Using *Arduino*-Based Experiments to Integrate Computer Science Education and Natural Science

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Abstract: Current curricular trends require teachers in Baden-Wuerttemberg (Germany) to integrate Computer Science (CS) into traditional subjects, such as Physical Science. However, concrete guidelines are missing. To fill this gap, we outline an approach where a microcontroller is used to perform and evaluate measurements in the Physical Science classroom.
Using the open-source *Arduino* platform, we expect students to acquire and develop both CS and Physical Science competencies by using a self-programmed microcontroller. In addition to this combined development of competencies in Physical Science and CS, the subject matter will be embedded in suitable contexts and learning environments, such as weather and climate.

Keywords: Computer Science Education, Natural Science Education, Inquiry-based Learning, Physical Science, Measurement, Arduino, Sensors

1 Introduction

Studies on K12 education, such as PISA, have revealed widespread deficits in learning outcomes. These disappointments have led to a shift in objectives from content knowledge to skills and competencies. Learning scenarios that integrate various subjects have become increasingly important. More and more, school curricula are demanding interdisciplinary approaches to education. For example, in the German state of Baden-Wuerttemberg, at the level of secondary schools, Physical Science and CS Education are to be combined. Moreover, this combination will soon be cancelled and CS will be placed as a central theme in secondary schools. Central themes are themes that are not assigned to one specific subject; they have to be taught in an integrated manner.

Although current educational standards describe a general framework for interdisciplinary learning, they fail to supply concrete contents and methods. Consequently, teachers find it hard to integrate scientific subjects. This is especially true regarding a proper integration of learning objectives in the fields of Physical Science, Information Technology, and CS. In this paper, we address two consequences of this educational dilemma, specifically in the fields of Physical Science and Computer Science Education:

- The teaching of Physical Science in integrated science tends to be poor and fragmentary.
- Current and future educational standards require CS to be taught as an integral part of the established subjects (Ministerium für Kultus, Jugend und Sport, 2014). Some teachers simply subtract some teaching time from science to teach CS in a mostly isolated way. Moreover, course contents are mostly limited to the handling of application software such as Microsoft Word® and PowerPoint®. Higher-level competencies can hardly be achieved this way.

This paper outlines a new approach to integrating Physical Science and Computer Science. We suggest specific scenarios involving *Arduino* as a measurement tool. Furthermore, we propose competence areas to be promoted thereby.

2 Approach

What would be a possible approach to integrating CS and Physical Science education in a balanced manner? Science education in both fields has been broadly investigated (Coll, Taylor, 2008; Pientka, 2008). Following worldwide trends, the integration of Physical Science and Computer Science education has become a crucial element of integrated STEM (Science, Technology, Engineering, and Math) curricula (Berlin, Lee, 2005; Asghar et al., 2012). However, when integrated, Physical Science and Computer Science are mostly treated unequally:

In Physical Science lessons, computer-based technologies are typically used as mere tools to solve physics-specific problems. They are hardly used to increase CS competencies. The computer acts as a black box with several functions. For example, it simulates the lift in different liquids or helps students create models (such as the atomic models). Software is used as an interactive learning environment, for example to balance forces, or to collect data from ready-made sensors, delivering a well-formatted output.

In CS teaching, there has been some research in the area of robotics, for instance Lego Mindstorms®. Although these technologies have been very successful in teaching programming skills, their potential for teaching Physical Science concepts is low. After all, modern physics is more than the motion of a robot.

To avoid this unbalanced treatment of physics and CS, we suggest a Physical Science scenario where the design and application of CS instruments stimulates students to deal with both the informatics and the physical principles involved.

Specifically, we suggest using a microcontroller to record experimental data, handle the recorded data, and process them for presentation.

Our teaching method is based on three principles:

1. **Principle**: In order to go beyond mere knowledge toward application-centered skills, we suggest establishing a learning environment where students are responsible for most part of their learning process and outcome. **Theory**: Our approach builds on theories of problem-based learning and inquiry-based learning (Dewey, 1910). **Example**: The microcontroller is not treated as a black box. Instead, it has to be designed, constructed and programmed by the students themselves.
2. **Principle**: To promote a sense of purpose within the students, Physical Science is to be taught in a natural context and in a way that reflects the nature of science. **Theory**: Our approach draws on the concept of situated learning (Lave, Wenger, 1990) and learning in real-world contexts (Muckenfuss, 2006). **Example**: Within the context of weather, students may solve the question of how to acquire weather data. The use of *Arduino* allows students to observe and record processes in the real world.
3. **Principle**: The students themselves design, construct and perform computer-based experiments, guided by the instructor as necessary. **Theory**: In particular, we follow the idea of a guided-inquiry lab (Colburn, 2000). **Example**: Students would be asked to plan and build the experiments in a way that the sensors accurately measure the required data. Then they would write an *Arduino* program to

apply and convert the data into useable formats. These formats would allow the students to create a spread-sheet or other graphical forms for their presentation.

Because students' skills vary, individual scaffolding is important. Depending on the individual skill level of the students, the teacher can guide and support them by offering a set of ready-made elements for the construction and programming of the micro-controller.

3 Technological Approach: Measurements with Arduino

Media for schools should be reasonably cheap. The only way to have a dozen micro-controllers in a classroom is to use an electronic prototyping platform that is open-source, where no licenses have to be paid for. There is a large variety of relevant and interesting products on the market. The most common platforms are *Arduino* and *Raspberry Pi*. Both are single-board computers (the size of a credit card), with enough peripherals to connect the sensors to. Although *Raspberry Pi* is more focused on net-working and multimedia than *Arduino*, the latter is cheaper and more suitable for handling data. In contrast to other, less common platforms, *Arduino* comes with a large supply of accompanying material, such as tutorials, examples, and other resources. This encourages students to learn autonomously, possibly beyond what is expected by the teacher. A remarkable advantage of *Arduino* is the freedom in choosing the different sensors to get the data needed. Therefore, one can use sensors for experiments in all areas of Physical Science education.

Moreover, the *Arduino* integrated-development environment is specially designed to introduce newcomers to software development.

4 Scenarios

Using *Arduino* to analyze Physical Science experiments is possible in almost all scenarios. For beginners it is recommended to confine the subject matter to a basic domain of thermodynamics or mechanics, and to a related context. As an example, we introduce a weather station as a scenario, see Figure 1. We also worked with scenarios where measuring g-forces or measuring temperature in four different units are the central tasks.

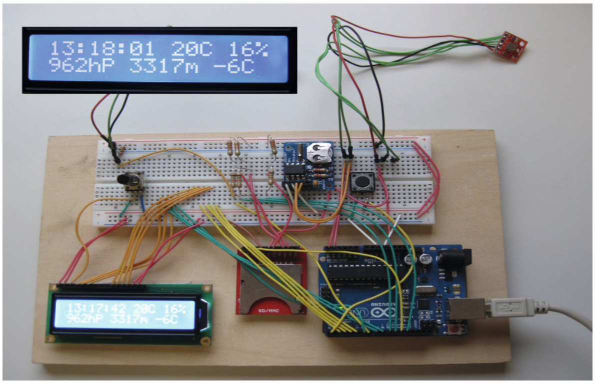

Figure 1: Weather station

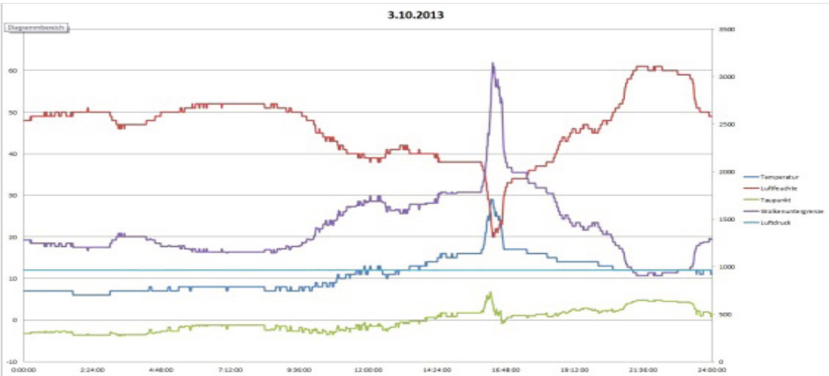

Figure 2: Weather diagram

4.1 Weather station

In meteorology (the science of weather), the main measurable variables are pressure, t3emperature, and humidity. For these three thermodynamic variables, there are numerous sensors available. Moreover, the timing of the measuring process need not be very fast. This makes it relatively easy to create a working code. Nonetheless, even simple temperature measurements, for example, require a large set of competencies in order to get correct values. Analogue sensor values, ranging from 0 to 1024, have to be mapped onto a suitable scale. Here, the students need to know (or find out) how a temperature scale is defined. Other thermodynamic variables can be calculated on the basis of the three main variables, and visualized as in Figure 2. The weather station may provide the actual values of temperature, humidity and pressure. Furthermore, as examples of calculated values, it can provide the cloud level and the dew point. Data can be visualized by a simple processing application created by the students.

5 Skills and Competencies

With the outlined approach, key competencies in both Physical Science and Computer Science will be addressed.Specifically, we aim to address some of the key competencies in the natural sciences, such as: Breaking down complex issues into simpler parts, planning experiments, collecting data, documenting and presenting experimental results and working autonomously with measurement systems. A more comprehensive list can be found in the German educational standards (Ministerium für Kultus, Jugend und Sport, 2004), or on the website of Next Generation Science Standards (Achieve, Inc., 2013).

Note that competencies in Physical Science and CS are to be trained with equal importance. For the purposes of KEYCIT, however, our presentation will be focused on the CS competencies. Not only do we aim to achieve the German media competence standards as formulated for Baden-Wuerttemberg (see above), but also the more comprehensive CS-related standards, *cf.* ACM K-12 (Tucker, 2003).

Overall, we address competencies in accord with the Guiding Ideas as put forward in Ministerium für Kultus, Jugend und Sport (2004):

Basic knowledge should be comprehensive, sustainable and experience-based. Therefore, teaching needs to be contextualized, taking into account students' pre-concepts, school equipment, and curricular organization.

It is a supreme goal of general school education to develop the ability to use information in a purposeful, responsible, and creative way. Important competencies in this respect are especially the sensible acquisition, choice, processing, and delivery of information.

Specifically, based on the German educational standards (Ministerium für Kultus, Jugend und Sport, 2004), we cover the following competencies and subject matters:

Table 1: Examples (right) for meeting curricular expectations (left)

Curricular requirements: The students are able to…	**Suggested realization: The students are able to…**
establish quality features of computer systems and software	specify necessary features of a weather station to get weather data that are as accurate as possible.
present the structure of a data processing system	describe and present the steps that are required to show sensor data
use the computer for measuring and controlling	connect sensors (for humidity, temperature and pressure) to a microcontroller to acquire weather data
solve a problem using a simple programmed algorithm	design a working code to display the value of the measured variable, such as temperature
handle the basic items of digital coding	translate analog into digital data when using analog sensors
use a wide range of basic IT-applications in an independent and purposeful way	use standard Microsoft Office ® applications to process and present the collected data
present data and facts vividly and clearly	create a weather diagram for the collected and the calculated data (*cf*. Fig. 2)

6 Summary and Outlook

Our research focuses on the various competencies that could be acquired and consolidated by using a self-programmed *Arduino* microcontroller in a Physical Science context. In addition to the competencies, we expect a positive effect on students' motivation and interest, both in CS and Physical Science.

In the upcoming two years, the first prototypes of an *Arduino* Measurement Box will be evaluated in close relation to live situations. This evaluation will take place both at college and high school level. The increase in Physical Science and Computer Science competencies will be measured and evaluated.

With our interdisciplinary teaching approach, we hope to foster key competencies in both Physical Science and Computer Science.

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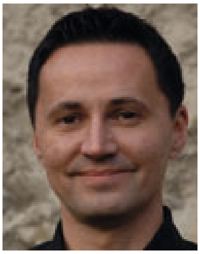
Biographies

Herbert Gerstberger is professor of physics and science education at the University of Education Weingarten. His research interests cover several aspects of interdisciplinarity connected to the teaching and learning of physics.



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