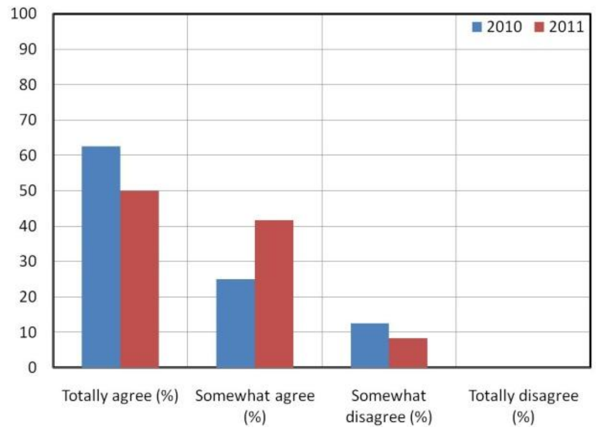

Fig. 7. Question 3 - Automation tools.

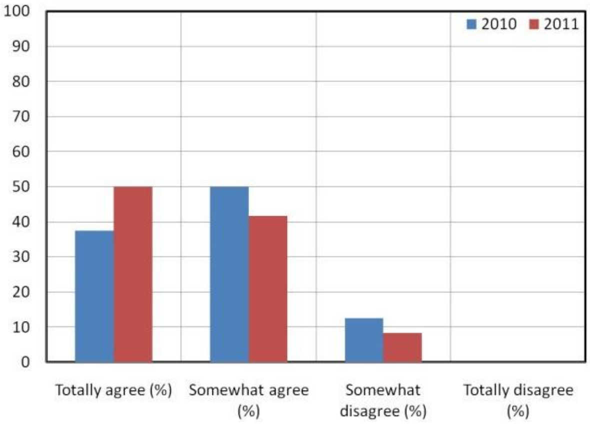

Fig. 8. Question 4 - Team interaction and cooperation.

IV. Conclusion

This paper exposed briefly the communication environment of the project and detailed the laboratory experience in the automation field between two different levels of education (UQAR and CEGEP). The learning scenario is elaborated and developed to provide an assessment of the satisfaction level from the students and evaluated the impacts of the learning activities. The obtained results demonstrated that the experience was appreciated by the both sites students. Moreover, the engineering and technicians students can communicate efficiently, collaborate together and exchange data in order to resolve complex industrial tasks. Globally, the objectives are achieved and a lot of lessons are learned and will be used to enhance the training next year and eventually apply them in other context. Results once again showed that students from both institutions succeeded in working and communicating together despite their different skills and backgrounds. The training objectives were successfully attained and the lessons learned were effectively used to enhance the training level and student-acquired skills through the activities.

Acknowledgment

The authors would like to thank the MELS (Quebec Ministry of Education, Leisure and Sports) for funding this project. Additional staff that supported this project should also be thanked: Mr. Pierre-Olivier Proulx, Mr. Louis Bernier and Mr. Abderrazak El-Ouafi (UQAR), Mr. Denis Paradis, Mr. Mario Michaud, Mr. Christian Potvin and Mr. André Roy (CEGEP).

References

[1] I. Calvo, M. Marcos, D. Orive, and I. Sarachaga,"Building Complex Remote Learning Laboratories," *Comput. Appl. Eng. Educ., Wiley*, vol. 18, no. 1, 2010, pp. 53-66.

[2] E. Tanyildizi and A. Orhan, "A Virtual Electric Machine Laboratory for Effect of Saturation of the Asynchronous Machine Application," *Comput. Appl. Eng. Educ., Wiley*, vol. 17, no. 4, 2009, pp. 422-428.

[3] C. A. Jara, F. A. Candelas, F. Torres, S. Dormido, F. Esquembre, and O. Reinoso, "Real-time collaboration of virtual laboratories through the Internet," *Comput. Educ*., vol. 52, 2009, pp. 126-140.

[4] C. A. Jara, F. A. Candelas, F. Torres, S. Dormido, and F. Esquembre, "Synchronous collaboration of virtual and remote laboratories," *Comput. Appl. Eng. Educ*.

[5] R. Zavbi and J. Tavcar, "Preparing undergraduate students for work in virtual product development teams," *Comput. Educ*., vol. 44, 2005, pp. 357-376.

[6] J. O. Chan, "Real-time value chain management," *Commun. Int. Inf. Manage. Assoc*., vol. 7, no. 3, 2007, pp. 79-88.

[7] L. Wang, W. Shen, P. Orban, and S. Lang, "Remote Monitoring and Control in a Distributed Manufacturing Environment," in *Condition Monitoring and Control for Intelligent Manufacturing*, L. Wang, and R.X. Gao, Eds. Springer Series in Advanced Manufacturing, London, 2006, pp. 289-313.

[8] J. S. Liang, "Design and Implement a Virtual Learning Architechture for Troubleshooting Practice of Automotive Chassis," *Comput. Appl. Eng. Educ.*

[9] E. Scanlon, C. Colwell, M. Cooper, and T. D. Paolo, "Remote experiments, re-versioning and rethinking science learning," *Comput. Educ*., vol. 43, 2004, pp. 153-163.

[10] J. Brousseau, D. Paradis, A. El-Ouafi, and S. Loubert, "Physical and Virtual Environment for Automation Education of Engineers and Technicians - Part 1: Engineering an Automated Recycling Facility for Bottles and Cans," in *Proc. 6th CDEN Int*.

[11] J.-S. Deschênes, N. Barka, D. Paradis, M. Michaud, S. Loubert, and J. Brousseau, "Physical and Virtual Environment for Automation Education of Engineers and Technicians, Part 2: Laboratory activities in closed-loop control and automation through a virtual and physical environment," presented at Canadian Engineering Education Association Inaugural Conference, June 2010, Kingston, Canada.

Noureddine Barka is the professor of mechanical engineering in the Department of Mathematics, Computer Science and Engineering at the University of Quebec at Rimouski (Canada) from 2011. He received a Ph.D. degree in Mechanical Engineering at the École de technologie supérieure in Montreal (Canada) during 2011. He has also completed a Master's degree in Mechanical Engineering at the University of Quebec at Chicoutimi in 2005. Besides having a wide experience in mechanical design and manufacturing, he taught as a lecturer at the University of Quebec at Rimouski since 2003.

Jean-Sébastien Deschênes is the professor of control engineering at the University of Quebec at Rimouski. He obtained his Ph.D. in engineering from Laval University (Canada) in 2007 on the subject of process control and bioprocesses. His research program at UQAR involves the development, modeling, control and real-time optimization of marine biomass-based bioprocesses, mainly involving microalgae. He has a great dedication for teaching, with a history of implication since 1998 (as a second-year undergraduate student), and the realization of a Masters project (2002) on the development of tools for teaching control engineering.

Jean Brousseau is the dean of undergraduate studies at the University of Quebec at Rimouski, holds a Ph.D. in mechanical engineering from Laval University. He has been at UQAR since 1994 and was the first professor hired to start the electromechanical system-engineering program. He particularly contributed to the success of its implementation by introducing the design workshop courses throughout the curriculum. From 2006 to 2011, he was one of the two chairholders of NSERC-UQAR Chair in Design Engineering. Within the chair project, the professor had the opportunity to improve the level and quality of design component of the engineering programs.