Hybridization of automation practical courses

B. RIERA*, C. MAZE**, S. DEBERNARD***, A. PHILIPPOT*,
M. GALAUP**, D. PANZOLI**, D. RENARD*, B. PETTINELLI* and B. EYNARD****

*University of Reims Champagne Ardenne, CReSTIC, UFR Sciences Exactes et Naturelles,
Moulin de la Housse, BP 1039, 51687 Reims, France (bernard.riera@univ-reims.fr, alexandre.philippot@univ-reims.fr).
** Jean-François Champollion National University Institute for Teaching and Research, SGRL, Pl. de Verdun, 81000 Albi – France
(christophe.maze@univ-jfc.fr, michel.galaup@univ-jfc.fr, david.panzoli@univ-jfc.fr).
***Univ. Polytechnique Hauts-de-France, LAMIH, CNRS, UMR 8201, F-59313 Valenciennes, France
****Université de Technologie de Compiègne, Department of Mechanical Engineering, Roberval Institute, CS 60319, F.60203 Compiègne
Cedex, France (benoit.eynard@utc.fr).

Abstract: Since 2020, the Covid-19 pandemic has led universities around the world to hybridize courses (i.e., replacement of classroom time by online activities), most often as a matter of urgency. The difficulty of hybridization depends on the kind of course (lectures, tutorials, practical works) and the type of course (mathematics, chemistry, engineering, informatics…). ET-LIOS is a 2 year project started in November 2020, led by the GIS S.mart (scientific interest French grouping for Industry 4.0) and 14 French universities. The objective is to propose solutions and resources to hybridize higher education courses dedicated to the Industry of the Future. In this paper, firstly, we present the problems to be solved to hybridize practical works. One of the challenges is to carry out solutions which can be used easily and adapted by all partners of the ET-LIOS. Secondly, for combinatorial logic practical work, we propose to use simulation softwares (HOME I/O and CONNECT I/O) installed on the students' computer, conjointly with customizable SCORM (Sharable Content Object Reference Model) packages which can be integrated in existing learning platforms of course management (LMS) like Moodle. This SCORM package enables students to test and to get feedback of their proposed solutions. The approach has been tested with Bachelor students in a combinatorial logic practical work. First results are very encouraging.

Keywords: control education, hybrid learning.

1. INTRODUCTION

Since 2020, the health crisis following the Covid-19 pandemic has led universities around the world to develop, most often as a matter of urgency, hybrid, or blended courses. A blended course is designed so that some classroom time is replaced by important online activities. This means that, ideally, the classroom and online portions of a course are complementary and have been thoughtfully combined to best meet the needs of the student and the objectives of the course. The online components are not an addition to a full course load, but rather a thoughtful substitution for some classroom activities. The difficulty of hybridization depends on the kind of course (lectures, tutorials, practical works) and the type of course (mathematics, chemistry, engineering, informatics…). The health crisis, with decisions taken very quickly by political governments to confine the population, has shown the need to be able to hybridize practical work, because it can be necessary to switch instantaneously from classroom courses to online courses. Aware of this situation, the French Ministry of Education launched in June 2020 a call for projects for the hybridization of bachelor's level courses. The ET-LIOS project, led by the GIS S.mart (French academic group for Industry 4.0 – www.s-mart.fr) and 14 French universities, was one of the winners of this call for projects. ET-LIOS is a 2-year project, starting in November 2020, for the hybridization of higher education courses dedicated to the Industry of the Future. Indeed, the specificity of technological education and the need to have access to machines and industrial equipment make the issue of hybridization of education crucial and impactful.

The work presented in this paper is part of the "Digital twin and virtual commissioning of automated production systems" module of the ET-LIOS project. We present the problems to be solved to hybridize practical works. The main challenge is to carry out solutions which can be used easily and adapted by all partners of the ET-LIOS. For that, for combinatorial logic practical work, we propose to use simulation softwares (HOME I/O and CONNECT I/O) installed on the students' computer, conjointly with customizable SCORM (Sharable Content Object Reference Model) packages which can be integrated in existing learning platform of course management (LMS) like Moodle. This SCORM package enables students to test and to get feedback of their proposed solution, promoting learning by doing, and learning from errors.

The first part of the article briefly presents the ET-LIOS project and its modules. The second and the third part of the article lists the organizational and technological obstacles to the hybridization of practical work, for the teaching of combinatorial and sequential logic and the programming of PLCs, and the solutions we have adopted. The fourth part of the article presents HOME I/O (virtual house) and CONNECT I/O (soft PLC) released for the ET-LIOS project.

This software is available for free to ET-LIOS partners. The fifth part of the paper deals with the original SCORM (Sharable Content Object Reference Model) package. The last part presents first feedback by means of an example of hybridization of practical work in combinatorial logic which was carried out with undergraduate students.

The article ends with a summary of the first results obtained and development prospects.

2. ET-LIOS PIA3 ANR PROJECT

French National <ET-LIOS> project (ANR-20-NCUN-0009) aims to develop educational content designed to be used in scientific and technological curriculum on broad topics related to Factories of the Future with a combined focus on competitiveness and sustainability. To largely disseminate them in academic communities of educators in an open manner, this content will be implemented and hosted under creative commons licenses in a network of Information Technology infrastructures which also aims to virtualize software solutions to enable remote access by students. Regarding the project objectives and based on the deep expertise of 14 French Higher Education institutions, the ambition is to pool the experiences acquired by these universities during the Covid-19 period. These experiences address remote education and continuous training of students in technological and scientific fields, for broad topics related to the Factories of the Future and especially:

- 3D design-simulation-prototyping;
- Advanced manufacturing and Inspection;
- E-Maintenance of cyber-physical production systems;
- Digital twin and virtual commissioning of automated production systems;
- Smart systems and multidisciplinary modelling;
- Sustainable engineering.

The main objective of the project is to provide platforms and resources consistent with a hybridization of scientific and technological teaching considering the empowerment of students' educational paths and non-supervised training (or project activities) times which are now included in certain curriculum (as in the new programs proposed in the French Bachelor of Technology). The specificity of these technological courses and the need to train students and have them practice on industrial machines and equipment make this issue even more crucial and impactful to keep the teaching time. Saving practical time is considered as essential for the training of students on technological resources while specific times for initiation, preparation and restitution can be all or partly on remote format.

The educational modules offered clearly call on the expertise and experimentation of members of the S.mart group. The transformation of the proofs of concept (resulting from the Covid-19 period of spring and autumn 2020 or having benefited from previous projects supported by S.mart) to a larger and operational education scale (in particular and as above-mentioned with the implementation of new programs in French Bachelors of Technology) is really challenging. The use of these new and hybrid teaching contents by the entire national education community and S.mart academic experts requires developments and high maturity of innovative educational materials. Then, the under-progress

tests and experiments will make it possible to disseminate and offer extremely valuable results for a whole or partial transformation of the pedagogical paradigms and educational practices in specific courses which may require a huge evolution of the educational model as well as the introduction of project-based education or even flipped classroom approaches carried out in the past.

Université Polytechnique des Hauts de France (UPHF) and Reims Champagne-Ardenne University (URCA) oversee the sub project D "Digital twin and virtual commissioning of automated production systems". The main objective of this module is to propose solutions and resources to be able to hybridize automation practical work (combinatorial logic, sequential logic, and programmable logic controllers) as fast as possible.

3. HYBRIDIZATION OF AUTOMATIC CONTROL PRACTICAL COURSES: LOCKS AND SOLUTIONS

3.1 Automatic control education

With rapid technological change in industry around the world, it is likely that specific skills demanded in the future will differ from those required in the past. Learning (and teaching) industrial control and automation is a hard task for many reasons (William 2005). For instance, and just to mention a few, it deals with complex problems requiring a multidisciplinary knowledge, spanning from mathematics and physics to computer science and logic programming while including sensors, actuators, and electrical and mechanical drives engineering. Bridging theory and practice is a major requirement in industrial control and automation training. This means that learners must master a considerable number of functional features and operating procedures of the supporting equipment, most of which differ a lot from a manufacturer to another.

Control engineering courses, as all technical courses in the broad sense, require the transfer of knowing and know-how to learners. Usually, courses are divided into theoretical courses (lectures), exercises (tutorials), and practices (practical works). Control engineering training requires an interdisciplinary and applied approach that is coupled with hands-on, and problem-based learning. Control education practice requires the use of real or virtual systems coming from the real life. From a pedagogical point of view, the technical system must be adapted to the teacher's objectives which are linked to the learner's level and to the curriculum. Practical courses enable the students to learn by doing and to learn from errors. This point is going to be developed in the next paragraph.

3.2 Learning from errors

Learning from errors is not new. For early educational reformer John Dewey (1859-1952): "Failure is instructive. The person who really thinks learns quite as much from his failures as from his successes". Failure is an opportunity for students to receive feedback on their strengths as well as their areas of improvement. When reframed as a good, constructive, and essential part of learning, failure is a master teacher. More, making errors is a natural part of the learning

process. A lot of errors do not occur randomly, but originate from misconceptions (Nesher, 1987). Nevertheless, although errors should be eradicated, different theoretical approaches on learning see them as beneficial for learners when used in a constructive way (Wernecke et al., 2018) (Metcalfe, 2017) (Riera et al., 2019). This pedagogical approach presents several advantages:

1. The pedagogy of error promotes the personal development of learners who take more risks.
2. The pedagogy of error promotes problem solving and critical thinking.
3. The pedagogy of error reinforces the retention and understanding of knowledge.
4. The pedagogy of error removes the limits created by the fear of failure.
5. Learning from errors allows learners to be more confident in general in all aspects of their lives.
6. The pedagogy of error helps students to make connections between ideas and concepts. Giving an incorrect answer is better than getting a good answer without doing anything.

One of the roles of the teacher, during practical courses, is to assist the student in understanding and correcting their errors. This activity is easy to do in a classroom setting. However, learning from errors could be difficult in automatic control teaching. Hence, when the use of real equipment is mandatory, it is not always possible to allow students to make errors in the controller. Indeed, real equipment requires considerable room and regular maintenance, which has important costs and requires qualified people; finally, most applications of interest tend to be risky for the inexperienced students who are trying to enable them work. Software simulation can help a lot in this subject. Real time computer-based simulation can be a risk free, affordable, and easy to replicate. In the specific case of industrial control and automation education and training, software simulations recreating industrial plants can often replace physical target systems (Callaghan et al., 2009). However, teachers must show to students that controller design based only on errors corrections is not the right way to work, at all.

3.3 Obstacles of hybridization of Automatic Control Practical courses

As has been shown at the various IFAC ACE symposia, there are many pedagogical experiences in the field of automation education, among which we can mention several different subjects: teaching aids for control engineering, virtual and remote labs, E-learning & blended learning in control engineering, virtual reality in control education, control education using laboratory equipment, interactive control education tools… Today, universities, all over the world, propose web resources (text, video, applications, MOOC). These resources can be open either to everybody or only to some students through a learning platform of course management (LMS) like Moodle. These resources can also be used either in asynchronous mode (i.e., in autonomy) or in synchronous mode with a teacher, using video conferencing software apps like Teams, Zoom, etc.

Since 2020, the health crisis following the Covid-19 pandemic has led universities around the world to develop,

most often as a matter of urgency, hybrid courses. It is to say, that the practical courses, usually taught in presential, must be able to switch instantaneously in distance. This means that the students must also be able to perform the practical courses online at home. For that, it is necessary to solve specific organizational, technical, and human problems, including:

- the students must have access to hardware and software resources necessary to perform the practical courses.
- the students must be more autonomous in detecting and correcting errors.

3.4 Hybridization of Automatic Control Practical courses: pragmatic solutions

One can note that each university has its own organization and its own LMS (Learning Management System). Consequently, even if it is not possible to share resources through a common LMS between universities, using standards, sharing material can be done. In our case, Moodle is widely used by the ET-LIOS partners. In addition, a course depends very much on the teacher. Consequently, if you offer a complete course (lectures, tutorials, practical works) to a teacher, he or she will, in most cases, want to adapt, modify, and enrich it. It may be the main difference between a teacher and a trainer. It is possible to export and to share Moodle modules. It is the solution we have chosen. A complete Moodle module about combinatorial logic has been taught by several teachers from URCA and UPHF, integrating different lectures, tutorials, practical works resources (video, web site, pdf, SCORM packages, applications…) developed separately or conjointly by both universities. An export of this Moodle module (mbz file) will be soon available for all the ET-LIOS partners in a specific ET-LIOS web site.

Depending on the practical courses, sometimes the use of physical technical system is mandatory. In this case, remote labs are the one and only solution. It is the case for instance for the module "e-maintenance" in the ET-LIOS project. However, as it has been seen previously software simulation, when it can be used, can be an interesting solution. At the previous IFAC ACE conferences in 2016 and 2019 (Riera et al., 2016, 2019), we presented HOME I/O, the virtual home simulation software and CONNECT I/O, the soft PLC for HOME I/O. Their possibilities for teaching, from secondary school to university, automatic control and STEM (science, technology, engineering, and mathematics), with an innovative pedagogy have been detailed. Initially, the use of HOME I/O and CONNECT I/O were envisaged for face-to-face use, during practical courses. The health crisis led us to consider HOME I/O and CONNECT I/O in the context of practical distance learning.

For that, it is necessary to give access to the software to the students. The best solution seems a cloud solution, but that requires technical choices and large investments that cannot be made in the short term by the organization. It is why, as a first approach for the ET-LIOS project, we have decided to supply all the necessary softwares to the students. However, that requires:

1. The student must have a computer at home. Fortunately, it is now most often the case. Support is also needed to help with the installation and use of the software, which can be done in different ways (slides, video, etc.) so that the students do not get lost and discouraged.

2. Software must be free of charge, with no problem of installation and activation for students and teachers.

3. Develop specific tools to help the students to test his/her practical work. To fulfill this requirement, Serious Game Research Lab from Institut National Universitaire Champollion, partner of the ET-LIOS project, has developed an original SCORM Package that can be easily integrated in a LMS.

Firstly, HOME I/O ET-LIOS and CONNECT I/O are going to be presented. Secondly, the SCORM package, will be detailed.

4. HOME I/O ET-LIOS AND CONNECT I/O

HOME I/O ET-LIOS is a specific release of the HOME I/O software developed within the ET-LIOS project. It is free of charge and without time limit for all ET-LIOS institutions and can be given to all teachers and students (Fig. 1).
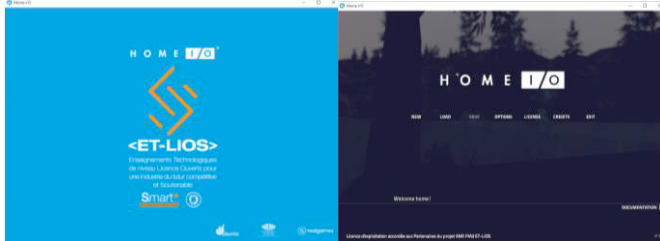

Fig. 1. HOME I/O ET-LIOS

HOME I/O was built from the beginning to cover a large spread of educational applications in technology and engineering sciences (Riera and Vigario, 2017). More than a simulator, HOME I/O has been designed to be a learning, experimenting and project development environment dedicated to students from middle schools, high schools, and universities (Fig. 2). All controllable objects can be used in three modes: wired, console or external. In wired mode, the house is not automated. This is a conventional electrical installation where all devices are wired. It is the mode by default when you start HOME I/O. This mode enables to discover an "unsmart" virtual house.

In the console mode, the controllable objects are programmable through home automation box software by defining scenarios (lighting, motor, heating, intrusion security and domestic security). This mode has been initially designed for middle school because the functional aspect of smart home can be easily explained and understood by kids, without going into too technical considerations.

In the external mode, inputs and outputs of each object can be used through HOME I/O SDK which is made of a .NET 2.0 assembly (EngineIO.dll). HOME I/O SDK opens the field of applications of HOME I/O. This makes it possible (and simple) for instance to control a room temperature with LabView (Riera et al., 2016), MATLAB or PYTHON.

The external mode has been designed initially for high school and higher education. These 3 modes enable to modify the level of automation and offer a wide range of applications adapted to middle school, high school, and university. In addition, HOME I/O is supplied with a free soft PLC called

CONNECT I/O which uses HOME I/O SDK. At least, HOME I/O integrates an open http server, which enables, using external mode, a direct connection with Scratch 2 or 3 (https://crestic-scratch3.univ-reims.fr/).

Fig. 2. HOME I/O

With CONNECT I/O (Fig. 3), several functionalities can be implemented by drawing a diagram with nodes and linking them together. Basically, CONNECT I/O can be used for three different purposes:

- Control HOME I/O by designing a soft controller with function blocks.

- Connect HOME I/O to external automation technologies (e.g., PLC, Modbus, microcontrollers, etc.). In this case, CONNECT I/O can be seen as a gateway between external technologies and the simulation.

- Perform acquisition and analysis of data coming from HOME I/O.

All these functionalities can be used at the same time and even extended by developing plugins.
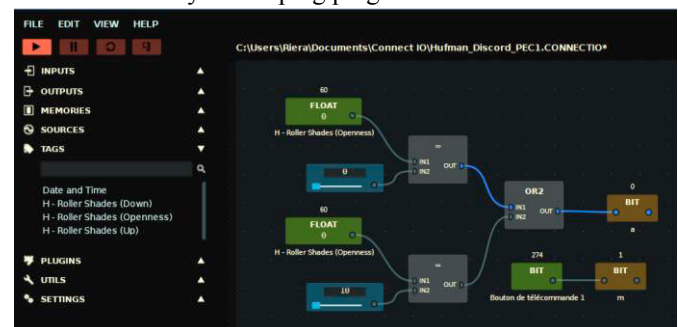

Fig. 3. CONNECT I/O: soft PLC for HOME I/O

HOME I/O ET-LIOS with CONNECT I/O are interesting software to manage practical courses about combinational logic and sequential logic. They seem adapted to e-learning and promote learning by doing and learning from errors.

Serious Game Research Lab from Institut National Universitaire Champollion has developed an original SCORM Package that enables students to test his/her controller designed with CONNECT I/O. As it has been seen, this functionality is almost mandatory with blended practical courses.

5. CONNECT I/O TEST SCORM PACKAGE

Serious Game Research Lab has developed in collaboration with URCA for the module "Digital twin and virtual

commissioning of automated production systems" an application which can be easily integrated into the Moodle LMS allowing verification and automated feedback to the student of combinatorial practical courses. It allows to work complementarily with the CONNECT I/O software by assessing the performance and quality of the student's proposal (Fig. 4).

It has been decided to use SCORM (Parmar, 2012) to design this verification tool. SCORM is a set of technical standards for eLearning software products. It is an industry standard for eLearning interoperability. Specifically, SCORM governs how online learning content and Learning Management Systems (LMSs) communicate with each other. The idea has been to give to the teacher the possibility to adapt the SCORM package to his or her need. In other words, the teacher is going to create very simply a SCORM package (zip file), for his or her own practical work to integrate to his/her LMS. Design by teacher and use by students of the SCORM package is performed as follows.

First, teacher creates a practical course about combinatorial logic. He or she designs a CONNECT I/O solution. One can note that for a combinatorial logic problem, it can exist several possibilities to implement the solution.

In a second stage, teacher creates his or her SCORM package for the practical course. For that, it is only necessary to change 2 or 3 files in the SCORM framework supplied. After, teacher can integrate it in his or her LMS.

The SCORM resource can now be used by students through the LMS. They do the practical exercise using HOME I/O ET-LIOS and CONNECT I/O which are available for free to them and installed in their computer. They can test their CONNECT I/O solution, using the SCORM application and they get feedback about their proposal.

The SCORM application calculates the truth table of the student's CONNECT I/O solution. This truth table is compared to the truth table obtained from the CONNECT I/O solution given by the teacher. Indeed, for a combinatorial logic problem, it can exist several Boolean equations which are solutions, but it exists only one canonic equation, and so one truth table.

Several feedbacks can be given to the student, concerning the errors (inputs used, outputs used, logical gates not connected, bad behavior of outputs…). For instance, Fig. 4 shows an example of the use of a SCORM Package to convert Reflected Binary code in Binary code. In addition, learning analytics is possible through several data which are stored like: username, time, number of logic gates used, etc.

This approach presents several advantages:
- automatic data collection at each student session.
- customization by the teacher easily.
- variables (student information) already present in the LMS (Moodle for instance).
- easy integration with a LMS widely used in higher education.
- possible link to "competencies".
- use of the application for multiple exercises.

It can be noted that the SCORM applications can be used both face-to-face and at a distance. Hence, the hybridization is easy to manage. However, it is important for the teacher to study learning analytics coming from the SCORM package to

be sure that the solution got by the student is not a randomly approach based on trials.

We tested the applications in October and November 2021 with some Bachelor students on several practical courses. One of them is detailed in the last part of the paper.
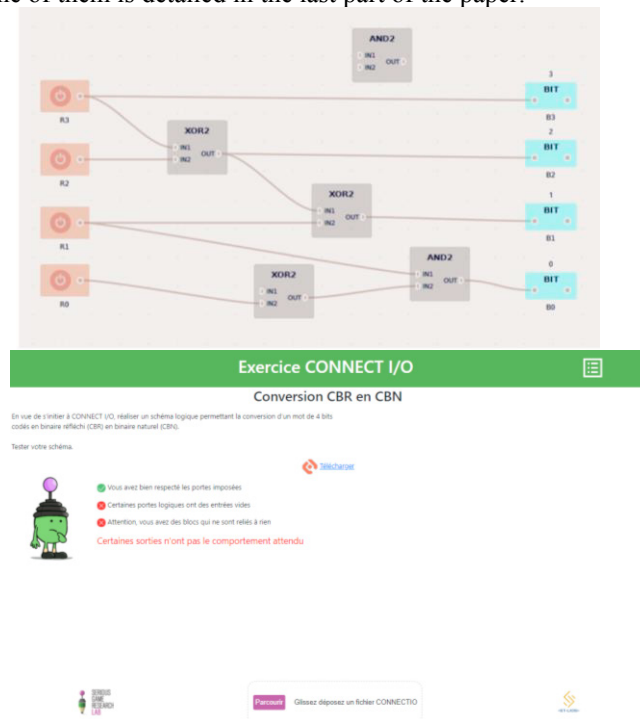

Fig. 4. SCORM package

6. EXAMPLE OF HYBRID PRACTICAL COURSES IN COMBINATORIAL LOGIC

Combinatorial logic is the basis for teaching engineering sciences in general, and automation. The ET-LIOS project is primarily intended for undergraduate students. It therefore seemed important to us, as a first step, to focus on the hybridization of practical work in combinatorial logic.

The main objective of this practical course is to display the percentage of opening of the blind on a 7-segment display type HDSP-5503 of the blinds in the child's room (marker H on the HOME I/O mini board) using a very simple controller (1 push button from the remote control have to be maintained to open the blind, and 1 other to close it). A numerical sensor in HOME I/O, readable in CONNECT I/O, enables to know the opening of the blind (from 0 (closed) to 10 (opened)). The connection to CONNECT I/O is made through an Advantech 4704 I/O DAQ (Fig. 5).

There is a correspondence between the digital outputs of the DAQ 4704 and the inputs of the 7-segment display. For instance, when output DAQ 4704-ID0 is high, the E segment of the display is powered. It is proposed that the numbers from 0 to 10 be represented on the display as follows (Fig. 6). The number 10 will be represented by displaying a 0 and the dot (DP). Students have first to indicate the I/O of this control problem and give its truth table. Then they must calculate the logic functions of the 8 outputs (7 segments + the "."), and implement and test the controller using CONNECT I/O and test it with HOME I/O. However, only 2 DAQ 4704 with HDSP-5503 are available in the practical classroom. Hence, students must often wait before performing a test.

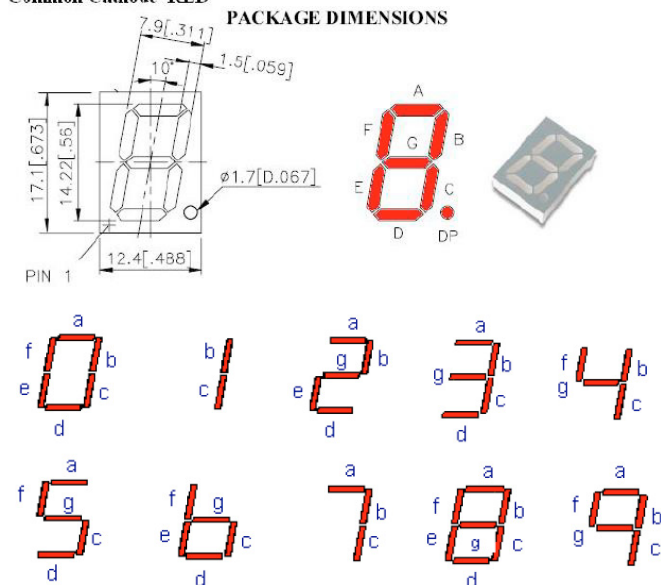Fig. 5. HOME I/O, CONNECT I/O and 7-segment display

Fig. 6. HDSP5503 - 7-segment display

The SCORM application enables the students to test the controller offline, without the hardware. This work can be done at home, but also during the practical course. So, it is very easy to hybridize this practical course. 52 students have tested and used the LMS including the SCORM applications. They fulfilled questionnaires to evaluate the use and the usability of the tools. Results are more than encouraging and seem to show the interest of the approach. 90 % of the students have found the concept (LMS with SCORM) simple and very useful. We have also noted that the students have used the LMS with the SCORM package to prepare or to finish the practical course, doing a lot of tests, and hence learning from errors.

7. CONCLUSIONS

In this paper, we have presented an original solution to hybridize practical courses of combinatory logic. The proposed approach is pragmatic. The idea is to let teachers using the LMS of their university, supplying verification SCORM tools that teacher can adapt to their own needs. Learning from errors, is here, a key point in the pedagogical approach. However, teachers must show to students that controller design based only on errors corrections is not the right way to work, at all. A perspective is to work on learning analytics to define "smart" feedback to the students. In addition, specific release of HOME I/O and CONNECT I/O have been performed in the context of ET-LIOS project, enabling distance work using partially student's computer. This software is downloadable freely for partners, without activation key. All these points enable to hybridize practical courses quickly, easily, with no cost. First feedback from students and teachers are encouraging. In a near future, we intend to extend the approach to sequential logic and PLC programming and to exploit data for learning analytics to adapt the way to help students and the exercises.

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