Flipped Classroom Concept for Industry 4.0 Pump Monitoring in Building Information Technology

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Abstract. The Flipped Classroom teaching concept has already proven itself in regular school and university teaching for some time. It is already regularly used for frontal teaching, lectures, seminars, and exercises at many universities. For some time now, practical laboratory courses and projects have become the focus of digitalization. Considering distance learning in particular, solutions must be found in this field. This paper describes the didactic concept, the technical background as well as the implementation of a flipped project in the master course Building Automation. It answers the research question: "How to design didactics and implementation of a practical laboratory project on the topics of information modeling, OPC UA and Self-X capabilities using the example of pump monitoring for realizing it as a flipped classroom teaching concept for master students of Building Automation?" To answer the research question, established concepts of didactics were combined with established and new technologies. On the didactic aspect, resources and methods such as explanatory videos in the form of screencasts, competency-oriented learning objectives of different taxonomy levels and group work according to the partner-ship model are used. Combining this with technological tools and concepts, such as a GitHub Repository as reader, task collection and forum, Node-RED as low-code environment, OPC UA, information modeling and Self-X as challenging content emphasis, results in a modern and demanding Flipped Classroom teaching concept. Evaluation, student feedback and conclusion show that even high complexity practical projects can be realized as a Flipped Classroom concept on the level of a master's program. Furthermore, the project can be replicated at any time and, thanks to the manual, can in principle be carried out by any teaching staff or even other laboratories. Further work must primarily address the potential for optimization in terms of organization and content, yet the abstraction of the described project to a meta-level is also conceivable.

Keywords. flipped classroom, project oriented, explanatory videos, competence orientation, OPC UA, information modelling, monitoring, dashboards, self-x
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1. Introduction

1.1 Initial Situation and Motivation

As part of the project phase of the Building Information Technology module of the part-time master's degree programme in Building Automation at FH Münster University of Applied Sciences and Biberach University of Applied Sciences, students develop requirement criteria for information technologies from an application perspective and can apply these independently to the technologies studied and document the main results. [2, p. 28]

To achieve this qualification goal, students carry out several supervised projects. However, the coronavirus pandemic from 2020 onwards has virtually disrupted the daily work and teaching routine at colleges and universities around the world. Classroom-based events have become rare and digital alternatives are being successively expanded. At the same time, however, teaching must not stand still, but must continue to be measured against technological developments.

New business models and integrated applications in industry are driving the use of information models and information modelling. Where data was previously seen as available anyway and not as a strategic business asset, there is now a paradigm shift towards valuing the information that is available. [3]

Industrial companies started to develop standardised information models a few years ago. This is often done in cooperation with or under the auspices of organisations such as the VDMA. The increase in standardised information models is particularly noticeable in the field of OPC UA. The VDMA now accompanies more than 30 working groups for the development of OPC UA Companion Specifications [4]. In 2020 and 2021, more than 20 companion specifications with concrete information models were published [5]. Currently, 13 more OPC UA Information Models are in their review phase as Release Candidates [6].

The developments in the fields of OPC UA and information modelling have not yet become part of building automation practice, but it is only a matter of when and not if. The integration of building technology into the process technology is already common practice, and the widespread use of information models and OPC UA will increase the demands on building automation accordingly.

The project described in this paper is the result of the circumstances previously outlined. Within the framework of a flipped classroom teaching concept, the building automation specialists of tomorrow learn important skills in forward-looking concepts such as information modelling and OPC UA. The merging of industrial and building technology is progressing inexorably. Engineers in building automation must be prepared for this.

2.1 Purpose

The project is intended to provide engineers within their master's degree programme with extended competences in the use of information models, OPC UA and the development of monitoring applications.

The paper describes the didactic concept and the technical implementation of the project as a flipped classroom teaching concept. It is intended to serve as an example for committed teaching staff in higher education to develop their own flipped projects for students. In addition, the project can also be implemented at other universities in other degree programmes if the technical requirements are met.

2. Research Methods

One of the defining methods of the project is the Flipped Classroom teaching concept. In preparation for the project work, the students work on basic competences with the help of explanatory videos and accompanying tasks.

However, it is common pedagogical knowledge that it is not enough to simply play films. [6, p. 138]

This method allows the brief attendance time to be put entirely at the disposal of practising and helping. In addition, small groups can emerge in advance, which support each other and thus strengthen the weaker students in particular [7, p. 117] - virtually integrated internal differentiation.

In practice, the combination of explanatory videos on YouTube and flipped lessons has proved particularly successful. The students are usually on the platform anyway, which eliminates the technological hurdle and the technical requirements for implementation are manageable, since perfectly produced, professionally edited, and brilliantly set to music content is not necessarily expected on a platform like YouTube [8, pp. 127-128].

The project work takes place in the partnership model and in small groups. The group work basically consists of additive and disjunctive tasks. The students come together independently in small groups of five people each. Although this procedure involves social risks, it can be carried out quickly and is feasible with a socially balanced group that is appropriate to the level of proficiency. [9, p. 85]

The group methods used are discussion in the whole group format and short presentations. At the beginning of the second day of the project, the students must decide together in a fixed time frame which data will be uploaded to the database and in which format. For this, a consensus must be reached, and a common understanding must be developed. The task sheet for the second part and instructions from the supervisor on the first day are used for preparation. [9, p. 96]

The short presentations serve as a form of examination. Students are given sufficient time on the second day of the project work to prepare for a 10-minute presentation without formal requirements. The structure of these short presentations should already be explained during the kick-off presentation by the supervisor, so that the students have sufficient opportunity to prepare. [9, pp. 98-99]

In addition to the integrated murmur phases [9, pp. 88-89], the method of the presentation [9, p. 87] by the supervisor is used at the very beginning of the project work. In this kick-off presentation, all details of the information model used, and the process of the project work are explained. In addition, an outlook on the expected result is given.

A specific survey via an online tool and a personal feedback round with the students are used to evaluate the success of the project.

To teach in a competence-oriented way, entry and target competences must first be defined. The entry competencies can be used to determine which skills the students need to bring to the project in order not to be overwhelmed by the entry tasks. This is because the use of didactic reduction is also limited and must not jeopardise the level of the course [9, p. 54].

The target competences are presented here in the form of the "Taxonomy Table" according to Anderson et al [10]. Thus, the learning objectives are classified in the taxonomy levels and the knowledge dimensions.

Since some topics are close to computer science, in addition to the usual operators, some of the operators defined by the Ministry for School and Further Education of the state of North Rhine-Westphalia for the subject of computer science [11] are also used.

3. Project Description

3.1 Required Skills

Since the target group is master's students in the second half of their programme, the entry-level competences can be set on a high level. It should be noted, however, that the content of the project was not necessarily part of the students' previous education and thus differentiation is required depending on the topic.

Generally, the competences in the following section are expressed as learning objectives.

Before the start of the preparatory phase of the project, the students must already possess the following skills:

The students ...

- ... know the monitoring application Grafana, name the basic functions and navigate the user interface.
- ... explain the HTTP REST methods GET and PUT, dissect and modify complex requests and construct simple requests themselves.
- ... analyse XML files and complete their content with further elements and values.
- ... explain the concept of the asset administration shell and model simple information models, both technology-neutral and according to the meta-model of the asset administration shell.
- ... analyse the OPC UA meta-model and name the function of the OPC UA namespaces.
- ... describe the principles of object-oriented programming and evaluate the benefits for automation technology.
- ... describe how Modbus RTU works and create any queries of the Modbus register.

Due to the internal differentiation and the possibility of mutual exchange, it is not mandatory that all students already have these competences at the beginning of the project - developing these competences during the project, however, is essential.

3.2 Goals

As mentioned at the beginning, the target competences are mapped in the form of the taxonomy table. For the learning objectives, tasks and examinations, a coding of designation and number is used in order not to overload the table and thus keep it clear.

The students ...

Goal 1: ... explain the context of the tools used.

Goal 2: ... use the AASX Package Explorer to model an asset administration shell with sub models and sub model elements.

Goal 3: ... parameterise a BaSyx AAS Server.

Goal 4: ... explain the data flow from Modbus to AAS Server.

Goal 5: ... design a Node-RED flow to read data from an XML file and write it to a BaSyx AAS Server.

Goal 6: ... conceptualise a cyclic query/write routine in Node-RED.

Goal 7: ... apply NodeOPCUA to create a simple OPC UA server.

Goal 8: ... modify an OPC UA server and extend it with additional data types.

Goal 9: ... model OPC UA models with the UaModeler program.

Goal 10: ... construct OPC UA namespaces.

Goal 11: ... parameterise the OPC UA Logger to load data into an InfluxDB database.

Goal 12: ... evaluate data regarding their usefulness in monitoring applications.

Goal 13: ... design a monitoring application based on a common data set.

Goal 14: ... define the requirements for a smart pump.

Goal 15: ... compare OPC UA with similar technologies.

Goal 16: ... assess the self-x capabilities of the components used.

3.3 Taxonomy Table

The competence levels of the individual project elements can be clearly identified using the taxonomy table shown here. The focus in the cognitive process dimension is clearly on 6. Create. In the knowledge dimension, there is an even spread across conceptual and action knowledge. Only one learning objective is allotted to metacognitive knowledge.

Tab. 1 – Taxonomy Table referencing the project goals

	1	2	3	4	5	6
A		4	7		14	13
B		1	11	8 1	12 16	5 10 13
C			2 3			6 9
D					16	

3.4 Teaching Material

All tasks of the teaching material are designed according to the quality criteria that they are challenging, solvable and authentic [9, p. 70]. In particular, the tasks accompanying the explanatory videos are demanding and often expect the students to transfer their knowledge. In addition, in terms of internal differentiation, some tasks can only be solved through the students' commitment and willingness to research.

For the preparation, students have nine explanatory videos at their disposal, which they can replay, pause, watch faster or slower, depending on their personal needs [12, p. 17].

All the explanatory videos belong to the screencast category. As they are mainly demonstrations of software products and web applications, with accompanying explanations, this is the common style [13, p. 13]. Generally, they are simple and quickly produced and give precise instructions for otherwise complex actions [12, p. 26]. To get started, the technical requirements are manageable and can be easily and inexpensively extended to produce professional-looking screencasts [8, pp. 128-129].

Christian [14] also describes that flipped classroom concepts with explanatory videos and accompanying tasks work well and can even put learners in a "learning-by-teaching" [14, p. 132] situation.

In addition, a GitHub repository is available to the students, which assumes the role of a Reader in the didactic context. After the effort of creating such a compendium, all information about the project is available to the students in a central and well-organised place. This makes it clear what the contents of the project are, what is expected in the preparation and how the students can prepare. [9, p. 68]

To achieve an internal differentiation already in the preparation, all tasks have a Hints and a Tips section. The hints are mainly technical or organisational hints, whereas the tips are intended for students who need help to solve the tasks.

The Issues section allows students to use the repository as a forum. Students are encouraged to help each other and ask questions if they encounter problems. [9, p. 69]

After the kick-off presentation, during the project work, students are given two worksheets. Basically, each of the two parts consists of only one task, which is specified by mandatory characteristics. In addition, both task sheets contain technical and organisational hints. The students will have to do without tips here, since the internal differentiation during the project work is exclusively achieved through the group dynamics as well as assistance from the supervisor.

Task 1: Create an OPC UA server with static and process data based on the information model provided and the data of your pump.

Task 2: Create a dynamic dashboard in Grafana and visualise static and process data of all pumps.

The project result of the individual groups is primarily examined in the form of a short presentation. The students must summarise their project in a maximum of 10 minutes and present the final dashboard. The presentation is followed by a question-and-answer session and discussion. In addition, the technical execution of the tasks will be assessed. During the students' presentation, a simple evaluation grid is used [9, p. 141]. This is then translated into points.

3.5 Technical Implementation

Currently, the test stand is equipped with four liquid pumps, manufactured by KSB, Grundfos, Wilo, and Spandau Pumpen, as well as a vacuum pump by Gebr. Becker, and a turbo vacuum pump by Leybold. The pumps are not connected to any media circuit and therefore cannot be operated normally. The pumps and the corresponding accessories were kindly provided by the respective manufacturer for the test stand. Figure 1 shows the layout of the pumps on display.

Fig. 1 – test stand front view

The cabinet below contains a router, a switch, and six Raspberry Pis. The router connects to the external (university) network or the internet, while the switch connects to the internal demonstrator network. For each pump, a Raspberry Pi is provided, which serves as an extended embedded controller. Node-RED, an AAS Server, an OPC UA Server, and the OPC UA Logger all run here. Together, the Raspberry Pi and the pump form the industry 4.0 component.

3.6 Guide

The project is essentially divided into two parts - preparation and project work. The preparation should be carried out by the students in the run-up to the presence part, the project work. Whether this is done at home or at the university is up to the person carrying out the project.

A GitHub repository with tasks, explanations and explanatory videos on YouTube serves as preparation for the students. The tasks are intended to help develop the necessary competences for the project work. Four tasks with the focus on Node-RED, AAS, REST, OPC UA, InfluxDB, Grafana and dynamic dashboards are to be completed. There is no performance review or submission of the preparation. It must be made clear to the students that preparation is essential for the project work and that successful completion is not possible without sufficient preparation.

The explanatory videos are intended to illustrate the steps necessary to solve the tasks by means of an example. They do not represent a sample solution for the tasks. The students must be aware that simply working through the videos does not lead to the necessary acquisition of competences. Students should be encouraged not to write project-related questions or comments in the comments under the YouTube videos and instead use the Issues section of the GitHub repository. The comments section can be used if the comments are related to the video only.

The explanatory videos use an example to illustrate the necessary steps to solve the tasks, but do not provide the complete solution for the tasks. Students must be aware that simply watching the videos does not lead to the necessary acquisition of competences.

The project work takes place in the laboratory and uses the test stand, several laptops, and an external server as work equipment. Through the preparation, the students have acquired all the necessary competences for carrying out the project work and are able to perform the project work independently. In this scenario, the teacher is responsible for responding to the students' questions and giving decisive advice on how to solve the respective work step.

In principle, all project steps build on each other and deviations are only possible in specific cases. The person carrying out the project should make sure that no group falls too far behind and, if necessary, provide targeted support. However, except for selected moments, individual steps should not be completely prescribed, or the standard solution should not be provided.

3.7 Scoring

The scoring of the results should be based on the three core elements presentation, dashboard, and technical realisation. Furthermore, the assistance provided should be considered. The teacher does not have to keep a tally of the assistance provided but should bear in mind how extensive the assistance was for individual groups and take this into account in relation to the result. In this context, (partial) model solutions should be considered severely. Thorough preparation enables all students to work on the project without a model solution; accordingly, the need to provide model solutions suggests that no thorough preparation has taken place.

The teacher should also make sure that the whole group works together and that individual group members do not just float along. In case of doubt, this can also be clarified through dedicated group discussions. Under certain circumstances, a devaluation of individual group members may come into question. However, this should be treated with caution, as it can be difficult to evaluate the group dynamics from the outside.

4. Discussion

The project has already been carried out in real operation and evaluated. From the evaluation, the direct feedback of the students and the achieved results, some aspects for improvement could also be identified.

The aim of developing a project that is suitable for familiarising students with the practical application of information modelling, OPC UA, and dynamic dashboards with the self-x concept can be regarded as fulfilled. Thanks to the methods used, the flipped classroom teaching concept made it possible to develop and implement a challenging but also supportive project. Based on the evaluation and direct feedback, the students are subjectively satisfied with the competences they have acquired and have been able to expand their knowledge in these forward-looking areas.

Many planned aspects and processes could be implemented accordingly in practice. For example, the GitHub repository and YouTube videos were used intensively for preparation. The Issues section of the GitHub repository was also used by the students to clarify open questions. However, mutual support between students could not be observed here.

Thanks to the preparation, the students were able to complete the project work largely independently in their groups. Assistance was required mainly because of certain technical issues in the concrete implementation and the difference between the setup at home and the test stand.

The final presentations of the students made it clear, that the topics were largely understood, and most of the goals (see 3.2) were reached. In this first run of the project, only the aspect of self-x capabilities was not fully understood by the students and could therefore only be presented in its broad outlines.

Additionally, through process-oriented assessment during the project work, the person carrying out the project can objectively assess the individual progress and goal fulfilment of each learner.

To evaluate the results objectively during the project work and final presentations, the examiner can use an assessment form like the one shown in chapter 7.

Even though a high workload was basically intended, certain aspects took up more time and prominence than originally planned. Accordingly, the greatest potential for improvement lies in optimising the time schedule.

In summary, the resulting project represents a solid foundation for further development. Some elements need to be revised or refined, but the basic concepts, the methods used, and most of the technical solutions can be retained.

To further verify the projects effectiveness, case studies from its implementation must be conducted.

5. Conclusion

The project demonstrates that the well-tested flipped classroom teaching concept can be used for project-based work in addition to the usual application for lectures or traditional frontal teaching.

However, it is important that the learners are supported in their competence development through an intensive preparation phase with explanatory videos, tasks, and on-demand support from the teacher.

The project also shows that even complex and partly foreign subjects can be successfully dealt with in such a concept.

The results of the first run of the project have shown, that even during times of distance learning, and for distributed programs such as the Building Automation program in particular, the flipped-classroom teaching concept is an effective alternative to more conventional methods – even for project-oriented courses.

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7. Assessment Form

This assessment form can be used by the examiner for scoring during the process-oriented assessment, and the final presentations. Most indicator complete the sentence "The learners …".

Goal	Indicators	not met	partially met	fully met	exceeded
#1	… showcase the used tools and how they interact with one another.	0	1	2	3
#2	… use the AASX Package Explorer to model an asset administration shell.	0	0.5	1	1.5
	… showcase their asset administration shell and its sub models.	0	0.5	1	1.5
#3	… achieve a working BaSyx AAS Server.	0	1	2	3
#4	… show the data flow from Modbus to AAS either exemplary or using a concrete value.	0	1	2	3
#5	… achieve a working Node-RED flow.	0	0.5	1	1.5
	… describe their flow and what design decisions they made to accomplish the goal.	0	0.5	1	1.5
#6	… show live data from the pump at the output of Node-RED or in the final dashboard, without manual refreshing the flow or data.	0	1	2	3
#7	… show a working OPC UA Server.	0	1	2	3
#8	… use the provided tools to customize the OPC UA servers source code.	0	0.5	1	1.5
	… showcase challenges they faced during the implementation of all required data and how these challenges were overcome.	0	0.5	1	1.5
#9	… use UaModeler to model an OPC UA information model.	0	0.5	1	1.5
	… showcase their OPC UA information model in UaModeler or by using screenshots of the software.	0	0.5	1	1.5
#10	… show their used namespaces and have created at least one additional namespace for their information model.	0	1	2	3
#11	… use the provided tools to customize the OPC UA Logger source code.	0	0.5	1	1.5
	… show live data in the dashboard and explain the usage of OPC UA Logger.	0	0.5	1	1.5
#12	… showcase the final dashboard and account for used and unused variables during the project work or Q&A portion of their presentation.	0	1	2	3
#13	… showcase the monitoring applications of their dashboard.	0	0.5	1	1.5
	… account for the data points collected in the common data set.	0	0.5	1	1.5
#14	… list common properties of smart pumps and describe delimiting properties to pumps.	0	1	2	3
#15	… state similar technologies and describe common as well as distinctive features of the selected technologies.	0	1	2	3
#16	… define self-x as a concept.	0	0.3	0.6	1
	… list and describe self-x capabilities.	0	0.3	0.6	1
	… assess if and to what degree the used components can be described as self-x (capable) components.	0	0.3	0.6	1
The learners required no additional assistance.		-10	-5	0	0
Completeness		0	2	4	6
Comprehensibility, technical terms, factual accuracy		0	3	8	13
Eye contact, body language, speaking loudly and clearly, pace		0	1	2	3

Total score:

Score	70-68	67-64	63-61	60-57	56-54	53-50	49-47	46-43	42-40	39-35	34-0
Grade	1.0	1.3	1.7	2.0	2.3	2.7	3.0	3.3	3.7	4.0	5.0

Grade:

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