Pilot 3 report and final pilot report

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Glossary

IoT: The Internet of things (IoT) is a system of interrelated computing devices, mechanical and digital machines (see https://en.wikipedia.org/wiki/Internet_of_things)
Moodle: Moodle is a free and open-source learning management system (LMS) (see https://en.wikipedia.org/wiki/Moodle)
Slack: Slack is a proprietary business communication platform developed by American software company Slack Technologies (see https://en.wikipedia.org/wiki/Slack_(software))
Python: Python is an interpreted, high-level, general-purpose programming language (see https://en.wikipedia.org/wiki/Python_(programming_language))
HH: Haaga Helia University of Applied Sciences
LEI: Leiden University
TUD: Delft University of Technology
UTN: University of Trento

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D6.4 Final pilot report

Summary

In the IoT Rapid-Proto labs, student learning labs have been implemented as a part of course curricula on IoT. In these learning labs, students work on authentic tasks to enhance both their domain-specific skills and knowledge as well as generic competences, such as creativity, collaboration skills and problem-solving skills. This student learning supports project-based learning in higher education. From a literature review, four domains of learning outcomes of project-based learning have been extracted: cognitive outcomes (knowledge and cognitive strategies), affective outcomes (perceived benefits and experiences), behavioral outcomes (skills and engagement) and artifact performance. Various ways of measuring these learning outcomes have also been identified. Following the literature review, the projects and courses on IoT of the IoT Rapid-Proto labs project were evaluated. These were called pilot projects. In four rounds, 13 pilot projects have been evaluated, some of them twice or three times after some redesign based on the evaluation of the previous instance. The evaluation data mainly consist of interviews with teachers and students.

In general, the students were satisfied with the courses and the projects. They liked the complex authentic tasks as this gave them some idea of what to expect in later professional career. Yet in some courses, these complex authentic tasks were evaluated by some students as too difficult and they needed more direction of what to do. Although in most pilots the tasks were extracted from professional practices, companies were not directly involved (e.g. by the assessment or by providing feedback), with one exception. In that latter course, the students presented their results for the 'client', which added the benefit of having a real client, but also the difficulty of what could be expected from the company. The international collaboration between students and teachers from the three partner countries that carried out the pilots was limited to the asynchronous data flow from one party to another.

Implications for future implementation of student learning labs include that a balance should be found between student autonomy and collaboration, on the one hand , and clarity about expectations what students should do, on the other hand. Related to this issue, the level of complexity and authenticity might increase with the ability level of student, providing more complex authentic problems in the final year of the bachelor programme or in the master programme. Another implication is that in order to implement student learning labs that are multidisciplinary, teachers from the different domains should form their own learning lab to design the tasks and curriculum of the student learning labs. These teacher learning labs might be even more important in multidisciplinary student learning labs with students from different countries and cultures.

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1 Introduction

In higher education, both generic competences (i.e. 21st Century Skills) and competences specific for the STEM domain (e.g., particular designing, programming and prototyping skills) require different educational setups compared to traditional teacher-centered ways of learning. One promising way and commonly used in design and technology studies is the use of student labs, which are small groups of students working together on solving authentic problems and producing solutions within a limited time period, imitating professional practice of design and technology workers. These student labs can provide an optimal learning environment to prepare students as future workers building on two main principles. First, these labs can be designed as authentic learning environments that simulate qualities of the future workplace. Second, these labs can enhance particular student competences the labor market requires, in terms of both generic competences and competences specific to the STEM domain. These student learning labs mentioned are the main part of courses on IoT implemented and evaluated in the Rapid Proto Labs project. These student labs and the IoT course as a whole are evaluated in four so-called pilot rounds. The main research question in these pilots is formulated as

> "How do students and teachers perceive the quality of the IoT courses in terms of students' motivation, engagement, learning outcomes and satisfaction?"

In this final pilot report we will present the findings from the evaluation of the pilots in round 1, 2, 3 and 4. In Table 1, we provide an overview of the courses evaluated in this project (see also https://www.rapidprotolabs.eu/projects/) and whether these can be understood as a disruptive innovation. Disruption is a sudden break or interruption. Disruptive education, therefore, disrupts established practices, often starting with a small number of users, but growing over time to the extent that they displace previously dominant, incumbent educational practices. It means that disruptive intends to break with the established model to improve the existing one (cf., Flavin, 2012).

Table 1. Overview of the 13 pilot projects evaluated in the IoT Rapid-Proto Labs projects.

	Partner	Pilot 1	Pilot 2	Pilot 3	Pilot 4
Connected products	TUD			X	
Smart waste bin	HH		X		
Smart wheelchair	TUD	X	X		
Cafetaria queue monitoring	HH	X	X	X	
Smart display*	HH		X		
Machine learning	TUD		X		
IoT Experimental course*	HH				
Swarm of drones monitor air quality*	UTN		X	X	
Intelligent IoT device for pest detection in precision agriculture*	UTN		X	X	
IoT-powered flower pot	HH			X	
Gamified dental brace*	HH			X	
Dementia patient monitoring*	HH			X	
Preventing COVID-19 contagion through anonymous contact tracing*	HH/UTN			X	X

Note. This table only includes the courses on which evaluation data have been collected. *means that these course can be understood as disruptive education following the definition described above.

Student learning labs of the IoT Rapid-Proto Labs can be understood as a way to deliver project-based learning in higher education. Therefore, we summarize the results of a literature review on outcomes of project-based learning in higher education, before we go into the evaluation of the pilots.

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2 A review of outcomes of project-based learning in higher education

Project-based learning (PjBL) refers to an inquiry-based instructional method that engages learners in knowledge construction by having them accomplish meaningful projects and develop real-world products (Brundiers & Wiek, 2013; Krajcik & Shin, 2014). Krajcik and Shin (2014) indicated six hallmarks of PjBL, including a driving question, the focus on learning goals, participation in educational activities, collaboration among students, the use of scaffolding technologies, and the creation of tangible artifacts. Among all these features the creation of artifacts that solve authentic problems is most crucial, which distinguishes PjBL from other student-centered pedagogies, for example, problem-based learning (Blumenfeld et al., 1991; Helle et al., 2006). This creation process requires learners to work together to find solutions to authentic problems in the process of knowledge integration, application, and construction. Instructors and community members (e.g. clients), normally as facilitators, provide feedback and support for learners to assist their learning processes.

2.1 Overview of the studies

A literature search have been conducted on studies published until September 2019. This resulted in a list of 76 journal articles selected for inclusion. More details about the methodology of this literature review can be found in Guo, Saab, Post, & Admiraal (2020). In Table 2, we give an overview of these 76 articles in terms of the learning outcomes addressed and ways of measuring these outcomes.

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Table 2. Studies coded by research design, data collection time point, student learning outcomes, and measurement instruments.

	Source	Research design			Data collection time point			Cognitive outcomes		Affective outcomes		Behavioral outcomes		Artifact performance			Measurement instruments							
		One-group	Comparative-group																					
			Comparative	Control	Pre	During	Post	K	CS	Pe(b)	Pe(e)	S	E	P	D	M	Q	R/T*	I	T*	J	R/L*	O*	A*
1.	Affandi & Sukyadi, 2016			x	x		x			x					x*			x	x					
2.	Alsamani & Daif-Allah, 2016			x	x		x	x*												x				
3.	Assaf, 2018	x					x			x	x					x*	x	x						
4.	Balve & Albert, 2015	x					x				x						x							
5.	Barak & Dori, 2005			x	x		x	x*	x*		x						x		x	x		x		x
6.	Başbay & Ateş, 2009	x					x				x								x					
7.	Beier et al., 2019			x			x			x							x							
8.	Belagra & Draoui, 2018			x	x		x			x							x							
9.	Berbegal-Mirabent, Gil-Doménech, & Alegre, 2017	x					x				x	x*					x	x						
10.	Biasutti & EL-Deghaidy, 2015	x					x		x								x							
11.	Bilgin, Karakuyu, & Ay, 2015			x	x		x	x*		x							x			x				
12.	Botha, 2010	x					x			x	x						x							
13.	Brassler & Dettmers, 2017			x	x		x					x					x							
14.	Brennan, Hugo, & Gu, 2013	x			x		x			x							x							
15.	Çelik, Ertaş, & İlhan, 2018	x			x		x	x*		x							x			x				
16.	Chua, 2014		x		x		x	x*		x		x*		x*			x	x		x				
17.	Chua, Yang, & Leo, 2014		x		x		x	x*		x		x*		x*			x	x		x				

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	Source	Research design			Data collection time point			Cognitive outcomes		Affective outcomes		Behavioral outcomes		Artifact performance			Measurement instruments							
		One-group	Comparative-group: Comparative	Comparative-group: Control	Pre	During	Post	K	CS	Pe(b)	Pe(e)	S	E	P	D	M	Q	R/T*	I	T*	J	R/L*	O*	A*
18.	Costa-Silva, Côrtes, Bachinski, Spiegel, & Alves, 2018			x	x		x	x		x							x							
19.	Cudney & Kanigolla, 2014	x					x			x			x				x							
20.	Dauletova, 2014	x					x				x						x							
21.	Davenport, 2000	x					x			x	x						x							
22.	Dehdashti, Mehralizadeh, & Kashani, 2013	x					x				x						x		x					
23.	Dzan, Chung, Lou, & Tsai, 2013	x					x			x							x							
24.	Frank & Barzilai, 2004	x				x	x				x				x*		x	x	x		x			
25.	Frank, Lavy, & Elata, 2003	x					x			x	x								x					
26.	Fujimura, 2016	x				x	x						x*						x		x	x		x
27.	García, 2016	x			x		x	x									x							
28.	Genc, 2015	x			x		x			x							x		x					
29.	Gülbahar & Tinmaz, 2006	x					x				x						x		x					
30.	Hall, Palmer, & Bennett, 2012	x			x		x				x						x							
31.	Helle, Tynjälä, Olkinuora, & Lonka, 2007			x	x		x		x	x							x		x					
32.	Heo, Lim, & Kim, 2010	x					x		x*									x						
33.	Hogue, Kapralos, & Desjardins, 2011	x					x			x							x							

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		One-group	Comparative-group: Comparative	Comparative-group: Control	Pre	During	Post	K	CS	Pe(b)	Pe(e)	S	E	P	D	M	Q	R/T*	I	T*	J	R/L*	O*	A*
34.	Hou, 2010	x					x						x*									x		
35.	Hou, Chang, & Sung, 2007	x					x		x*									x						
36.	Iscioglu & Kale, 2010	x					x			x									x				x	
37.	Karaman & Celik, 2008	x					x			x	x						x							
38.	Katsanos, Tselios, Tsakoumis, & Avouris, 2012			x	x		x	x									x			x				
39.	Kettanun, 2015	x			x		x	x*		x								x	x					
40.	Koh, Herring, & Hew, 2010	x					x						x*									x		
41.	Lee, 2015	x					x				x			x*			x	x						
42.	Lima, Carvalho, Flores, & Van Hattum-Janssen, 2007	x					x				x						x							
43.	Lucas & Goodman, 2015	x			x		x	x									x							
44.	Luo & Wu, 2015	x			x		x	x									x							
45.	Mahendran, 1995	x					x				x						x							
46.	Mohamadi, 2018		x	x	x		x	x*												x				
47.	Mou, 2019	x					x			x									x					
48.	Musa, Mufti, Latiff, & Amin, 2011	x					x			x	x						x							
49.	Mysorewala & Cheded, 2013	x					x			x	x						x							
50.	Ngai, 2007	x					x				x						x							

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Source	Research design			Data collection time point			Cognitive outcomes		Affective outcomes		Behavioral outcomes		Artifact performance			Measurement instruments							
		Comparative-group																					
	One-group	Comparative	Control	Pre	During	Post	K	CS	Pe(b)	Pe(e)	S	E	P	D	M	Q	R/T*	I	T*	J	R/L*	O*	A*
51. Ocak & Uluyol, 2010	x					x			x							x							
52. Okudan & Rzasa, 2006	x					x			x	x						x		x					
53. Papastergiou, 2005	x			x		x			x	x					x*	x	x						
54. Poonpon, 2017	x					x			x	x								x					
55. Rajan, Gopanna, & Thomas, 2019	x					x								x*			x						
56. Raycheva, Angelova, & Vodenova, 2017	x					x				x						x							
57. Regassa & Morrison-Shetlar, 2009	x			x		x	x*		x									x	x				
58. Rodríguez et al., 2015			x	x		x	x		x		x					x							
59. Sababha, Alqudah, Abualbasal, & AlQaralleh, 2016	x					x			x							x							
60. Sadeghi, Biniaz, & Soleimani, 2016			x	x		x					x*								x				
61. Seo, Templeton, & Pellegrino, 2008	x			x		x	x		x							x							
62. Stefanou, Stolk, Prince, Chen, & Lord, 2013			x	x	x	x		x		x						x							
63. Stozhko, Bortnik, Mironova, Tchernysheva, & Podshivalova, 2015			x			x		x*									x						
64. Terrón-López et al., 2017	x					x			x							x		x					

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	One-group	Comparative-group																					
		Comparative	Control	Pre	During	Post	K	CS	Pe(b)	Pe(e)	S	E	P	D	M	Q	R/T*	I	T*	J	R/L*	O*	A*
65. Thomas & MacGregor, 2005	x					x				x					x*	x	x						
66. Torres, Sriraman, & Ortiz, 2019			x	x		x	x							x*		x	x						
67. Tseng, Chang, Lou, & Chen, 2013	x			x		x			x							x		x					
68. Usher & Barak, 2018		x				x		x*						x*			x						
69. Vogler et al., 2018	x				x	x				x	x							x		x			
70. Wildermoth & Rowlands, 2012	x					x			x							x						x	
71. Wu, Hou, Hwang, & Liu, 2013			x		x			x*									x						
72. Wu, Huang, Su, Chang, & Lu, 2018			x		x	x			x	x	x					x							
73. Wurdinger & Qureshi, 2015	x			x		x					x					x		x					
74. Yam & Rossini, 2010		x			x				x	x						x							
75. Yang, Woomer, & Matthews, 2012	x			x		x				x						x							
76. Zhang, Peng, & Hung, 2009	x				x	x				x								x					
Totals	**54**	**5**	**18**	**30**	**8**	**74**	**17**	**9**	**37**	**31**	**9**	**4**	**3**	**5**	**3**	**54**	**17**	**21**	**10**	**3**	**4**	**2**	**2**

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2.1 Cognitive outcomes

2.1.1 Knowledge

In 17 studies, students' content knowledge, conceptual understanding, and course achievement were reported as outcomes of PjBL. For example, biological knowledge, such as cloning and DNA isolation (Regassa & Morrison-Shetlar, 2009), psychological knowledge relevant to healthy living habits and pressure management (Lucas & Goodman, 2015), and technical knowledge related to space engineering (Rodríguez et al., 2015), were investigated. Students' academic performance of programming course was measured in Çelik et al. (2018).

Four types of instruments (i.e. self-report questionnaires, tests, rubrics, and artifacts) were adopted to measure students' knowledge, in which self-reported questionnaires were most applied. Both Likert scales (e.g. Lucas & Goodman, 2015; Rodríguez et al., 2015; Torres et al., 2019) and qualitative questionnaires with open-ended questions (e.g. García, 2016; Luo & Wu, 2015) were adopted. For example, Katsanos et al. (2012) required students to evaluate their knowledge of web accessibility on a Likert scale from 1 (very low) to 5 (very high). Tests were the second frequently used tools to assess students' academic knowledge (e.g. Çelik et al., 2018; Katsanos et al., 2012; Mohamadi, 2018). For example, students' self-directed knowledge was measured by written tests with knowledge-based, application-based, analysis-based, and synthesis-based questions (Chua, 2014; Chua et al., 2014). In Regassa and Morrison-Shetlar (2009), concepts of biology were examined with a test with three multiple-choice and seven open questions. Only one study (i.e. Kettanun, 2015) measured students' course performance with rubrics. In this study, English learners' presentation was evaluated via six criteria, such as how authentic the words they used and how well they organized the facts and opinions. In another study, Barak and Dori (2005) evaluated students' understanding of chemistry via the analysis of their projects.

2.1.2 Cognitive strategies

Nine studies measured the cognitive learning strategies that students adopted in PjBL. For instance, students in Wu et al. (2013) adopted seven strategies, including remembering, understanding, applying, analyzing, evaluating, creating, and straying off-topic. Similarly, learners in Stozhko et al. (2015) also used seven strategies, which were divided into four levels, namely lower level (identification), basic level (knowledge and comprehension), middle level (application and analysis), and upper level (synthesis and evaluation). Both Heo et al. (2010) and Hou et al. (2007) identified students' five phases of knowledge construction, namely information sharing, disagreement detection, negotiation of meaning, modification of new ideas, and agreement statement. In the study of Helle et al. (2007), two cognitive processing strategies of students were investigated, namely relating (i.e. the connection of new knowledge to prior information) and structuring (i.e. the outline of a set of ideas).

Five types of instruments (i.e. rubrics/taxonomies, questionnaires, interviews, observation, and artifacts) were used to assess students' learning strategies, in which rubrics and taxonomies were most frequently adopted (e.g. Hou et al., 2007; Usher & Barak, 2018). For example, Heo et al. (2010) developed and used a grading rubric with several criteria, such as learners' understanding of the design value and their creativity. Both Stozhko et al. (2015) and Wu et al. (2013) adopted the revised Bloom's Taxonomy to assess students' cognitive strategies. However, they used different operationalization of this taxonomy. Other studies used questionnaires as the assessment tools (e.g. Biasutti & EL-Deghaidy, 2015). Stefanou et al. (2013) adopted a 7-point Likert scale, with statements indicating 1 (not at all true of me) to 7 (very true of me), to assess students' learning strategies. Nine subscales, such as the strategies of organization and self-regulation, were included. Helle et al. (2007) adopted both 5-point Likert scales and semi-structured interviews to investigate students' cognitive processing. Barak and

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Dori (2005) determined students' four levels of chemistry understanding by the analysis of students' projects, classroom observation, and student interviews.

2.2 Affective outcomes

The affective outcomes are distinguished into both evaluations by students about what they learned (i.e. whether PjBL was effective) as well as how they perceived the learning experience.

2.2.1 Perceptions of the benefits of PjBL

Thirty-seven studies reported the evaluations by students about what they obtained from PjBL. A number of studies explored students' perceptions of the improvement of content knowledge and skills (e.g. Affandi & Sukyadi, 2016; Botha, 2010; Costa-Silva et al., 2018; Cudney & Kanigolla, 2014; Dzan et al., 2013; Mou, 2019; Rodríguez et al., 2015). Some studies reported students' attitude (e.g. Genc, 2015), motivation (e.g. Terrón-López et al., 2017), and self-efficacy to the subject (e.g. Bilgin et al., 2015; Brennan et al., 2013; Costa-Silva et al., 2018; Ocak & Uluyol, 2010; Tseng et al., 2013; T.-T. Wu et al., 2018). For example, Assaf (2018) investigated the impact of PjBL through video creation on students' attitude towards English courses. Belagra and Draoui (2018) measured students' mastery orientation to the electronic power course after three-month PjBL. Beier et al. (2019) assessed students' perceived ability, skills, and motivation to master STEM courses. Helle et al. (2007) explored the impact of PjBL on learners' intrinsic motivation. Other benefits of PjBL that students perceived, such as the help with their horizon (H. C. Çelik et al., 2018) and future career (Beier et al., 2019; Papastergiou, 2005), were also reported.

Three types of instruments (i.e. questionnaires, interviews, and observation) were adopted, in which questionnaires were most frequently used. Both Likert scales (e.g. Assaf, 2018; Beier et al., 2019; Cudney & Kanigolla, 2014; Helle et al., 2007; T.-T. Wu et al., 2018) and questionnaires with open-ended questions (H. C. Çelik et al., 2018; Genc, 2015; Karaman & Celik, 2008; Ocak & Uluyol, 2010; Yam & Rossini, 2010) were adopted. Interviews, including unstructured interviews (Kettanun, 2015), semi-structured interviews (Frank et al., 2003; Genc, 2015; Helle et al., 2007; Poonpon, 2017), and focus groups (Okudan & Rzasa, 2006; Regassa & Morrison-Shetlar, 2009), were also used. Apart from questionnaires, classroom observation was also used (Iscioglu & Kale, 2010; Wildermoth & Rowlands, 2012).

2.2.2 Perceptions of the experience of PjBL

Thirty-one studies investigated students' feelings about PjBL. Several studies reported students' general feelings about PjBL (e.g. Assaf, 2018; Başbay & Ateş, 2009; Berbegal-Mirabent et al., 2017; Botha, 2010; Frank et al., 2003; Hall et al., 2012; Mahendran, 1995; Poonpon, 2017; Thornton & Scheer, 2012; Vogler et al., 2018; Yang et al., 2012). Some studies evaluated students' attitude towards PjBL (e.g. Barak & Dori, 2005; Frank & Barzilai, 2004; Y. M. Lee, 2015; Musa et al., 2011; Raycheva et al., 2017) and satisfaction with it (e.g. Balve & Albert, 2015; Dehdashti et al., 2013; Gülbahar & Tinmaz, 2006; Okudan & Rzasa, 2006). Several studies reported the difficulties that students encountered during the learning process (e.g. Dauletova, 2014; Davenport, 2000; Gülbahar & Tinmaz, 2006; Karaman & Celik, 2008; Lima et al., 2007; Mysorewala & Cheded, 2013; Papastergiou, 2005; Zhang et al., 2009). For example, T.-T. Wu et al. (2018) explored whether the adoption of an e-book system produced extra mental load and effort of nursing students during their course practice. Yam and Rossini (2010) investigated students' perceived challenges during the learning process in a property course integrated with the PjBL method. One study explored whether PjBL supports students' autonomy during learning activities (Stefanou et al., 2013).

Likewise, both questionnaires (e.g. Dauletova, 2014; Stefanou et al., 2013) and interviews (e.g. Dehdashti et al., 2013; Zhang et al., 2009) were adopted to measure students' experience. In addition, learners' experience was also measured by reflective journals in Frank and Barzilai (2004) and Vogler et al. (2018).

2.3 Behavioral outcomes

2.3.1 Skills
Nine studies explored both students' hard skills and soft skills in PjBL. Hard skills, such as marketing skills for students of hotel administration (Vogler et al., 2018), general care skills for nursing students (T.-T. Wu et al., 2018), EFL learners' writing skills (Sadeghi et al., 2016), and the skills of students of engineering management to decide where to locate public services in real-life situations (Berbegal-Mirabent et al., 2017), were reported. Besides hard skills, several soft skills were reported, such as skills of problem-solving and critical thinking (Vogler et al., 2018; T.-T. Wu et al., 2018; Wurdinger & Qureshi, 2015), collaboration and team working skills (Berbegal-Mirabent et al., 2017; Rodríguez et al., 2015; Vogler et al., 2018), and lifelong learning skills (Vogler et al., 2018; T.-T. Wu et al., 2018). For example, Brassler and Dettmers (2017) emphasized student problem-solving skills from three interdisciplinary perspectives: (a) considering and applying different views, (b) re-considering the strategies used, and (c) adopting discipline-based methods. Some phases to solve a scenario-based problem, such as problem identification, data collection and analysis, and backup plan design, were investigated in Chua (2014) and Chua et al. (2014).

Five types of instruments (i.e. questionnaires, tests, rubrics, interviews, and reflective journals) were adopted to assess students' skills, in which questionnaires were most adopted (e.g. Rodríguez et al., 2015; T.-T. Wu et al., 2018; Wurdinger & Qureshi, 2015). For example, Brassler and Dettmers (2017) used a self-reported scale which was adapted from previous research. Several development steps, including literature review, concept identification, focus group interview, items creation, pilot study, and revision, were used to revise the scale. Scenario-based tests were developed by instructors and used in Chua (2014) and Chua et al. (2014). In these studies, students' performance in applying strategies to solve problems related to industrial drying was assessed with tests. A rubric for assessing students' technical skills through oral presentations was adopted in Berbegal-Mirabent et al. (2017). Students' performance was evaluated by the content, comprehension, and style of the presentation and ranked in four levels (from advanced to inadequate). Also, Vogler et al. (2018) adopted both self-reflection journals and focus group interviews to assess learners' skills.

2.3.2 Engagement
Four studies focused on students' learning processes in PjBL. Learners' perceived engagement was reported in Cudney and Kanigolla (2014). Three aspects of students' engagement, i.e. the level of general involvement in the semester project, the degree of participation in class discussions, and whether they applied the course concepts to practice were investigated. In Fujimura (2016), the educational activities that students participated in during the whole project, such as making a research plan and collecting and analyzing the data, were explored. Moreover, the process of how students learned content knowledge was also examined. In D. H.-T. Hou (2010), learners' seven behavioral patterns, including project topic analysis, data collection, data evaluation, project content analysis, comprehensive analysis, comments proposal, and irrelevant information discussion, were explored. In Koh et al. (2010), five levels of student knowledge construction, namely sharing, trigger, exploration, integration, and resolution, were examined in both PjBL and non-PjBL activities.

A five-point Likert scale (from strongly agree to strongly disagree) with 23 questions was adapted from Yadav et al. (2010) and used to assess students' level of involvement in the semester project (Cudney & Kanigolla, 2014). Students' online discourse was recorded to get insight into their learning processes in D. H.-T. Hou (2010) and Koh et al. (2010). In Fujimura (2016), both student reflection journals and audio-recordings of discussions were used to determine their learning activities. Apart from these two instruments, three more instruments, namely the artifacts created by students, students' reflection journals, and focus group interviews with students, were also adopted to investigate student learning processes.

2.4 Artifact performance

Three types of artifacts (see Table 2.1), i.e. physical objects, documents, and multimedia were most frequently measured in ten studies reviewed. All products were assessed by rubrics. For example, Chua (2014) and Chua et al. (2014) assessed the dryers that students created by a 5-point rubric made by instructors. The grading criteria included, for example, original design and product quality. Papastergiou (2005) evaluated the website that students created by five criteria, including topic, content and aesthetics, pedagogy, technology, and usability. Rajan et al. (2019) assessed students' project reports by a 5-point rubric (from excellent to poor) for several writing tasks, such as literature review, analysis, and presentation. Torres et al. (2019) evaluated students' bid reports based on three aspects, including accuracy of report (40%), completeness of report (40 %), and neatness of report (20%).

2.5 Conclusion

This literature review has found four categories (cognitive, affective and behavioral outcomes and artifact performance) of learning outcomes of project-based learning in higher education. These four main categories have been subdivided into seven subcategories. Finally, for each outcome, various types of data collection and instruments have been summarized.

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3 Pilots round 1

3.1 Introduction

In this chapter, we describe the evaluation of the curriculum of pilot 1. First, we describe the evaluation of the Smart Wheelchair curriculum of TUD. This is only based on the experiences of a HH student who participated the course. Second, we focus on the evaluation of the Multidisciplinary Software curriculum of HH (Cafetaria queue monitoring). This is based on the evaluation data we have collected, including students' perception of the course, students' motivation in the course, and students' course performance. Last, discussion, suggestions, and conclusion will be presented. For the details of the settings of the two curricula of pilot round 1 please see D4.4 Interim Curriculum Report.

3.2 Evaluation of Smart Wheelchair curriculum of TUD

This course evaluation is revealed by the bachelor thesis of a HH student who participated the course and his teacher's comments on it. According to the student, the course was well-organized and the course instruction was clear. Several course objectives (i.e. knowledge acquirement; collaboration with engineers; integration of software method; selection and use of suitable tools) were shared with students at the beginning. The content knowledge and relevant concepts were also well-explained. In addition, three benefits of the course were reported: a) student's freedom to work at his own space and time; b) student's increase of content knowledge and skills; c) the development of student's ability to develop a similar prototype after the course.

Several difficulties that the student encountered were also reported: a) the development of smart wheelchair was challenging; b) the scaffolding technologies used in the course were not stable; c) the interactions with other students were limited; and d) teachers' feedback for students who worked online was not timely.

The teacher was not satisfied with the student's performance. The student only received a grade of 2 out of 5 because he was more focused on building the prototype of an IoT-wheelchair which should have been only a side result in his thesis. On the contrary, the student did not achieve the most important goal, i.e. the analysis of the collaboration process with others.

3.3 Evaluation of Multidisciplinary Software curriculum of HH

3.3.1 Evaluation materials and instruments

The evaluation data for this course was collected by several materials and instruments during and after the course. These included student motivation questionnaire, student and teacher interview, student self-reflection essay, student online discussion, and teacher comment about student performance etc. The instruments of questionnaire and interview were designed by researchers and other materials were provided by the teacher.

Student questionnaire of Learner Motivation in Project-based Learning Course consists of three parts: 1) background information; 2) scale of students' perception of PBL course; 3) scale of students' motivation in following PBL course. Student perception scale was adapted from previous studies of Standage, Duda, and Ntoumanis (2005) and Chen et al. (2015). This scale measured students' perceptions of autonomy, competence, and relatedness in this course. One example of items is "In this PBL course I feel certain freedom of action". Student motivation scale was adapted from the studies of Ratelle, Guay, Vallerand, Larose, and Senécal (2007) and Vansteenkiste, Sierens, Soenens, Luyckx, and Lens (2009). This scale measured students' intrinsic motivation, extrinsic motivation, and amotivation in following the current course. One example of items are "I am following this course because I am highly interested in doing this". Students were required to choose a number between 1 (completely not applicable) and 5 (very applicable) from the scale. Three open questions were also asked after each scale in order to get students' further feedback and opinions.

Student interview was designed mainly based on the results from the student questionnaire. In this way, we could explore the reason behind students' choices regarding their course perceptions and motivation. In addition, we also asked about students' their learning process, both the benefits and difficulties of the course, and their suggestions to improve the course in the future.

Teacher interview was designed to investigate the teacher's satisfaction with student performance in this course. Seven elements of PBL course from Kolmos, de Graaff, and Du (2009) were adapted for the interview. These elements included course objectives, driving questions of the final product, students' progression, students' collaboration, the role of the teacher, the use of educational technology, and course assessment etc.

3.3.2 Participants and data collection

Three students out of four responded the student questionnaire (with the consent letter) via the system of Qualtrics provided by LEI. Two of these three students agreed to participate in the follow-up interview. One of the researchers from EI interviewed them individually by Skype. Each interview took approximately 50 minutes. Before the interview, both students signed the consent letter for the student interview in Qualtrics.

One of the teachers of this course was interviewed by the same researcher by Skype. The interview took about 50 minutes. Before the interview, the teacher signed the consent letter for teacher interview in Qualtrics.

Other materials above-mentioned were provided by the teacher via emails.

3.3.3 Evaluation results

In general, students interviewed evaluated this course as a useful course which was better than other courses they took. The benefits of the course consisted of two parts. First, it provided students with a real working environment, in which students had enough space to achieve their innovation and could be responsible for themselves. Second, students learned new knowledge, practiced the way to do research, and improved their team working skills. Thus, their course-related confidence might have increased.

Two main difficulties were also reported by students. The biggest challenge of this course was the lack of clear task division. Thus, students did not know exactly which parts to work on, which may lead to their fluctuation in course motivation. Also, the whole course took approximately five months, which was too long for students to focus on.

3.3.3.1 Students' perceptions of the course

Students' perceptions of their autonomy during the course, competence to accomplish project tasks, and collaboration with peer students were revealed. In general, students felt much autonomy in different phases and the whole process of the course. They could choose any activities they liked to work on. They could also decide which solutions to implement and how to do that. Additionally, if there was something wrong, they were free to do changes to the original idea.

Students had different levels of competence to follow this course. One student reported little confidence and ability to complete project tasks. This was mainly because he was not familiar with the course itself and the solutions needed to work on. He also mentioned that the

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tasks were better to be done in a group rather than by the individual. On the contrary, another student reported a high level of confidence and competence to take the course. There were two reasons for this. First, previously he attended similar IoT courses and had some course experience. Second, although he had little confidence regarding coding, he had a lot of experience related to hardware, which made the coding even more interesting.

Overall, students were satisfied with the collaboration among group members. Their division of labor was clear. For example, one student worked mostly on hardware while others focused on software. They got along and communicated well with each other. They also supported and helped each other. For instance, if someone was stuck on something eventually everyone would concentrate on that, and then they would discuss and try to solve that problem. However, there were some difficulties with collaboration. The most serious one was group members' weakness with the project topics and techniques. Other problems included low attendance for group discussion and limited skills on time allocation and utilization etc.

3.3.3.2 Students' motivation in the course

The motivation in following this course of some students fluctuated during the learning process. At the beginning of the course, students were excited and enthusiastic about the IoT idea and equipment. Then the motivation of (at least) one student started to drop after about one month because he did not know what to do and felt that he could not contribute to the project as much as the beginning. Another student's motivation suffered towards the end when nothing seemed to progress. This might also because, according to the teacher, that the project was not like what the students expected and wanted to do as they have had less training for hardware in previous courses.

3.3.4 Students' course performance

According to the teacher, there were two important course objectives. First, students need to develop the ability to learn new programing related technologies. Second, they should learn how to define a project and divide the work among the group. The acquirement of content knowledge, however, was the least important aim of the course. Therefore, the teacher was not satisfied with student course performance as none of the most important course objectives were achieved.

Student performance was evaluated by five methods of assessment: a) teacher observation; b) teacher-student discussion; c) student self-reflection essay; d) student peer assessment; and e) final product performance.

3.3.4.1 Teacher observation and teacher-student discussion

During this course, the teacher mentored and assessed students' performance via his class observation and talked with students. He observed what and how students worked on the solutions for the project and discussed the problem they encountered. He also gave may hints and face-to-face instructions to the students, showed the process of solving problems, observed how well they adopted and applied those instructions to their work, and assessed their performance based on that. At the end of the course, the teacher and students had discussions about how far the students got and how well they worked and made an agreement about their course performance.

3.3.4.2 Student self-reflection essay

Student self-reflection essay consisted of seven parts. The first part required students to describe the aim of this project as they understood. All students thought the course aimed to implement a prototype of the queue monitoring system. However, as discussed earlier, this is

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students' misunderstanding of the aims of this course. The second and third parts asked students to describe what and how they did in each stage. In the fourth to sixth parts, students gave self-assessment based on what they did well and what could be done better. Most of them reported doing well at the beginning of the project by, for example, helping with technology. However, there were still needs to improve communication between team members. In the last part, they assessed their peers' performance.

3.3.4.3 Student peer assessment

Students gave each other a final grade from one to five at the end of the course as the assessment of the performance of their classmates. Some assessment criteria were given by the teacher in the online discussion forum: a) overall contribution to the project; b) availability and contribution to teamwork; and c) contribution to joint learning. However, these criteria were loose and weak as there were no specific instructions for grading. In addition, students interviewed formed different reasons for grading, which were mainly based on their perceptions and observations. For example, one student said "(I observe) what they did wrong and how they could be improved" and "were they active doing the classes". Another student used some criteria like "how much work they did" and "how much were they were trying to do". As a result, the scores of the peer assessment were different from and (much) higher than the grades that the teacher gave (4.3/4; 4.6/3; 3/2; 2.6/1).

3.3.4.4 Final product performance

The final product of this PBL course was a prototype of a queue monitoring system for cafeterias that required a lot of skills of both software and hardware. The main driving question behind this product was to find a way to train students to use new technologies. Another driving question was related to the real needs of the school cafeteria.

Since the feature of developing final products differentiates PBL from other forms of education (Blumenfeld et al., 1991; Helle, Tynjälä, & Olkinuora, 2006), it is vital to assess the final product that students created. It turned out that the teacher was not satisfied (grade 2.5 out of 5) with the queue system that students made. There might be two reasons for this. First, some students lacked competence in hardware skills because they haven't been trained for hardware in any previous courses. Second, at least one student reported that he joined this course with little background knowledge as the course did not require any of it.

3.4 Discussion and suggestions

The most significant finding from this evaluation was that there was a gap between the course aim that students achieved and the aims that the teacher wanted students to achieve. In specific, students reported the improvement of their content knowledge and skills, which from their perspective, was the most important course aim. Nevertheless, none of the three important course objectives that teacher believed, i.e. the analysis of the collaboration process, the ability to learn new technology, and the competence to define and divide problems, were achieved.

There might be three reasons for the gap. First, the course aims were not clear. There was a lack of specific sub-goals of each aim and feasible approaches to achieve it. Second, students lacked the competences to achieve the higher-order goals. This was demonstrated by, for example, students' little experience and training for both software and hardware. Third, the teacher interfered students' independent thinking. Although students should be encouraged to communicate with teachers, this, however, does not mean that the teacher should actively offer help to students before students ask for help (which was the case in the HH course).

Therefore, several implications and suggestions for the future are provided. First, the aims of future courses should be divided into specific and feasible sub-aims. In doing so, teachers

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could set criteria for each sub-goal and evaluate students' performance accordingly. It is suggested that teachers and researchers work together to achieve it. Second, students' prior knowledge needs to be checked and relevant course training should be provided to help them match the course aim. Third, teachers should be aware of their role in PBL courses. Instead of actively offering help, teachers could show their availability to students and work as a facilitator who assists the learning process of students (Gavin, 2011; Tseng, Chang, Lou, & Chen, 2013).

Possible solutions for other problems students encountered were provided: a) to make peer assessment more effective in future courses, clear and consistent criteria for peer assessment should be provided to students by teachers; b) in order to decrease the potential side-effects on students' course motivation, the duration of future courses can be considered shorten. A meta-analysis conducted by Chen and Yang (2019) and the study of Larmer, Ross, and Mergendoller (2009) recommended 2 to 5 hours implementation of PBL per week.

3.5 Conclusion

Overall, students were satisfied with the courses. They were interested in the real-world working environment and satisfied with peer collaboration. They also reported the improvement of their content knowledge and skills. However, the teacher was not satisfied with the students' course performance as he believed none of the significant course objectives were achieved. Future courses need to put effort to set clear course aims and improve students' competences.

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4 Pilot round 2

4.1 Introduction

In this chapter, we describe the evaluation of the curriculum of pilot round 2. The aim of this evaluation is to investigate both teachers' and students' satisfaction with the teaching and learning process and perceived student outcomes in the curriculum of pilot round 2. Background information (e.g. course settings) will also be explored to reach the research aim. Therefore, the evaluation data have been collected via individual interviews with both teachers and students from the projects of Smart Display, Smart Bin, and Smart Wheelchair and the courses of Machine Learning and Electronic Embedded System (Swarm of drones monitor air quality and Intelligent IoT device for pest detection in precision agriculture). In the following sections, the method, results, discussions and suggestions of the evaluation will be presented.

4.2 Method

The evaluation data for pilot round 2 was collected by individual interviews with both teachers/coordinators and students. All interviewees agreed to participate in the interview either with a consent letter or email agreement. Table 3 shows the overall information of the data collection.

Table 3 Overall information about the data collection for pilot round 2.

Interviewee		Data collection method	
		Semi-structured interviews (40-50 minutes via Skype)	Written interviews (Via Qualtrics)
Smart Wheelchair	Coordinator	√	
	Teacher 1	√	
	Student 1	√	
	Student 2	√	
Machine Learning	Coordinator	√	
Smart Display	Teacher 1	√	
	Student 1		√
	Student 2		√
	Student 3		√
	Student 4		√
Smart Bin	Teacher 1	√	
Electronic Embedded System	Techer 1	√	
	Student 1	√	

Note. One researcher from LEI conducted all interviews.

The interview was designed based on the seven fundamental elements of project-based learning curriculum in the study of Kolmos, de Graaff, and Du (2009). This was in line with the pilot 1 report (Guo, Saab, & Admiraal, 2019). Moreover, questions about teachers' and students' satisfaction with the curriculum were adopted: a) overall, what were you satisfied with this course, and why?; b) overall, what were you unsatisfied with this course and how to improve that? In short, the interviews focused on the following aspects of the courses/projects: 1) course settings; 2) course objectives; 3) final products; 4) teaching process (i.e. the role of teachers); 5) learning process (i.e. group work); 6) perceived learning outcomes; 7) difficulties during the teaching and learning; 8) satisfaction and dissatisfaction with the course.

Based on the content of the interviews, we have set up a matrix that involved all the information from the interview (e.g. Miles, Huberman, & Saldaña, 2014). Based on this matrix

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and the above-mentioned eight aspects, we summarized the similarities and differences in the main findings from the interviews. The main results are presented in the next section.

4.3 Results

4.3.1 Course settings

All courses were designed and implemented in a way of combining lectures/workshops and hands-on practices of prototyping. The lectures/workshops were adopted mainly to introduce theoretical knowledge and new assignments and discuss the assignments of previous weeks and answer students' questions. Hands-on practices were adopted to let the students implement the ideas of their prototyping. Students normally worked in groups of three to six people.

While teachers and researchers believe that educational technology is an important element of project-based learning (Krajcik & Shin, 2014), most teachings were done in a traditional way (e.g. Machine Learning). Smart Wheelchair and Smart Bin, for example, used a learning management system (Moodle and the system provided by the university). However, these systems were mainly used as a repository where teachers delivered course materials and distributed some information and students submitted their assignments. For the communication between teachers and students, in one course (i.e. Smart Wheelchair), Slack was used as a real-time communication medium to support teacher-student in-time interactions. In other courses, however, discussions between teachers and students were mainly achieved by face to face. Overall, educational technology was not integrated into teaching and learning.

4.3.2 Course objectives

The objectives of all courses/projects (see Table 4) can be categorized into cognitive objectives (e.g. knowledge) and behavioral objectives (e.g. skills). Regarding cognitive ones, students were expected to learn and understand the content knowledge of the course. Moreover, they were expected to understand how IoT products work and tell the differences between diverse technologies and explain the reason. In addition, they were expected to master the way of using prototyping tools and techniques. As for behavioral objectives, students were expected to develop in four aspects: 1) to acquire practical skills in developing products; 2) to be able to use and apply different methodologies (e.g. system modeling); 3) to learn how to work in teams and collaborate with peers. This included, for example, learning how to divide labors, how to work with unknown technologies, and how to solve problems together; 4) to learn how to work with clients, such as politely communicate with clients, understand the needs of clients, define the goals of clients, present the results to clients, and improve the products based on the feedback of clients and so on.

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Table 4. Main course objectives of each course/project.

Courses/projects	Objectives
Smart Display	1. Learning to work in a software project and build software in a team with unknown technologies. 2. Working in a team and solving problems in teams. 3. Learning to work with clients.
Smart Bin	1. Leaning to use innovation methodologies and produce prototypes. 2. Learning to use prototyping tools and techniques.
Smart Wheelchair	1. Students acquire practical skills in prototyping and developing a connected product. 2. Learning the competence of working as a team when it comes to software development. 3. Students are able to explain course concepts. 4. Students are able to make a working prototype and explain it to others.
Machine Learning	1. An introduction to machine learning and modeling of smart systems. 2. The application of different methods of modeling intelligent systems and system modeling to the case studies.
Electronic Embedded System	1. Practicing the theory and proving that a similar structure would be feasible. 2. Teaching students the way to design a program electronic device. 3. Students are able to solve problems and challenges and decide which technology is better and also demonstrate why it is better than another.

4.3.3 Final products

Overall, the performance of the final products that students created was not as ideal as expected. This was confirmed by both teachers and students. The prototype created in Smart Display was assessed as not working well and "not even close in many ways", which was more like a semi-finished coding product. Two third of the smart bin developed was evaluated as not ideal. A student from Smart Wheelchair also admitted the prototype did not work well and should be improved in many ways.

The evaluation of the quality of final products was mainly through the assessment of students' reports and course essays via grading rubrics made by teachers. In Smart Bin, there was a group outperformed other groups because this group performed well in the aspect of comping up with many new perspectives and ideas. However, there was a problem with this evaluation method mentioned by a teacher from Machine Learning, namely the grading can be fuzzy because it was difficult to confirm from reports what knowledge and skills were applied by students to the products.

4.3.4 The role of teachers

Apart from taking a traditional role, such as introducing course objectives, giving lectures, and presenting assignments to students, teachers also had diverse roles during the teaching. These included five aspects:

1. Creating suitable course materials. For example, at the beginning of Machine Learning, the teacher discussed with clients about how the project would be going. In so doing, all the relevant content knowledge was designed and presented in an easy way that makes sense to the students.
2. Finding students learning resources. For example, in Smart Bin teachers provided students with external resources like ready posters that students can use directly for their assignments.
3. Making up students' knowledge. For example, in Electronic Embedded System students joined in the course with different educational backgrounds. In order to help these students to compensate for the lack of their background knowledge, teachers provided them with relevant resources, such as online courses, books, and slides.

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4. Inspiring students to reflect. For example, teachers from Smart Wheelchair encouraged students to propose their own ideas and discussed and extended these ideas in a more open direction. In so doing, students perceived not only the coding itself, but higher things, such as rationales and theories, related to it.
5. Providing help for students' collaboration. Students often get stuck when they collaborated with peers during hands-on activities. They needed teachers' suggestions and feedback to go forward. For example, during a hands-on programming activity in Electronic Embedded System, the teacher was available for explaining and repeating the code that students did not understand. Sometimes, however, teachers did not bother the practices. For example, the teacher from Smart Bin did not step into students' problems but observed how would students do and end up the conflicts by themselves.

4.3.5 Group work of students

Several procedures of learning were adopted by students, particularly during hands-on activities. Generally speaking, at the beginning of the project, students searched the internet for the materials needed and the things that they did not understand. Afterwards, they had brainstorm sessions to discuss what problems they wanted to solve and which technologies could be used. Before dividing the labor, students tried to understand different skills and competences of each group member. In so doing, each member could take responsibility for different parts, which could lead to a shared responsibility to the development of the project. Basically, plans were discussed and decisions were made together by all group members. Sometimes students also gave and received advice from other groups. As for the implementation of the project, there was a lot of trial and error. Students needed to do a lot of testing to find out whether their ideas and prototype could work out. Therefore, much improvement was done based on the data that students got from the testing.

4.3.6 Perceived learning outcomes

Students' perceived learning outcomes (see Table 5) were categorized as cognitive, behavioral, and affective outcomes (e.g. Guo, Saab, Post, & Admiraal, 2020; Post, Guo, Saab, & Admiraal, 2019). Regarding cognitive outcomes, students learned theoretical content knowledge by taking the lectures, reading books, and writing the final reports and essays. In so doing, students got the insights into the whole picture of IoT products and had a deeper understanding of what IoT is. For the students who major in design, the projects opened their horizons and allowed them to understand how to connect design to a digital project. As for behavioral outcomes, students gained some skills, including teamwork skills, problem-solving skills, and the skills of leadership. They also improved specific technical skills through hands-on practices, such as embedded programming, physical debuggers, and Python. For example, students from Smart Display noticed the difficulties with communicating between smaller groups and improved during the project. The student from Electronic Embedded System mentioned that he developed the right way of approaching problems. That is, however, not something that students can get from only one course or project. For the student who was better at coding than other group members, she learned how to help and manage other people while not hurting their feelings during the Smart Wheelchair project. In terms of affective outcomes, students from Smart Display and Electronic Embedded System felt they were more independent in solving problems and more interested in group work. However, some students from Smart Bin were not actively involved in group work.

Table 5. Main students' perceived learning outcomes of each course/project.

Courses/projects	Perceived learning outcomes

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	Cognitive	Behavioral	Affective
Smart Display	• Content knowledge	• Skills of communicating with group members • Skills of using certain tools	• Being independent on problem solving as an individual
Smart Bin	• Content knowledge	• Skills of dealing with clients • Skills of presenting ideas	• Different levels of motivation for group work
Smart Wheelchair	• Content knowledge • The understating of how IoT system works. • Expanded horizons for designers	• Leadership skills • Skills of using certain tools	
Machine Learning	• Content knowledge • Personal insights into course concepts	• Skills of applying knowledge in a project	
Electronic Embedded System	• Content knowledge	• Skills of approaching to problems • Skills of working with different people	• Interests in collaborative learning

4.3.7 Difficulties of the courses

Several difficulties that teachers and students encountered during the teaching and learning are presented as follows:

1. Although there are innovative pedagogies that focus more on student-centered learning (e.g. flipped classroom), it is hard to adopt these methods as students need to learn fundamental content knowledge in detail.
2. As many of the projects are about new technology, the biggest difficulty for students was the lack of information. Although most of them searched the internet, they could not find a useful frame or references. Even when students found something that might help they could not understand because the knowledge was above their current level.
3. The background and the level of understanding of students are diverse. This makes it difficult for teachers to give guidance to the students who have knowledge gaps. It is also not easy for students to collaborate with team members with different knowledge.
4. Some group members (e.g. Electronic Embedded System) did not care about the project and presented details of life out of class. Some students (e.g. Smart Display) were not willing to collaborate with others.

4.3.8 Course satisfaction

In general, students were satisfied that they learned and understood many things related to IoT in a short period. They were also satisfied that the courses were designed in a way that is different from many theoretical courses they had. Moreover, although courses were not easy to follow, it constantly kept students growing and pushing them toward the next step. Students were also satisfied with the teaching. Overall, teachers gave lectures, tutorials, and suggestions about students' plans and presentations in an interesting and clear way. More importantly, teachers often encouraged students to explore their own ideas. As for the feelings of group work, students enjoyed the collaboration with others. This is a good way of exchanging knowledge with others and you can improve faster.

4.4 Discussion and suggestions

The courses/projects implemented in pilot round 2 were evaluated by research interviews that were designed based on the key elements of project-based learning (Kolmos et al., 2009). The results showed that students were generally satisfied with the course. The course settings and objectives were reasonable. Teachers fulfilled their roles and students actively engaged in group work. Three types of learning outcomes (i.e. cognitive, behavioral, and affective) were perceived by both students and teachers, in which, however, the performance of final products was not ideal as expected. Moreover, several challenges during the courses were reported by both students and teachers.

In order to improve future courses, several suggestions are presented:

1. The most important thing for future courses might be the choice of a suitable project for the background of both teachers and students.
2. Before the project starts, an introductory course with a couple of sessions should be provided.
3. More tutorials are needed, particularly the tutorials that focus on specific topics (e.g. programming). For the coding that students do not understand, it is better to provide them with individual worked examples as reference.
4. A clear weekly schedule of assignments that are not complex should be provided to students. By finishing these assignments students are able to make progress step by step.
5. To improve group work, a group leader should be designated to keep group members focused and motivated.

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5 Pilot round 3

5.1 Introduction

In this Pilot 3 report, we describe the evaluation of the curriculum of these pilot rounds. The aim of this evaluation is to investigate both teachers' and students' satisfaction with the teaching and learning process and perceived student outcomes in the curriculum. Background information (e.g., course settings) will also be explored to reach the research aim. The evaluation data have been collected via interviews with both teachers and students from the three universities participating in the pilots: HH (2 courses; 4 pilots), TUD (1 course; 1 pilot), and UTN (2 courses; 3 pilots).

5.2 Method

The evaluation data for pilot round 3 was collected by group interviews with both teachers and students. All interviewees agreed to participate in the interview. Teachers gave their verbal consent prior to the interview. Students agreed through an informed consent form. Table 6 shows the evaluated courses and the interviewees per institute.

Table 6. Pilot round 3 and interviewees.

University	Pilot	Teachers	Students
Haaga-Helia	Gamified Dental Brace Project	HHT1	
	Dementia Patients Course	HHT1	
	Flowerpot Project	HHT1	HHS1
	IoT Experimental Course	HHT2	HHS2
Delft	Prototyping Connected Products	TUDT1, TUDT2	TUDS1
Trento	Contact tracing	UTT1	UTS1
	Smart Agriculture Project	UTT1	UTS2
	Swarm of Drones	UTT1	UTS3

Note. As can be seen by the IDs in the Teachers column (e.g., HHT1), some teachers were interviewed about more than one course.

All interviews took place online, using MS Teams. Three of the LEI researchers conducted the interviews, with two researchers per interview. The interviews had an open character. In line with the interviews conducted in pilot 1 and 2 (Guo, Saab, & Admiraal, 2019; Guo, Post, Saab, & Admiraal, 2020), interviewees were invited to tell as much as possible about the content, process, and experiences regarding the pilot 3 course(s). The researchers made sure all relevant aspects for evaluation of the pilot were covered. These topics were: (1) course settings (e.g., level, duration, level, instruction type), (2) use of technology, (3) course objectives, (4) role of the teacher, (5) collaboration with external parties, (6) role of the students, (7) perceived learning outcomes, and (8) course satisfaction.

Based on the content of the interviews, we have set up a matrix that involved all the information from the interview (e.g., Miles, Huberman, & Saldaña, 2014). Based on this matrix, we summarized the information according to the above-mentioned eight aspects of the pilot 3 courses. Teachers also provided us written information about the courses. The combined findings are presented in the next section.

5.3 Results

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5.3.1 Course settings

At Haaga-Helia, the four pilots belonged to one or both of two courses: Multidisciplinary Software Project (15 credits) and IoT Experimental Course (5 credits). The Multidisciplinary Software Course was also part of pilot round 2 and the course settings remained the same for pilot round 3. The two pilot 3 projects within the Multidisciplinary Software Project were the Gamified Dental Brace Project (six students) and the Dementia Patients Course (five students). Besides the main teacher of this course, there was a second teacher involved who communicated between the client (city of Helsinki) and the students and provided feedback to students. The IoT Experimental Course was a pilot project in its entirety and was taught by one teacher. There were 20 students in this course. In an introduction, he demonstrated many things students could build. After that, students were free to choose one of those options or come up with their own idea for something to build in this project – alone or together with another student. Students were mostly first- or second-year students, but also some third-year students were in the course. The last pilot at Haaga-Helia was the Flowerpot Project, which was conducted by a group of two students. They started this project as part of the Multidisciplinary Software Project and then got the option to combine it with the IoT Experimental Course. The student who was interviewed about this pilot appreciated this opportunity very much.

One pilot was run at Delft University. This was an 8-week Master elective course called Prototyping Connected Products. It was a design course focusing on how ta handle IoT data, devided into six modules. This course was supposed to be about the same topic as in pilot 1 and 2 (i.e., a smart wheelchair), but due to traveling restrictions caused by the covid-pandemic in 2020, the topic switched from a smart wheelchair to a connected system of lightbulbs, at the students' homes. Two teachers and 38 students were involved in this course. Students worked from home in groups of three to make a series of (three) lightbulbs.

The three pilots at Trento University were all part of two Master-degree courses: IoT Laboratory (spring 2020) and Electronic Embedded System Design (fall 2020). Both courses consisted of both lectures and hands-on work. However, students chose whether they followed a theoretical path (with an exam) or a practical path (with a product). About 70% chose the practical pathway (which is in fact the relevant subgroup for pilot 3). Besides the main teacher, another teacher was involved in the course who supervised the student projects. The IoT Laboratory course was an optional course and students could earn 6 credits. About 10 to 20 students were in this course. The course was about managing data that is collected from a certain device (depending on the specific project). The Electronic Embedded System Design course is an obligatory course for which students can get 9 credits. Sixty students were in this course. Students in this Embedded Systems course continued the project work of the students in the IoT Laboratory course. Students design their own specific platform with sensor processing and transmission of the same device. Two of the pilot 3 projects (Smart Agriculture Project and Swarm of Drones) within the two courses were follow-ups of the pilot 2 courses. The third pilot – the Contact Tracing project – is newly developed in 2020 when the need for such an app arose due to the covid-pandemic. In the student interview, one student from each of the three pilot projects participated. The student working on the Smart Agriculture Project stipulated being really happy to have the opportunity to implement something real (i.e., by being allowed to choose a practical pathway).

5.3.2 Use of technology

Regarding educational purposes, technology was mainly used for communication. The teacher of the Prototyping Connected Products project (TUD) provided weekly demonstrations through MS Teams. The teacher of the Trento pilots shared slides and other materials through a university platform. Students in the Trento pilots uploaded their code to GitHub so they could see and learn

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from each other's work. Not surprisingly given the topic, most technology was related to the content of the courses.

In the Gamified Dental Brace project (HH), students designed and built a gamified mobile app through which data was collected about how people were wearing a dental brace. In the Dementia Patients course (HH) students developed software to collect data from a bracelet and to display the relevant data on a mobile app or webpage, so nurses can detect whether patients are somewhere they are not supposed to be. In the IoT Experimental course (HH) it was not predetermined what students would build, but as a basis they used an ESP32 chip, which has Bluetooth. Students could use C++ or Python for programming. If students wanted to have a full-blown computer, they could also use a Raspberry Pi. Student appreciated the availability of many different technical tools to choose from. Even though one student felt that it was a bit too much, he thought it was a good thing, because this freedom kept him enthusiastic throughout the project.

For the Prototyping Connected Products project (TUD), students received a kit with all the hardware they needed at home. This included a Raspberry Pi and a light bulb. Students used Python code for programming. They used GitHub to operate with each other and this also allowed teachers to monitor students' progress. Documentation of everything students did (and learned) was also done in GitHub.

The Smart Agriculture Project (UTN) involved developing an IoT node for the camera which consumes less battery than the previous one (of pilot round 2). The camera has wireless radio and can send pictures. Students also compared different machine learning techniques because the camera could be able to distinguish between pests and benign insects through an image processing technique. Students used a Raspberry Pi and programmed in Python. For the Swarm of Drones project, unmanned vehicles with gas sensors were used to monitor air quality. Whereas the goal of this project in pilot round 2 was to have a drone measure the presence of chemicals, the goal in pilot round 3 was to have a coordinated group of four drones. This way the same area could be monitored more quickly (e.g., locating a gas leakage) or the region of investigation could be extended. Students synched their work in a shared Google Drive folder and uploaded their code to GitHub. In the Contact Tracing project, a badge was used to monitor movement of employees in their workplace. All location data were collected from the sensors using a Raspberry Pi, and an algorithm could detect locations where employees were too close to each other (given the pandemic-related guidelines) and when during the day this occurred.

5.3.3 Course objectives

The main objectives of the Multidisciplinary Software Course (HH) were that students would be able to set up a systematic, methodological project to solve a client problem in a systematic manner and applying and learning new technologies while doing it. Students should learn to apply basic programming skills they have already learned. The objectives of the IoT Experimental Course were to acquire general understanding of IoT, the versality of IoT, and the simple basics of IoT. The teachers' reasoning is that having the students build something from scratch that works, elicits their interest and desire to learn more. Students described making people enthusiastic and thereby elicit learning to build an IoT solution as the goals of the IoT Experimental Course. They reported that the teacher wanted them to really think about a problem and a solution and to familiarize themselves with the technology and all its possibilities. Both students agreed that the course objectives were achieved.

The course objectives of the Prototyping Connected Products course (TUD) were that students learned to explain core IoT technology components, to develop a prototype using Python, to understand what sensor data should be collected and which technology components to use, to motivate choices, to express design (considerations), and to use Git and GitHub to

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document the prototyping process and collaborate with peers. The student who participated in the interview added that there was a focus on privacy and how to handle that in this context. As opposed to the pilot 2 course however, in the pilot 3 course, there was no objective relating to machine learning, because this was too difficult and time consuming due to the remote education. Perhaps related to that, the student felt he could have learned more in this course if he would have been able to go the campus instead of working and trying to solve problems from a distance.

The global learning objective of the courses in Trento were to give the students the capability to design a specific system. For the IoT Laboratory course specifically, the objectives were to teach the students how to collect, transfer, and convey data from sensors to the cloud, to a server. Students learn to combine data from multiple sensors (data fusion) and to choose the appropriate software. The Embedded Systems course focuses more on programming. The specific objectives were to learn students to detect embedded processes (to choose the appropriate algorithm to run), to acquire information (requires signal processing, machine learning), and to provide specific output from the chosen algorithm. The students from the Trento pilots felt that the course objectives were achieved and moreover, they learned very much about doing research and writing about it. One student explained: "I think it's just starting to show you are a bridge between the university and theoretical next step that can be a PhD or go inside an industry".

5.3.4 Role of the teacher

In all pilots the teacher had several roles: Instructor, expert, and guide/coach. In most pilots the most important role of the teacher was that of a coach while students worked independently on their projects. When students needed help, the teachers were available as an expert in the field. Of course, the division of these roles differed somewhat between pilots. For example, in the IoT Experimental Course (HH) and the Prototyping Connected Products course (TUD), the coach role was most pronounced (as opposed to instructor role) in comparison to the other pilots. Teachers in all pilots were content with their main role being a coach. All interviewed students shared this opinion, especially in the case of the IoT Experimental Course.

5.3.5 Collaboration with external parties

In most pilots there was collaboration with external parties. This concerned a client for whom students would build a prototype or partners from the IoT Rapid-Proto Labs Project. Involved clients were a dentist (Gamified Dental Brace), the city of Helsinki (Dementia Patients), Italy's biggest producer of small fruit (Smart Agriculture), Department of Agricultural Engineering of another Italian university (Smart Agriculture), and companies interested in air quality (Swarm of Drones). For most projects, communication with the client was through a teacher, not directly with students. The student involved in the Swarm of Drones pilot thought the collaboration with a client was a great opportunity to get a look outside of the academic work.

Regarding collaboration with partners from the project, a representative from Houston Inc and the professors from Delft and Trento provided feedback to some of the students in the Haaga-Helia pilots. There was also collaboration at the curriculum level. That is, the teacher of the IoT Experimental Course discussed the content of this course with the professor from Trento, who shared some materials through Moodle. For the Smart Agriculture Project Haaga-Helia and Trento shared a common space. For the Contact Tracing project, Trento asked Haaga-Helia to provide the report structure.

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5.3.6 Role of the students

In the Multidisciplinary Software Project (HH), the students were quite motivated at the beginning, but some lost their motivation during the course, leaving most work for one or two students in the group. The teacher thinks the decline in motivation was caused by the course being more difficult than students expected. Instead of explaining everything directly to all students, teachers tried to act mainly as a coach and encouraged the better students to help the weaker students. Students in the IoT Experimental Project worked individually or in a small group but talked a lot with classmates about what they were working on. Students had a very active role and only came to the teacher when they got stuck. As mentioned before, the students highly appreciated the freedom to choose what they wanted to do and to try out things. However, one of the students noted that all this freedom resulted in low pressure for him to actually finish a product by the end of the course and that a bit more structure in the course or an obligation to work in a group (social pressure) might have helped him with this.

The students from Delft worked alone at home, but still remotely collaborated in groups of three. Students were encouraged to think further than the course material, an aspect about which the interviewed student was very positive. At the beginning of the pilots in Trento, the students had the role of passive listeners during the lectures. After that, they actively worked in small groups on the practical projects. In addition, the students in the Swarm of Drones and Contact Tracing pilots also had the responsibility to collaborate with the client. The teacher indicated that the students from Trento worked quite independently, solving most problems they encountered without needing the help of the teacher. Overall, the students were very satisfied with their role in this course. One student explained “Oh, yes, yes, yes, because I had an opportunity to see different aspects of such a project and also learn new technology. […] So after this project, I could say that I know, I learned new technology and also when also dealing with the clients or the manufacturer and understand how to provide them at the same time.”

5.3.7 Assessment and perceived learning outcomes

Overall, both teachers and students were positive regarding the learning outcomes achieved in the pilots.

Students in the Multidisciplinary Software Course (HH) wrote a final essay. Based on this essay and the actual product students delivered, students were assessed on their skills and understanding of the systematic methodology that was used, how they produced solutions to the problem they worked on, and how well they had learned new technologies and applied these in the context of the problem. Performance was not very high, but not very low either. Students in the IoT Experimental Course wrote a weekly diary about what they had learned in that particular week, including pictures of the product and code they wrote. At the end of the course, the diary (60%) and the product (40%) were evaluated by the teacher. The teacher was very positive about the learning outcomes, because in their reports, all students showed that they put serious effort in learning and what they built mostly works. In line with this, students indicated that they tried to come up with new ideas and that they learned much more than they expected. As one student put it “And if I see the world before taking the course and now at least like I see a lot of possibilities and I see possibilities for myself as well to actually use this. So that's why I'm still working on it as well. At least I actually think there are a lot of fun things you could do with it.”.

Assessment in the Prototyping Connected Products project (TUD) was twofold: an individual open book exam (50%) and documentation by the group (50%). Students were prompted throughout the course to report on process, results, interpretation, and reflection, but the assessment documentation was done once at the end of the course. Although the interviewed

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student felt he could have learned more during this course, he was very positive about the things he did learn (given the covid-situation).

The students in the Trento pilots, are the ones who chose the practical pathway. Assessment for these students consists of evaluation of the product they have at the end of the project period (3-4 weeks). Students are not required to finish the product within this period, but the products are nevertheless evaluated at the end of the period. Students contact the teacher to evaluate their (un)finished product. If it was enough to pass the exam (right away or after some adjustments), students wrote a report which was the first part of the final evaluation. The report should be written in the format of a scientific paper. It was sent to the teacher before the oral exam, done with the student from a project group together. The oral exam consisted of a presentation by the students and answering the teacher's questions. The teacher evaluated the product and what they had learned, but also the collaboration and individual performance of the students. The students from the Trento pilots reported positive learning outcomes regarding learning new software programming languages and technologies, but also regarding problem-solving abilities, skills to conduct research and skills to present your work, both to a client as in the form of an academic research paper.

5.4 Discussion

Overall, teachers were positive about the pilot courses that were conducted. The teacher of the IoT Experimental Course (HH) especially enjoyed reading the final page of students' diaries, where they had to list things that they wanted to build in the future. The teacher explained: "Because if they do something here and they end up with six or seven ideas for the future, then I know that this course was really interesting for them." The teacher in Trento was also very positive. He indicates that some students even decided to present their work at a conference.

One thing the teachers were less satisfied about was the (absence of) international and interdisciplinary collaboration within the project. In other words, the planned joined IoT rapid-proto labs curriculum was not realized in the pilot rounds. This turned out not to be feasible because of the different schedules, levels, and other practical issues that could not be solved within the timeframe of the project. Instead, the three universities ran their own pilots with collaboration where possible. This was mainly on the level of sharing course materials and the teachers providing some feedback to students from one of the other universities. Even though this collaboration was productive, it was a pity that it did not go any further than that in the three pilot rounds. Nevertheless, the professor from Delft emphasizes that tremendous changes were realized thanks to this project (and its initial plans). That is, they were now forced to make all course material online, which students really appreciated according to the teacher. The professor from Haaga-Helia points out that this project forced them to add new things to their curriculum, in order to make a software course an IoT course that fitted in this project. Over the course of about two years in this project, the teachers learned to incorporate IoT in their courses and improved their guidance of students on this aspect of the course.

In line with the teachers, students were overall positive about the pilot courses. The Haaga-Helia students were most positive about the freedom to try new things, the coaching of the teacher and the work-atmosphere in the IoT Experimental Course. At the same time, they indicated that this freedom also has its drawback and therefore maybe there should be other courses focusing on coding or some specific professional tools so students can spend more time on actually experimenting in this course. The student from the Delft pilot experienced some difficulties with learning remotely. For instance, programming issues would have been resolved a lot faster if students were working on the campus with a teacher ready to help immediately. Now, he was a bit overwhelmed by the programming part of the course and this was a bit demotivating. The student suggested that the need for assistance with programming could be decreased if there was another course focusing only on Python programming, or if the current course was longer so that it would be incorporated in the same course. Despite experiencing these programming difficulties, the student was very positive about the course: “I think if you can code that opens a lot of doors for you, it's a magical thing.”. The Trento students very much appreciated the authentic context they were working in.

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6 Pilot round 4

6.1 Introduction

Pilot round 4 was an extra pilot round, run collaboratively by the universities of Haaga-Helia and Trento. It consisted of 1 pilot project which was based on the Contact Tracing project of pilot round 3. Students from the university of Trento developed the tracking device and software to collect data. Students from the university of Haaga-Helia developed software to visualize the data in a meaningful manner.

6.2 Method

The evaluation data for pilot 4 was gathered via e-mail correspondence with the responsible professor from Haaga-Helia and an interview with the professor from Trento. In line with the interviews conducted in pilots 1, 2 and 3 (Guo, Saab, & Admiraal, 2019; Guo, Post, Saab, & Admiraal, 2020), the teachers were asked about the content, process, and their experiences regarding the pilot 4 course. The same topics as in the previous evaluations were covered: (1) course settings, (2) use of technology, (3) course objectives, (4) role of the teacher, (5) collaboration with external parties, (6) role of the students, (7) perceived learning outcomes, and (8) course satisfaction. The teachers' answers were put in the matrix that was also used for pilot 3 and the results are reported below.

6.3 Results

6.3.1 Course settings

This project was run at the two universities at the same time as part of courses that also produced the previous pilot projects. At Haaga-Helia, this project was part of the Multidisciplinary Software Project. This 16-week (15 ECTS) bachelor course was about building software in a project team to a client commission. Once a week there was a teacher guiding session. At the university of Trento, this project was part of the IoT Laboratory course. The IoT Laboratory course was an optional course and students could earn 6 credits. About 10 to 20 students were in this course. The course was about managing data that is collected from a certain device (in this case a tracking device).

6.3.2 Use of technology

Students in Trento developed a wearable (anonymous) device. This device is simple, always on and connected. The battery lasts at least a workday. The device measures location and orientation (for example, whether people were oriented face-to-face or back-to-back). Data was collected at the end of the day, so no real time monitoring took place. This was done to avoid being like a big brother watching the employees.

Students at Haaga-Helia received an interface an earlier recorded data from Trento. They used this to do back-end analyses and develop visualizations of the data. Movement of people in a building of about 100 m^2 was visualized, including positions and filters of time interval or number of people to show. They also provided a second table with all people with contacts below 2 meters distance and where this was. They used web programming technologies (ReactJS, node.js). Trello was used for task management by the students and Microsoft Teams for the mentoring sessions.

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Both teachers were satisfied with the technology used in this course. During the IoT Proto Labs project, Houston Inc. had developed the IoT Solution Platform to be used as the shared infrastructure between the different partners and student groups in the project.[1] However, due to a strict NDA, the Italian client did not allow the data to be transferred to the platform.

6.3.3 Course objectives

The course objectives were different for the two universities. For both, course objectives were about the same as in the pilot round 3 courses. That is, the objective in Trento was to develop wearable devices in work environments (office, factory, office building) that can track (back-tracking), to know about contacts before possible contagion. The main objective of the development of the device, however, was to provide some kind of assessment, or certificate, for a company to give (for example) feedback to the manager of the building about regions that are more subject to contact. The company can use this to guarantee safety of its employees. The objectives for students were to develop a smaller device than was developed in the previous course (which was more of a box, not a small wearable) and to develop software to collect the data from the device.

At the university of Haaga-Helia, the objective was that students would be able to use most of the software engineering skills needed in solving a real customer problem. Students should be able to understand and document customer's needs and to propose appropriate software solutions. Students should be able to independently acquire unknown technology knowledge and skills. They learn to evaluate and choose between technologies and methods and are able to take personal responsibility over a certain part of the commonly created solution. Student should be able to share acquired knowledge to other members of the team or course.

While the teacher in Trento was very positive about achievement of the objectives, the teacher in Haaga-Helia indicated that results could have been better.

6.3.4 Role of the teacher

The roles of the teacher were also similar to the pilot round 3 projects. Thus, they were coaches and acted as experts when necessary. In addition, the teacher from Trento said he learned more about collaboration (with Haaga-Helia). There were periodical meetings, teachers had to consider both their own and the other university's students in creating the course. Small documentation during the courses from both sides was needed. The teacher from Haaga-Helia indicated he had to put a lot of effort in arranging client meetings, defining project goals and coaching the group because of the low level of the students and because one student dropped out. Overall, both teachers were satisfied with their teacher role.

6.3.5 Collaboration with external partners

There were two types of collaboration in this pilot project: between a university and a client/company and between the two universities. With regard to collaborating with clients, this was minimal for the students, because communication took place between the teacher and the

[1] IoT Solution Platform follows the Microsoft Azure IoT reference architecture and was used for demonstrating how commercial cloud PaaS and IaaS can be used to construct a complete, end-to-end platform for IoT prototyping. The IoT Solution Platform allows students to create IoT Prototypes without heavy investment in building the support infrastructure while it simultaneously allows them to experience a real, industry-level cloud environment. After the IoT Proto Labs project has ended, the open source solution codebase will continue to be available in GitHub (https://github.com/CeruleanDataHub) and DockerHub (https://hub.docker.com/u/ceruleandatahub). The IoT Solution Platform was primarily built for educational purposes. As the IoT Solution Platform is built on open source code, any future courses or IoT Pilots are free to utilize the source code available in the project.

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company. This way of collaborating was chosen to keep pressure low for students and really focus on developing the device and the software. At the final presentation, students were allowed to present for companies if they wanted to (but for the rest no pressure for students relating to working for a client). Even though Haaga-Helia students were originally supposed to interact independently with the client, this was done by the teacher in the end because of the low level of the students.

The collaboration between the universities was close, but at the same time the student groups were not dependent of each other. They had their own assignments and shared what they had worked on in periodic (feedback) meetings. At the end of the course, there was a meeting in which the activities of the two universities were merged. Haaga-Helia students shared their code and software, while Trento students connected the visualization chart of Haaga-Helia with new data (collected by the Trento students in this course) and shared the portal where data can be collected (by Haaga-Helia).

Both teachers had positive experiences with their collaboration. The teacher from Trento was happy to start the collaboration with Haaga-Helia. It was a good opportunity. He didn't know what to expect from the students know (i.e., from the other university), because he did not know them. Therefore, no deliverables were asked by Trento from the Haaga-Helia students and vice versa. This way, there were no dependencies between universities in this first Rapid-Proto Labs pilot involving student collaboration. Fortunately, the Trento teacher was quite (positively) surprised every meeting about what students presented and what they had thought of. Looking to the future he said: "Now, we could make a more complex or interactive course for the future. Now we know each other, a more tight collaboration is possible. We know that there are both competences and expertise on both sides."

6.3.6 Role of the students

As in the previous pilots, students in pilot round 4 were supposed to work as an independent active professional development team. In addition to that, they collaborated with the students from the other university. Besides the periodic meetings, students had the possibility to communicate with each other via e-mail if they had any questions. This, however, did not happen. Still, the teacher in Trento said his students really felt like they were part of a real collaboration project. The teacher of the Haaga-Helia course felt his students were somewhat passive and needed fairly much steering and encouragement. Nevertheless, he was satisfied with their persistence in finding solutions, that they asked for help, and that they did not give up.

6.3.7 Perceived learning outcomes

Learning outcomes (both planned and perceived) were similar to pilot round 3. In comparison to pilot round 3, which was with local (familiar) teams, in this type of collaboration students needed to present in meetings, speak English, provide and receive feedback, and answer questions. The teachers were satisfied with how the students did this.

6.4 Discussion

The teachers were positive about pilot round 4. Whereas they were somewhat disappointed that there was no substantial international and interdisciplinary collaboration in the previous pilots, this was very much improved in the current pilot. Students worked with each other's materials and or data, shared their progress, and provided feedback on each other's work. The pilot course was designed in such a way, that the student groups from the two universities followed a (pre-existing) course at their own university and were not dependent of each other.

To have a fully integrated collaborative course, more steps should be taken. However, this will be challenging for several reasons. First, there is the (lack of) alignment of courses, as was also discussed in pilot round 3. In pilot round 3, the different schedules, levels, and other practical issues that could not be solved within the timeframe of the project resulted in separate pilot projects for each university. These issues were partly resolved in pilot 4 because students were not dependent of the other university, except for the periodic meetings. If the universities were to take a next step in collaboration, these issues would arise again because tighter collaboration will mean more interdependence. For a future course more planning of the project, preparation of a timeline and of resources is needed. Second, there needs to be some sort of 'glue' to keep all parties together. There is a risk of this cohesion fading after the EU-project ends. Nevertheless, substantive bases for collaboration are created throughout this project and especially in pilot round 4.

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7 Concluding remarks

In the IoT Rapid-Proto labs, student learning labs have been implemented as a part of course curricula on IoT. In these learning labs, students work on authentic tasks to enhance both their domain-specific skills and knowledge as well as generic competences, such as creativity, collaboration skills and problem-solving skills. This student learning supports project-based learning in higher education. In four rounds, 13 pilot projects have been evaluated, some of them twice or three times after some redesign based on the evaluation of the previous instance. In general, the students were satisfied with the courses and the projects. They liked the complex authentic tasks as this gave them some idea of what to expect in later professional career. Yet in some courses, these complex authentic tasks were evaluated by some students as too difficult and they needed more direction of what to do. The international collaboration between students and teachers from the three partner countries that carried out the pilots was limited to the asynchronous data flow from one party to another. Implications for future implementation of student learning labs include that a balance should be found between student autonomy and collaboration, on the one hand , and clarity about expectations what students should do, on the other hand. Related to this issue, the level of complexity and authenticity might increase with the ability level of student, providing more complex authentic problems in the final year of the bachelor programme or in the master programme. Another implication is that in order to implement student learning labs that are multidisciplinary, teachers from the different domains should form their own learning lab to design the tasks and curriculum of the student learning labs. These teacher learning labs might be even more important in multidisciplinary student learning labs with students from different countries and cultures.

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