The Model Railroad as an Inspiring Platform for Microelectronics Education

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One thing most teachers are but happy with is knowledge that the students cannot apply in practice. This phenomenon is called tacit knowledge. It refers to knowledge that consists of just meaningless symbols that are sitting rather passively in the students' brains, and cannot be used in the context of real-world applications. From an economical point of view, tacit knowledge can be considered a massive waste of resources, since its acquisition consumes significant amounts of time and mental as well as financial capacities from all students and teachers.

To many readers it might be a surprise that tacit knowledge is indeed an issue in engineering sciences particularly electrical engineering and computer science, since these studies are on concrete physical entities and matters. However, many formal and informal evaluations reveal that very often, many students are not able to embed newly learned concepts into existing knowledge and/or real-world situations. For example, students industriously learn abstract concepts, such as Mealy and Moore finite state machines but are not able to use them as the basis of a controller for traffic lights or washing machines. As a collateral phenomenon these shortcomings result in frustration, and thus lack of motivation. But particularly *motivation* is one of the key factors for successful learning.

The learning situation sketched above has induced the question of how both motivation and embedding can be improved. The core idea was to resort to a very old concept: the model railroad. The major reasons for this choice were: the model railroad is well-known to virtually all students and teachers, the complexity is manageable but not trivial, the project and all the tasks can be divided into modules, the learning tasks are not limited to electrical engineering but also open to other engineering disciplines, e.g., civil and mechanical engineering, and it is a lot of fun for all.

Normally, privately owned model railroads employ an analog mode of operation. However, the utility of this mode of operation is very limited, and thus, way too simple for teaching on a university level. Therefore, the model railroad project at the University of Rostock employs the open digital command control (DCC) protocol that allows for controlling every train on an individual basis independently of all other trains. In its present form, the project employs trains and tracks of size N, i.e., a scale of 1:160, 35 switches, 5 crossings, 10 trains, many wagons, and is mounted on a wooden board of $3\,m\times 1.5\ m$ in size.

Due to its design, the model railroad project offers plenty of teaching opportunities. The first major teaching area is concerned with the digital control of the switches and crossings. The main idea is that the users can control all the switches and crossings by means of a personal computer. To this end, the students have to develop appropriate power amplifiers, consisting of, for example, simple (field effect) transistors or ready-to-go drivers. These power amplifiers are then connected to either a micro controller, such as a standard Atmel AT91 evaluation board or a field-programmable gate array (FPGA). These "main" controllers handle the required communication with the host computer, and also activate and deactivate the output ports to issue state changes of the switches and crossings (via the power amplifiers). In addition to the development on the hardware level, the students also have to do all the low-level hardware-oriented programming as well as the design and implementation of the actual communication protocol. Furthermore, the option of being able to operate different main controllers by means of different hardware communication facilities, e.g., Bluetooth, RS232, USB, and Ethernet, significantly increase the complexity of the control software. Finally, the students have to develop graphical user interfaces that visualize the track layout and offer excellent usability.

The second major teaching area concerns the motor controls of the trains. Normally, off-the-shelf products consist of the actual motor controllers as well as a main controlling station, which sends all the motor commands over the rail tracks by modulating the power supply (see, for example, the DCC description). Since this implementation of a motor control is but reliable, the students are expected to develop their own controllers as well as protocols. In so doing, the students have developed a wireless remote control. These controllers are based on standard wireless technologies, such as Bluetooth and ZigBee. The students then connect these wireless communication nodes to the actual motor controllers they have designed and realized on their own. The students have also designed and implemented their own communication protocols on the application level, which completes this teaching area. This teaching area as well demands user graphical user interfaces and the design and implementation of a distributed control architecture.

Several formal as well as informal evaluations indicate that when working with the model railroad project, the students indeed embed new teaching units into existing knowledge. They furthermore develop a fair understanding of the learned theories, since learning occurs in the context of a real-world application. These evaluations also indicated that the students are highly motivated since they want their projects work.

From a teacher's point of view, the model railroad project has the following advantages: (1) the students have to cooperate in small teams, (2) the students are highly self-motivated, and (3) the teaching subjects incorporate topics from many domains, such as digital circuit design, low-level programming, protocol design, board layouting, wiring, etc.