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An Educational Framework for Process Control Theory and Engineering Tools

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Abstract: The student's education conducted by the Chair of Process Control Engineering at RWTH Aachen University involves the two elements lecture and laboratory course. Due to the continuously rising number of students and the resulting variety of student's technical backgrounds, it is no longer possible to offer laboratory sessions to all registered students. As a result, we established a framework that allows the students to experiment by using the theoretical principles from the lecture without having to participate in the laboratory courses. That means, the framework has to cover a whole range of different aspects involving the planning and engineering of a plant by means of Piping and Instrumentation Diagrams, the physical simulation and the eventual implementation of the automation application. Our framework concept, while not originally part of the Blended Learning project, represents a teaching program that well aligns with the Blended Learning approach supported by RWTH Aachen University.

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1. INTRODUCTION

The student's education conducted by the Chair of Process Control Engineering at RWTH Aachen University involves the two elements lecture and laboratory course. The purpose of the lecture is to teach students about the theoretical principles that are involved in process control engineering. Additional private studies will help them to obtain a deeper knowledge of the topic. During the laboratory sessions, students have the chance to get hands-on experience by using state-of-the-art industrial process control systems. These practical demonstrations keep up the motivation levels of our students. Additionally, the student's motivation levels will noticeably rise, if they realize that the theoretical knowledge of the lecture can be applied to practical problems.

Due to the continuously rising number of students and the resulting variety of students' technical backgrounds, it is no longer possible to offer laboratory sessions to all registered students. This trend forced us to come up with new ideas to maintain or even improve our educational level. From this starting point, two possible and suitable approaches have been discussed:

- The professor or the tutors present additional real world use-cases that demonstrate the advantages of the introduced theoretical knowledge.
- Each student receives a demonstration framework that will provide hands-on practical experience and help them in developing a better understanding of the theoretical topics.

At first glance, both approaches seem to make up for the lack of laboratory sessions. However, as mentioned in Kolb (1984), learning is grounded in a transaction between the individual learner and practical real-world experience. Based on this observation, the use of a demonstration framework appears to be more beneficial for the students. Thus, we assessed that the demonstration framework represents the better alternative of the two approaches.

Our approach is to develop a framework that allows the students to experiment by using the theoretical principles from the lecture without having to participate in the laboratory courses. The framework is also used as a demonstrator during the lectures. The presented approach involves the combination of a simulation- and runtime environment which is provided to the students in form of a highly portable and deployable system. In order to demonstrate the engineering process, the system includes a PandIX model (cf. Schüller and Epple (2012)) of the simulated plant, a Function Chart Diagram (cf. Yu et al. (2012)) for implementing interlocks and a Sequential State Chart (cf. Yu et al. (2013)) for creating a two-point controller of a vessel's filling level.

In 2014, RWTH Aachen University initiated a Blended Learning project with the aim of providing additional teaching offers aside from traditional face-to-face teaching within all faculties and departments. In this context, the individual faculties are asked to develop Blended Learning concepts that utilize the vast educational opportunities of new media in a targeted manner. By implementing modern methods of teaching on a broad scale, RWTH Aachen University wants to offer all students a comprehensive teaching portfolio which incorporates in-class lessons and independent media-supported study phases. Our framework concept, while not originally part of the Blended

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Learning project, represents a teaching program that well aligns with the Blended Learning approach supported by RWTH Aachen University.

The paper is structured as follows: In Section 2, the education concept along with related work from the field of pedagogy is presented. The education framework and how it is used in teaching is introduced in Section 3. The student's tasks that should be performed as part of the framework are discussed in Section 4. Finally, a brief summary of this paper and an outlook towards future work in this area is provided in Section 5.

2. THE EDUCATION CONCEPT

In this section, we will start with a brief excerpt of pedagogical concepts that are relevant for our teaching concepts. This will be followed by the introduction of our actual education concepts for the laboratory course and the presented education framework.

2.1 Related Work

A hierarchical classification of educational objectives was introduced by Bloom et al. (1956). The objectives are divided into six categories:

(1) Knowledge
(2) Comprehension
(3) Application
(4) Analysis
(5) Synthesis
(6) Evaluation

The objectives are ordered from simple to complex, which indicates that the objectives shall be completed progressively. That is, each of the previous objectives must be completed before the current objective can be addressed. According to Felder et al. (2000), the categories (2) to (6) are the most important in engineering education.

The first category of the taxonomy involves objectives that emphasize the reproduction of factual knowledge. The remaining categories focus on higher goals of education that require the use and combination of knowledge. The *comprehension* category includes objectives involving the understanding of instructions and problems in all communications forms, be it written, oral or graphical, while *application* objectives revolve around executing or implementing a specific procedure or concept. Objectives of the analysis category are demanded when concepts and materials shall be dissected into constituent parts in order to fathom how they relate to each other and to the overall organizational structure. *Synthesis* objectives require students to consider individual constituent parts in order to combine and connect relevant elements into a coherent structural whole. The *evaluation* of material and concepts represents the highest category of objectives and includes all teaching goals that ask students to judge the value of ideas, tools, procedures, etc. according to certain criteria or standards (cf. Bloom et al. (1956)).

The objectives of Bloom's Taxonomy can provide a helpful guideline for curriculum design. In Krathwohl (2002), Krathwohl offers a revision of the original taxonomy and also adds a second knowledge dimension to the cognitive dimension.

In terms of engineering education, Felder et al. (2000) provide a summary of teaching techniques that have proven to be effective for teaching engineering students. The following list provides an overview:

(1) Formulate and publish clear instructional objectives.
(2) Establish relevance of course material and teach inductively.
(3) Balance concrete and abstract information in every course.
(4) Promote active learning in the classroom.
(5) Use cooperative learning.
(6) Give challenging but fair tests.
(7) Convey a sense of concern about students' learning.

Most of the mentioned points seem to be very intuitive and plausible which is why we focus on those aspects that are relevant for our following considerations. By suggesting to "promote active learning in the classroom", Felder encourages tutors to move away from ex-cathedra teaching styles and towards cooperative learning. During the lecture, instructors should ask questions and provide exercises every ten to twenty minutes. The duration of those exercises should lie between 30 Seconds and a couple of minutes. While this promotes active learning processes, Felder also suggests that it would be best, if the students were given the opportunity to solve tasks in groups. Nowadays, most engineering work is accomplished in cooperation with others which means that the ability to work as part of a team is becoming increasingly important. Besides the importance of team work, Felder also indicates that students who learn cooperatively tend to have better exam results and develop a deeper understanding of the relevant topics (cf. Felder and Brent (2007)).

In their research on learning and teaching styles, Felder and Silverman also discovered that most engineering students are visual-, sensing-, inductive- and active learners (cf. Felder and Silverman (1988)). The traditional ex-cathedra concept of lectures will naturally fail to cover all of these learning styles, which may affect the motivation and learning process of students. Thus, adapting the teaching style of lectures and adding complementary learning provisions will help to address a wider range of students and individual learning styles. In essence, all these findings support the inclusion of exercise-based and active teaching methods into the education of engineers.

2.2 Laboratory Education Concept

The education concept of the Chair of Process Control Engineering was introduced by Krausser et al. (2012). The concept is based on the learning cycle developed in the work of Hughes et al. (1992). Fig. 1 illustrates the learning cycle that was adopted at our chair involving the elements lecture and laboratory.

By including those two elements in the learning cycle, the education process can be logically-structured into a theoretical and a practical part. During the lecture, students gain knowledge about the theoretical aspects of a topic which they can enhance through additional self-studies. In the laboratory courses, students get the

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