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***Abstract*—Problem-based learning has proven successful in many areas and is especially well-fitted for computer science. As such, we want to present our experiences in applying problem-based learning in a course for building automation. We show the general structure of our course, the building automation specific learning outcomes, and the superordinate learning outcomes. Finally, we share our experiences (both positive and negative) we made during two iterations of the course (in Autumn 2022 and Autumn 2023) from the perspective of the lecturer, students and university employees.**

***Index Terms*—building automation education, case study, higher education, project-based learning**

I. Introduction

Building automation is a discipline spanning across computer science as well as different engineering disciplines (i.e., mechanical engineering, control engineering, electrical engineering) [2]. It is an important topic, covering multiple technologies such as BACnet, LON, KNX, ZigBee, Z-Wave and EnOcean [3] and provides many different services, such as climate control, visual comfort, safety, security, or energy management [2]. In addition, it has the potential to increase the energy efficiency of buildings [4], thus it can be seen as an important future technology (for an example in school buildings see [5]). Yet, finding an exact definition proves to be difficult, and definitions across literature are inconsistent [6]. Taking all that into consideration, building automation can be considered important for students in computer science and engineering to learn.

Many papers discussing the teaching of building automation can be found. For example, Väänänen et al. [7] present a virtual learning environment for programmable logic controller they intend to use for teaching building automation. Multiple papers discuss how to use modern hardware such as Arduinos [8], Raspberry Pi [9] or Programmable Logic Controllers [10] to create different experiments for building automation. Porter et al. [11] used building automation to promote careers in STEM disciplines in K-12 education. Finally, Ożadowicz [12] showed how modern concepts like blended learning can be used in building automation courses.

We want to extend the efforts of improving building automation teaching by introducing project-based learning to teach students not only building automation skills (see Sec. III-B), but also let students acquire general laboratory skills (i.e., [13], [14]). Project-based learning has been successfully used in similar areas (e.g., industrial automation [15], Computer Aided Design/Engineering (CAD/CAE) [16], or mechatronics [17]) so we think it fits well with building automation teaching. Therefore, we want to share our experiences of using project-based learning in our building automation course.

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II. Project-Based Learning

Project-based learning is a paradigm where students work together on a project (usually self-selected or presented by a company) [18] and can be considered a widely researched topic [19]. Project-based learning as a teaching approach seems to be well-fitting to computer science, where project-based learning can teach skills not usually acquired through traditional learning [20]. According to Krajcik and Shin, there are six principles found in project-based learning [21]:

1) Project-based learning **starts with a question**.
2) The learning activities are **based on learning outcomes** (aligned with learning standards).
3) Students use different **disciplinary practises** to engage with the question.
4) Students as well as teachers and community members **collaborate** to find a solution.
5) Students are **scaffolded with (learning) technologies** that enable them to solve their problem.
6) Students **create tangible products / artefacts** that solve their initial question / problem.

A literature survey by Ralph [22] reported a positive effect of project-based learning on content knowledge, interdisciplinary knowledge and skill development for future careers. In addition, Ralph [22] also mentioned that teamwork was mostly seen positively, but also brought problems and negative experiences to students such as lack of contributions from some students or misunderstandings. Closely-related to project-based learning is problem-based learning [23].

III. Buildung Automation Course

In this Section, the current design of the course is described. First, the actual course structure is presented. After that, we present the learning outcomes (LOs) we want to address in the course. This order was chosen in this paper since understanding the course structure first will make it easier to understand how we applied the LOs in the course.

A. Course Structure

The course is a required elective course, meaning the students can choose between different courses in different knowledge domains related to their study programme. At the same time, the course is offered in different programmes (i.e., applied computer science, business informatics, industrial engineering), so students have differing prior knowledge when starting the course.

In our required elective course, we want to employ project-based learning for students, since it shows positive effects and fits well with students' future work life (see Sec. II). However, before the students work on their self-directed project, they need to have the knowledge and tools to successfully finish their project. Because of this, the course was split into three parts: a more classical lecture, a project phase, and the final presentation of the projects. The lecture part ran for three weeks, with the project phase taking six weeks and finally the presentations during lab times in the last week of the course.

The **classical lecture** focuses on giving students an overview over existing protocols, open problems, and discussing the current status of the scientific field of building automation. Included in the lecture are demonstrations where applicable, for example students were able to experiment with a *Universal Robots UR5e*[1] robot arm (if desired). The goal of the lecture is to give students the fundamental knowledge they need to choose and complete their building automation project. At the end of the lecture phase (week three), students have to decide on a question they want to answer and a project they want to work on to answer their question for the remaining weeks.

In the **project phase**, the students have to choose a question they want to answer and realise a project they chose to answer that question by building a physical system. Working together in two-person teams, the students can choose any question / project they like as long as it relates to building automation in a broad sense (for all student projects in 2022 and 2023 see Fig. 1). By letting students choose an experiment themselves, we want to increase student engagement while also fostering their creativity. Each team had the option to have mechanical and/or electronic parts ordered for up to 100€ on university budget (abiding to an ordering process for easier management). In the first run, we allowed for free selection of stores, which made it hard for the university employees to actually process all orders, therefore we limited the number of shops students could use in the second run.

For the **presentation**, the students should show their artefact to the class and explain their creation process. The presentation took the form of a trade fair rather than a frontal presentation, with both course participants and visitors going around and discussing the projects with the groups. In addition to the presentation, each team had to deliver a short report (around 10 pages including parts list, assembly instructions, and circuit diagram if applicable). Both report and presentation were formally required for grading.

The six principles of Krajcik and Shin [21], as summarised in Sec. II, are addressed by the course as following:

1) **Starts with a question:** After a short introduction to building automation, each team has to find their own question to build a project around.
2) **Based on learning outcomes:** Besides students having to use industry-standard building automation technology, we used the learning outcomes described in [13], [14] (see Sec. III-B) as a basis for our work.
3) **Disciplinary practises:** Students have to apply standard building automation practises (and technology) they learned during the lecture phase to answer their question.
4) **Collaborate:** Students have to work in pairs as well as collaborate with university employees for the ordering process.
5) **Scaffolded with (learning) technologies:** The course starts with a lecture giving the students required knowledge. The students can order parts as needed (within a reasonable budget). In addition, there are fixed times each week at which students can ask teachers for help.
6) **Create tangible products / artefacts:** Each team has to deliver a physical artefact (besides presentation and report).

B. Learning Outcomes

Since the Bologna Process in the European Union, course and module descriptions should be defined by learning outcomes (LOs) [24], [25]. LOs are based on the Anderson-Krathwohl revision of Bloom's Taxonomy [26][2] and describe the skills and the level a student should have acquired at the end of a course / module as an observable action or behaviour [24]. For our course, we decided on the LOs a student should achieve based on two sources.

The first source are the building automation specific LOs. These were designed by the primary lecturer based on his experience in building automation and contain the following LOs:

1. Students know the **general problems** of building automation.
2. Students know **typical applications** of building automation.
3. Students know the **most important protocols** of building automation and can apply them to solve problems.
4. Students differentiate between **circuits and controllers**.
5. Students know about **energy efficiency** in the context of building automation.
6. Students **create a** building automation **related artefact**.
7. Students show **presentation skills**.

[1]https://www.universal-robots.com/products/ur5-robot/, accessed 2023-01-23

[2]The revised taxonomy maps cognitive competences into the hierarchy of six levels. These are: 1. Remember 2. Understand 3. Apply 4. Analyse 5. Evaluate 6. Create

8. Students perform a **literature research**.
9. Students **read and interpret data sheets**.
10. Students perform **troubleshooting** to find problems in (their) systems.
11. Students show **tenacity** solving problems.

The LOs 1. to 6. are building automation related, while 7. to 11. are more general skills students should learn.

In addition we want to teach general laboratory skills. For this, multiple sources of superordinate LOs can be found in literature. One such source is the work of Feisel and Rosa [13], who defined a total of 13 general LOs for laboratories. All of these learning outcomes were collected during a colloquy of experts from different engineering education disciplines [27]. While an argument could be made for all of the LOs from Feisel and Rosa [13] in the context of the building automation course we want to focus on the following:

- **Objective 1: Instrumentation**: Students should be able to choose the correct protocol, hardware and tools to complete a building automation project.
- **Objective 5: Design**: Students complete a building automation project and thereby design (and build) an artefact.
- **Objective 6: Learn from Failure**: While working on their project, students will almost certainly face problems and make mistakes. By overcoming these problems, the students should be able to learn from their mistakes.
- **Objective 7: Creativity**: Students should be able to use their creativity for both finding a project / question and actually realising it.
- **Objective 8: Psychomotor**: For actually realising their project and building an artefact, students need to learn how to operate all relevant tools.
- **Objective 9: Safety**: Students should know about safety in building automation (especially in working with electricity) and apply this knowledge while working on their own project.
- **Objective 10: Communication**: Communication is an essential skill students must learn and apply. This is important for communication in teams, with the supervisor as well as with the university employees organising the parts order.
- **Objective 11: Teamwork**: Students must work in teams on their project and develop necessary teamwork skills.

Since the projects are practical, *Objective 2: Models* and *Objective 3: Experiment* are addressed to a lesser degree. Similar arguments hold for the other LOs that were omitted.

Soll and Boettcher [14] interviewed industry representatives to collect a total of ten general laboratory LOs as well as some learning outcomes relating to specifiv knowledge. Out of those ten LOs, seven are closely related to the LOs of Feisel and Rosa [13], leaving three LOs which can be considered new. These three new LOs according to Soll and Boettcher [14] which we want to include in our course are:

- **Know Industry Environment**: For realising their project, students use standard protocols / hardware also found in industry.
- **Overview over Larger Context**: Besides getting knowledgeable in building automation, students have to learn about teamwork, presentation, as well as following a strict ordering process. In addition, for many projects knowledge about other computer science topics / engineering topics is required.
- **Working Mindset**: Students work on a project and thereby train soft skills required for modern working environments.

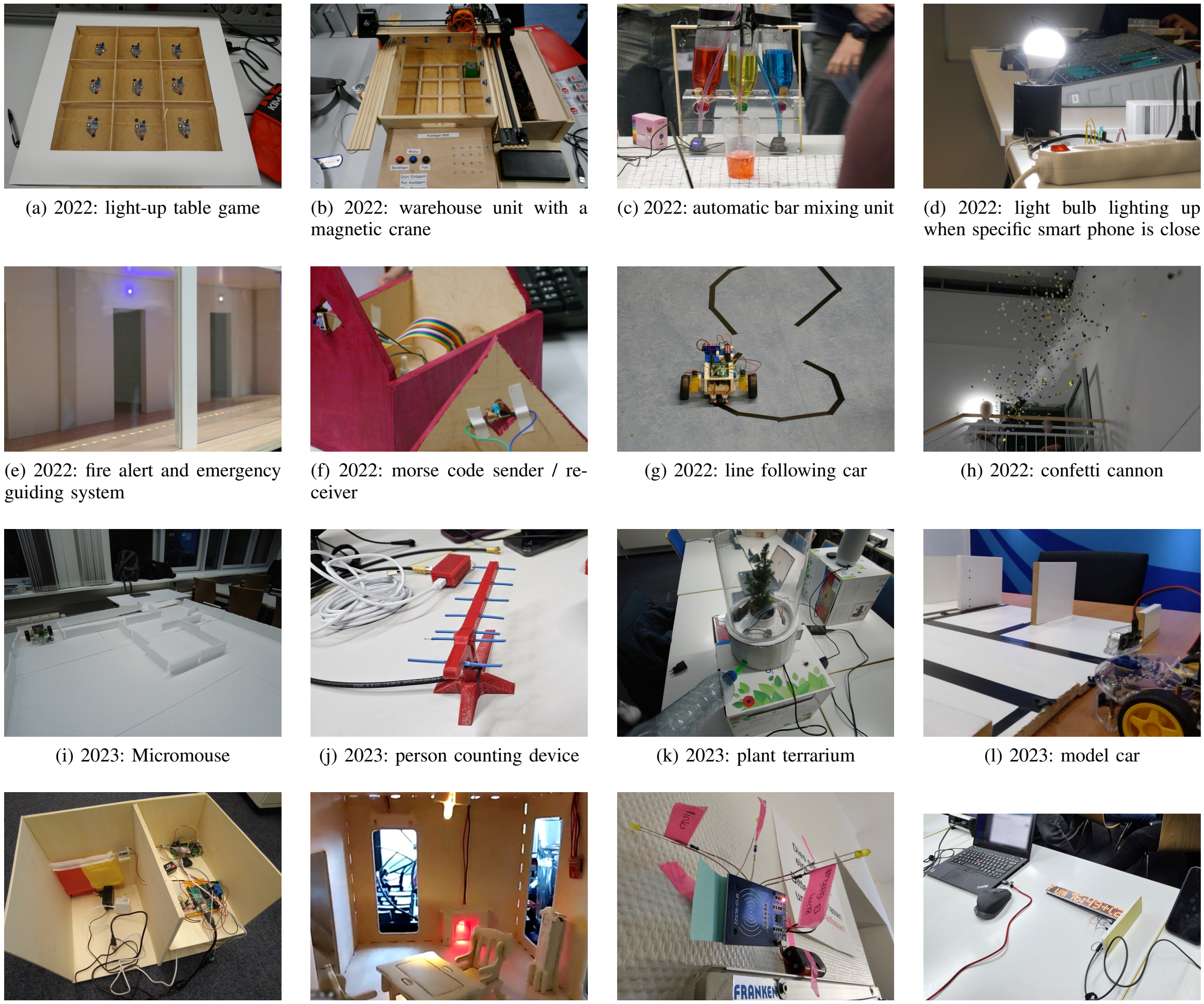
IV. Results

The course was held in multiple years. We want to present the last iterations, which were held in Autumn 2022 as well as Autumn 2023. A total of 16 students participated each year in the required elective course, working in teams of two for a total of eight projects, filling the course to maximum capacity due to limited laboratory space. We first present the submitted projects and afterwards discuss our experiences as well as the course evaluation given by the students.

A. Student Experiments

In total, eight projects had been worked on in 2022 and eight projects in 2023. An exemplary image of each is shown in Fig. 1. The projects were:

(a) 2022: a *Simon Says*-inspired light-up table game,
(b) 2022: a controllable warehouse unit with a magnetic crane,
(c) 2022: an automatic bar mixing unit for different drinks,
(d) 2022: a WiFi controlled light bulb that lights up when a specific smartphone is in range,
(e) 2022: a micro scale hazard and emergency warning system for buildings using lights in the floor for guidance towards emergency exits,
(f) 2022: a pair of houses that could communicate using Morse code using an LED and a light sensor,
(g) 2022: a line-follower robot car,
(h) 2022: a remote-controlled reloadable 2-shot confetti cannon for party locations such as clubs or concert halls with a fire extinguisher as a base,
(i) 2023: a *Micromouse* (maze-solving car),
(j) 2023: a person counting device based on the number of WiFi requests,
(k) 2023: a plant terrarium,
(l) 2023: a model car automatically finding an empty spot in a parking lot,
(m) 2023: a model garage using face detection for unlocking,
(n) 2023: a smart home containing different actors and sensors,
(o) 2023: a digital *guidepost* using RFID for guiding people, and
(p) 2023: a digital screen for booking rooms and displaying different information.



(a) 2022: light-up table game
(b) 2022: warehouse unit with a magnetic crane
(c) 2022: automatic bar mixing unit
(d) 2022: light bulb lighting up when specific smart phone is close
(e) 2022: fire alert and emergency guiding system
(f) 2022: morse code sender / receiver
(g) 2022: line following car
(h) 2022: confetti cannon
(i) 2023: Micromouse
(j) 2023: person counting device
(k) 2023: plant terrarium
(l) 2023: model car
(m) 2023: model garage
(n) 2023: smart home
(o) 2023: digital guidepost
(p) 2023: digital screen

Fig. 1: The experiments which were built by groups of two students each.

As a starting point, all student pairs had Arduino Starter Kits[3] available and could ask for other parts to be purchased, as mentioned above (see Sec. III-A). The students ordered a wide variety of parts, from additional Arduino sensors to LED strips and power supplies to a side table, which was used as the base for the *Light-up table game*. Other than the offered basic kits, the purchased parts, and the requirements for an artefact and documentation to be produced, the students were free to choose any project they desired (as long as it relates to building automation) and work on it in their own time, in their own way, leading to a wide variety of projects and a self-organised project phase.

[3]https://store.arduino.cc/products/arduino-starter-kit-multi-language, accessed 2023-01-23

B. *Parts Ordering Process*

Despite our best efforts, our process for material purchases needs to be overhauled. For the first iteration, we only gave students a budget without much of a framework, leading to a massive workload due to heterogeneous shopping lists covering a range of shops, which in turn caused much paper work for the staff and non-uniform delivery times.

Although we limited the number of shops the students could order from for the second iteration to shops that were known and reliable, we still had some problems. One major problem was that one shop did not have a (standard) battery in stock and made us wait with the whole order for over a week. Since we were able to buy that battery a normal grocery shop, this was quite annoying. In addition, some parts became out of stock between the time students selected them and the university employees trying to ordering them, resulting in additional time loss. Both problems delayed the ordering process and reduced the time students could actually work on their projects.

For future iterations, we want to investigate if we can just give the students a budget. Then, students can order on their own and we could reimburse them. While this seems like an easy way, we have three questions we still have to find answers for: What happens to students who could not afford the initial investment? What happens if a student overspends? And most importantly: How can we ensure that all regularities / laws are followed if students work on their own, e.g., students are able to produce proper invoices for all expenses?

C. Experiences from the Lecturer

From the perspective of the lecturer, the course was structured in two directions: bottom-up as well as top-down. The bottom-up part started with explaining the needed basics for all groups, giving all students a broad view on the subject area. However, this usually covers more ground than needed for the project phase in small groups, partly due to the fact that at that time the students did not yet decide which specific project they would like to work on. Furthermore, the students of this elective module originate from different study programmes, resulting in heterogeneous prior knowledge, which should first be homogenised. The bottom-up phase also offers insights into neighboring topic areas, such as in this case wireless networks, electronics, security systems, building floorplanning, and micro controller programming. This phase could be depicted as the question "*what can I do with...*".

In the top-down phase, the students have their actual task description in mind and thus come up with much more precise questions. In order to be helpful to all the teams of two students each which have different projects, the lecture then switched to a breakout session style, giving each team ample time with the lecturer to discuss upcoming problems or ask about clever ways to approach specific sub-tasks. For this, the weekly lecture time was dedicated for questions and discussions by appointment, i.e., the students "booked" a variable time slot to talk with the lecturer about their project. This phase can be interpreted as the question "*how can I achieve...*", which is much more focused on the outcome of specific projects.

The last phase of the course was the presentation of the project outcomes in a trade fair setting. All teams watched the other teams' built prototypes and results, and presented their own. This concluded the course a joyful manner.

The prior knowledge of the students was quite heterogeneous. Some students were experienced in constructing micro controller circuits from private home projects, while others only knew the pure basics from other lectures. The students formed mixed teams, though, so no team was completely inexperienced. In fact, most teams benefited from both members having different prior experience by splitting the tasks accordingly as well as sharing their knowledge.

Interestingly, several of the student teams did not make use of the possibility to have time with the lecturer to ask detailed questions in the second phase. Possibly, this is a result of starting very late due to having other assignments which were of higher priority at the time. In the end, some of the teams worked completely by themselves and had to cope with technical problems on their own. However, this might have had an even greater learning effect, since a problem found, identified, and solved by themselves usually teaches more than a description of a problem and solution in a lecture setting.

D. Feedback from Students

Students mentioned positively the project work in itself, how the project work would foster creativity, and that the project delivery had been a suitable examination form for the course (instead of, for example, a written exam). Positive responses also included communication with teaching and lab staff, work with microcomputers, and self-direction. The course structure found acceptance, with responses mentioning that the content was taught well and one could follow without much prior knowledge.

The negative responses can mainly be grouped into three categories. For one, the ordering process of the parts was not satisfactory. Additionally, the theoretical lecture part caught some negative feedback in the form of being perceived as both too condensed and too long without practical examples in between. Lastly, the students would have liked to have defined their project work earlier and with more specific instructions on goals. Starting the project earlier would serve to having more time to work on the project as well as a measure of buffering for part delivery times. Interestingly, starting the project work earlier might help mitigate some of the mentioned negative points. There would be both more time for parts to arrive and, given the lecture and the project are interwoven, the theoretical part might be perceived as less condensed due to the students being able to work on their project in between lecture sessions. However, this might also leave students without all knowledge they need for a self-directed project. Other negative responses mention coordination and lack of time due to setbacks.

Lastly, students mentioned take-away points which may be roughly grouped into four categories. Firstly, most students took away knowledge about micro controllers, especially working with Arduino, and C programming. There were mentions of wishing to learn even more about hardware components and a personal lack of required prior knowledge for the project. Additionally, some students came to the insight that working with micro controllers in a home automation context is more easily doable than they originally thought. The third category groups several mentions of good experiences and "life lessons" (e. g., one student made the discovery that hot glue is not waterproof), and the last category groups a handful of "other" responses like being sleep deprived or praise for the lecturer.

V. Discussion & Outlook

In this paper we presented a design for a required elective course on building automation utilising project based learning. We presented our interpretation of project based learning in

Sec. II. The actual course was described in Sec. III. In Sec. IV we describe the results of the course experiments.

In general, we can see that the course design worked quite well. The student responses were overall positive. Using project-based learning motivated the students to work on their own projects while not only getting building automation knowledge, but also getting important soft skills like teamwork or developing a working mindset. These are in our opinion two strong advantages project-based learning can add to any suitable course. We would therefore invite educators from other disciplines to try out project-based learning if it fits with the content of their course.

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