Students as Future Workers

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Abstract

One promising way to cope with changing requirements from the labor market in the domain of Science, Technology, Engineering and Mathematics (STEM), but also to keep the field up to date, to start innovations and to advance the STEM domain as such is the use of student labs. In these labs, students work together in small groups imitating professional practice of design and technology workers. More insights are needed in what competences student labs in the STEM domain address and what the implications would be for the design of student labs. A review of empirical studies on student labs and additional literature indicate that five generic competences are addressed in most student labs: Collaboration, communication, problem solving, critical thinking, and creativity. In order to effectively enhanced these competences, student labs should be designed as authentic productive learning environments based on three design principles: 1) Realistic, complex task situations, 2) Multidisciplinarity, and 3) Social interaction. IoT Rapid Proto Labs are examples of such a student labs, in which cross-border multidisciplinary teams of students, teachers (coaches), and practitioners jointly develop solutions to challenging IoT applications (Internet-connected objects), add value for enterprises, and strengthen the employability, creativity and career prospects of students.

Keywords: Student labs, Authentic learning, Higher education, Science, Technology, Engineering and Mathematics (STEM).

Introduction

Lack of skilled labor in the domain of Science, Technology, Engineering and Mathematics (STEM) is one of the main obstacles to EU economic growth in the coming years. In the period of 2015-2025, a growth in demand of STEM jobs of 8% is expected, compared to 3% for all occupations, leading to persistent shortages in terms of 700,000 job vacancies a year. University level education in the STEM domain is expected to provide future workers with a wide-range of technical skills and competences as well as an ability to understand and apply high level maths, science and other theory (Lucena, Downey, Jesiek, & Elber, 2008). Yet, at a time when there has been unprecedented attention around the need to increase training and recruitment, ‘Computer Science’ and ‘Engineering and Technology’ have the highest ‘subject-specific’ attrition rates in the UK university system (The Telegraph, 2017). Not only do the expected shortages create challenges for educational programs that prepare prospective professionals. Industries and businesses in the STEM domain form a dynamic, constantly changing field, which requires new skills from the professionals working in the field. These new skills are not only important to cope with these changing requirements, but also to keep the field up to date, to start innovations and to advance the domain as such.

These expected shortages and predicted changes means that prospective professionals in the STEM domain are required to develop a broad range of skills such as creativity, innovation skills, performance skills, critical thinking, problem-solving strategies, and self-regulation skills. As the range and complexity of these skills is so comprehensive that any one individual is unlikely to have them all, nor to have developed them all to the same high degree, prospective professionals should acquire communication, interaction and collaboration skills as well. All these skills are commonly referred to as 21Century Skills (21CS): cognitive, affective, motor and regulative skills that enable individuals and groups to face complex task situations effectively and efficiently. These 21CS are important to enable future workers to continuously adapt to and anticipate on what the profession, the labor market and society in general ask for.

Both these generic competences (i.e. 21 CS) and competences specific for the STEM domain (e.g., particular designing, programming and prototyping skills) require different educational setups compared to tradition 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 student 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- workplaces. Second, these labs can enhance particular student competences the labor market requires, in terms of both generic competences and competences specific for the STEM domain. Generally, three main types of student labs can be distinguished: 1) physical labs in which students learn and work together sharing the same location and time, 2) online labs in which students synchronously and a-synchronously learn and work together sharing the same virtual environment and 3) remote labs in which students control equipment in a lab from a distance. Often blends of the three main lab types are used. More insights are needed in what competences student labs in the STEM domain address and what the implications would be for the design of student labs.

In the current study, a review of the literature on student labs in higher education and the competences students need as future workers is presented. Subsequently, a newly developed design of learning labs (the IoT Rapid Proto labs) in higher education is discussed, which aims at developing and improving students' 21CS and preparing students as future workers.

Methods

A database search has been carried out on all databases available at the library of University of Leiden. The search terms included the terms "remote lab" "online lab", or similar (search in title: remote lab OR remote labs OR remote laboratory OR remote laboratories OR online lab OR online labs OR online laboratory OR online laboratories) and the term "higher education" (search in entire document: higher education OR undergraduate OR graduate OR post-secondary OR tertiary). The search was limited to peer-reviewed journal articles in English that were published the past 15 years (i.e., 2003 to 2017). This resulted in 133 articles from 20 databases (see Figure 1) and included five doubles.

Collection
Science Citation Index Expanded (Web of Science) (56)
OneFile (GALE) (43)
ERIC (U.S. Dept. of Education) (42)
Social Sciences Citation Index (Web of Science) (31)
Directory of Open Access Journals (DOAJ) (26)
MEDLINE/PubMed (NLM) (21)
ScienceDirect Journals (Elsevier) (20)
Taylor & Francis Online - Journals (16)
Wiley Online Library (15)
SpringerLink (12)
Health Reference Center Academic (Gale) (11)
SAGE Journals (8)
IEEE Journals & Magazines (4)
KESLI (ACM Digital Library) (3)
SHEDL- 2014 (ACM Digital Library) (3)
IEEE Open Access (3)
ACM Digital Library (3)
BIBSAM:2015-2018 (ACM Digital Library) (3)
AIP Member Society Journals (2)
Sociological Abstracts (1)

Figure 1. List of databases (and number of articles found)

After removing the doubles, 128 articles remained for manual selection. Titles and abstracts were read and articles were included if they described a study on the use of remote labs for education with a focus on student learning (i.e. not on teacher learning nor on technical design of educational lab). Reviews and meta-analyses were excluded. Based on these criteria, 94 articles were removed and 34 articles remained. After thorough reading these 34 articles, another 9 were removed because these studies were not about remote labs nor about student competences or student learning outcomes, or described the same data as reported in another article included in the review. The final number of articles for the review was 25. In Table 1, we give a summary of the steps from 128 journal articles to the 25 selected for review.

Table 1. Number of excluded articles arranged by reasons for exclusion (N= 103)

Reason for exclusion	Number of articles excluded based on information in:	
	Title/abstract	**Full article**
No remote lab	60	1
Review/overview	16	
Technical/design	12	7
No educational context	3	
Focus not on higher education students	3	
Other*		1

*This article described the same data as reported in another article included in the review.

Selected Studies

In Table 2, we give an overview of the journal articles included in this review. All remote labs described in the articles were conducted in education in the STEM domain and the majority was conducted in the field of engineering (20 studies). Many of the engineering remote labs focused on controlling of machines, robots, and other devices (Programmable Logic Controllers; PLC) rather than traditional engineering. For some of the labs remote students worked in small groups (9 studies), while in other labs students worked individually (16 studies). The authors of three articles on individual lab work indicate that it was technologically possible to work in groups, but that students worked individually in the specific courses that were evaluated in these articles.

Even though all but two of the reviewed studies evaluated their remote lab in some way, only fourteen used an experimental or quasi-experimental design for the lab evaluation. Evaluation of the impact of the remote labs – which was positive in general- referred to establishing students' learning outcomes and student evaluations.. *Learning outcomes* were in most cases measured with a knowledge test and were found to be equal or higher in remote labs than in hands-on labs. *Students' evaluation* was often measured by their satisfaction with the lab design and processes. Overall, students reported positive experiences with remote labs. They liked being able to work "in" the lab wherever and whenever they wanted. Drawbacks students mentioned most often were the lack of face-to-face contact with peers and teachers and the responsibility to work autonomously that came with the lack of teacher-centered instructions.

Findings: Student Competences

The reviewed students evaluated students' learning outcomes of their remote labs in terms students' domain-specific competences and not in terms of generic student competence. However, many authors (17 articles) did point out that generic competences are relevant for learning in remote labs as can be seen in Table 2. By far, the most addressed competences were collaboration (in 13 articles) and communication (in 10 articles). Other competences that were addressed (in 1 to 3 articles each) were problem-solving, planning, reflection, critical thinking, creativity, presenting, and autonomy. In 10 out of the 14 studies that addressed collaboration or communication, the remote labs involved group work. The studies that address collaboration describe it as a competence that is highly relevant for both hands-on labs and remote labs. Collaboration among students is sometimes realized by working in the lab from the same remote computer. In other studies, the remote lab environment allows multiple students to be logged in to the same experiment at the same time. Communication is often described as critical for collaboration and is usually realized by a chat option in the remote lab environment. The other competences addressed in the studies are not related to group work of the students.

Table 2. Details of the journal articles included in the review

Authors (year)	Discipline	Experimental design	Group work	N	Student learning outcomes		Student evaluation	
					Findings	Measurement	Findings	Measurement
Azad (2007)	Engineering	Remote vs. hands-on; pre-test-post-test	No**		Positive; equal to hands-on, but more efficient	test	Positive, but responsibility	Weekly survey
Barrios et al. (2013)	Engineering	No	Yes	43			Positive	Survey
Boix et al. (2008)	Engineering	No	No	22	Positive; learned more than expected	Survey	Positive	Survey
Broisin et al. (2017)	Computer science	No	Yes	139	Positive correlation	Test; activity log		
Chen & Gao (2012)	Engineering	Remote vs. hands-on	No	50	Positive	Report; presentation; final exam	Positive; equal to or higher than hands-on	Survey
Corter et al. (2007)	Engineering	Remote and simulated vs. hands-on	Yes	306	Positive; remote and simulated ≥ hands-on	Test	Positive, but preference for hands-on	Survey
De Jong et al. (2014)	STEM	No	No**					
Dominguez et al. (2014)	Engineering	No	No	71			Positive	Survey
Duro et al. (2008)	Engineering	No	No				Positive	Survey
Fiore & Ratti (2007)	Life science	No	No	27	Positive	Final exam	Positive	Conversation
Geaney & O'Mahony (2016)	Engineering	No	No	40			Positive	Survey
Jara et al. (2011)	Engineering	Remote vs. hands-on (previous year)	No	75	Positive; better and more efficient	Final exam; activity log	Positive	Survey
Lang et al. (2007)	Engineering	Remote vs. hands-on; pre-test-post-test	No	52	Equal to hands-on	Test; survey	Positive	Survey
Lehlou et al. (2009)	Engineering	Remote only; pre-test-post-test	Yes	48	Positive	Survey	Positive	Survey
Luthon & Larroque (2015)	Engineering	Remote vs. classroom; pre-test-post-test	No	107	Equal to hands-on	Tests; surveys; quizzes	First negative, later positive	Survey
Malaric et al. (2008)	Engineering	Remote vs. hands-on (within-subjects)	Yes	70			Positive	Survey
Morgan et al. (2012)	Engineering	Remote vs. hands-on (previous year)	Yes	13	Positive; better and more lab interaction	Final exam; activity log	Positive	Survey
Nedic (2013)	Engineering	No	Yes					
Nedic & Machotka (2007)	Engineering	Remote vs. hands-on (previous year)	Yes	78	Positive	Report (marks & process)	Negative; preference for hands-on	Report
Nickerson et al. (2007)	Engineering	Remote vs. hands-on (within-subjects)	No**	29	Equal to hands-on	Test; lab assignment	Positive; as effective as hands-on	Survey
Sauter et al. (2013)	Physics	remote vs. simulated; pre-test-post-test	No	123	Positive; similar to simulated lab		Positive	Interview
Soares et al. (2014)	Engineering	No	Yes	34			Positive	Survey
Tho & Yeung (2016)	Science teaching education	Remote vs. hands-on (within-subjects)	No	64	Positive	Survey	Positive	Survey; interview
Tirado-Morueta et al. (2018*)	Engineering	Remote simple exp. vs. remote complex exp.	No	98			Positive	Survey
Uğur et al. (2010)	Engineering	No	No		Positive		Positive	

N.B. Empty cells means this variable was not mentioned in the article.

*Available online in 2017 and therefore Included in this review (which is limited to 2003-2017).

** Students did worked individually in the remote lab reported here, but the system allowed simultaneous access to the lab, so group work would have been possible.

Table 2. Competences addressed in the articles

First author	Collaboration	Communication	Problem solving	Planning	Reflection	Critical thinking	Creativity	Presenting	Autonomy
Azad	X			X					X
Broisin	X	X							
Corter	X	X							
De Jong	X	X		X	X			X	
Duro			X						
Geaney			X						
Jara	X								
Lang					X				
Lehlou	X								
Luthon	X	X							
Malaric	X								
Nedic	X	X							
Nedic et al.	X	X							
Nickerson	X	X							
Soares	X	X							
Tho	X	X	X	X		X	X		
Tirado-Morueta		X							
Total	13	10	3	3	2	1	1	1	1

N.B. This table displays 17 out of 25 articles, because only articles that addressed at least one competence are included in this table.

Overall, students' learning outcomes were measured in terms of domain-specific competences. The findings with respect to the generic competences did not differ much between the studies. In the context of remote labs, collaboration and communication were addressed most often. Collaboration is understood to be very important for learning in a remote lab and effective communication is critical for successful collaboration. Not surprisingly, studies emphasizing these two competences often report remote labs in which students work in groups. Collaboration and communication are two very important competences to consider in designing authentic learning environments in STEM higher education. We can, however, not infer from the reviewed articles what are best practices regarding collaboration and communication, because none of the studies measured these competences as learning outcomes. The articles do nevertheless give useful examples of how one can facilitate collaboration and communication within a remote lab project, such as simultaneous login of multiple users and chat options.

Seven other competences are mentioned sporadically in the articles: problem solving, planning, reflection, critical thinking, creativity, presenting, and autonomy. It was not possible to relate these competences to impact of the remote labs as these competences were not measured as students' learning outcomes as well. In the descriptions of the remote labs, the focus was often on collaboration and communication. Therefore, it is plausible that some of these competences might be relevant, but simply did not get priority in the reviewed studies.

Other, more general literature about competences might help us to determine which competences are most relevant for learning in remote labs. The report "Digital skills for life and work" of UNESCO and Intel Government and Education (2017) provides an overview of many frameworks of digital competences and summarizes them. The report describes, among others, generic digital skills. In line with our findings it presents digital communication and collaboration as important competences. The report also describes higher-level cognitive skills, including not only domain-specific (programming) skills, but also 21CS. Collaboration, communication, problem solving, critical thinking, and creativity are the 21CS that are described in the overview by UNESCO and Intel Government and Education (2017), which are also addressed in the reviewed studies on remote labs. Even though there is not much to go on based on the empirical studies on remote labs, the combination of these studies and other literature on (digital) competences provides us with a good idea of which of the nine competences addressed in the studies are most relevant for learning in remote labs.

In sum, five generic competences are addressed in most student labs and refer to generic 21CS: Collaboration, communication, problem solving, critical thinking, and creativity. Both these generic competences and competences specific for the STEM domain (e.g., particular designing, programming and prototyping skills) can be developed and improved by the use of student labs, which are small groups of student working together on solving authentic problems and producing solutions within a limited time period. It is a challenge to develop design principles for students' learning labs, preferably supported by meaningful technology, in such as a way that they promote the five core competences of collaboration, communication, problem solving, critical thinking and creativity.

Implications for the Design of Student Learning Labs in Higher Education

Developments in theories of effective learning and teaching reflect shifts from behaviorism to cognitivism to situationism (Day & Goldstone, 2012; Putnam & Borko, 2000). Lave (1988) challenged traditional views of learning and teaching by stating that new knowledge is constructed in the course of understanding and participating in new situations, a process generally referred to as "situated learning", with an emphasis of the social and interactive nature of learning. Taking a situated approach on teaching and learning helps to advance to design robust interventions in higher education practice. The creation of knowledge and skills is a continuous but not always linear process. It involves actively researching and experiencing reality as well as experimenting, which means building up experience goes with making errors. Skill formation is a social activity determined by the context and the way in which groups of people share knowledge and experiences. Learners build up knowledge that is linked to concrete applications, contexts and cultures. It requires the construction of practices and apprenticeship (Lave & Wenger, 1991).

In student learning labs, these perspectives of situated learning are combined. In these learning environments, the boundaries between formal and informal learning are fuzzy to engage students in meaningful, collaborative and authentic learning situations, where learners meet each other and workers in the field. Student learning labs require authentic productive learning environments shaped by:

1) *Realistic, complex task situations*, which give scope for the participant's initiative and exploration via divergent assignments, global guidelines and global criteria. The complexity requires interaction with other disciplines and between learners. These learning situations are 'hybrid', in which school-based learning and workplace experiences are closely connected.
2) *Multidisciplinarity*, as the real-life problems and challenges to cope with are not compartmentalized into clear-cut disciplines (Heijnen, 2015). Most suitable for the present project seems what they call *pragmatic interdisciplinarity*: an outcome centered approach that involves envisioning an effective and workable final product and back-filling through strategic selection of disciplinary inputs from the STEAM domain.
3) *Social interaction*, as learners need to apply and build up multiple skills and expertise, reinforced by mutual interaction and cooperation. The most important forms of creativity are joint cooperative activities of complex networks of skilled individuals (Sawyer, 2008) Social interaction is a crucial element of authentic productive learning environments, as it enables participants to operate as a learning community in which various forms of expertise, experiences and skills are shared (Wenger, 1998; 2009).

Implementation of Student Learning Labs in Higher Education: IoT Rapid Proto Labs

IoT Rapid Proto labs are blended (virtual as well as real), user-driven, and authentic productive learning environments in which distributed multidisciplinary groups of five to then higher education students (from three European countries) collaborate on solving ill-structured problems. These students attend these blended multi-disciplinary learning and work environments as part of their bachelor or master program in the domains of Industrial design, Engineering and Technology. Throughout the discovery, design, develop and test process, student teams are continually supported by HEd teachers combining the roles of coach, guide and instructor. These labs are open environments, with flexible start and end dates, international virtual as well as local face-to-face interaction and collaboration, and dynamic boundaries between participants, and allowing both linear and nonlinear learning and work curves. The labs are also supported by a Project Arena (web-platform) which enables them to effectively collaborate on rapid-prototyping of IoT products/services. The Project Arena also stimulates the flow of knowledge and innovation between higher education, enterprises and other stakeholders. Each IoT Rapid Proto-Lab student-centered team will rapidly set-up, trial and test an innovative IoT solution for their SME/Start-up client. Technology regularly used in higher education support the learning and work processes of the lab participants, building on open-source learning platforms such as Moodle and open source collaborative writing tools, screen sharing, video conferencing, mind mapping and chat, as well as hard ware such as Whiteboards, tablets, smart phones and 3D printers.

IoT Rapid Proto Labs work on research challenges as well as assignment from SMEs or a network of SMEs. The research challenges deal with part-products, processes and tools that support and facilitate solutions for problems brought in by SMEs (e.g., embedded electronics, software efficiency, robotics control and vision). Through a newly developed portal, SMEs or networks of SMEs can provide two types of assignments:

1. Problem-oriented assignment: the SME presents problems they do not know how to solve and lab participants try to find a solution, and
2. Product-oriented assignment: the SME presents an idea or a product and the lab participants to address its development with an inter-disciplinary approach.

The labs can work on, for example, integration or adaptation of existing technologies, market and product analysis, industrial design, product design, and use experience. This combination of working on research challenges and authentic SME problems and issues create an innovative research-industry collaboration, with co-creation and interactions in communities of students and users. IoT Rapid Proto Labs, remotely networked, support participants with different skills and experiences to share competences and collaborate to find out IoT solutions (see Figure 2).

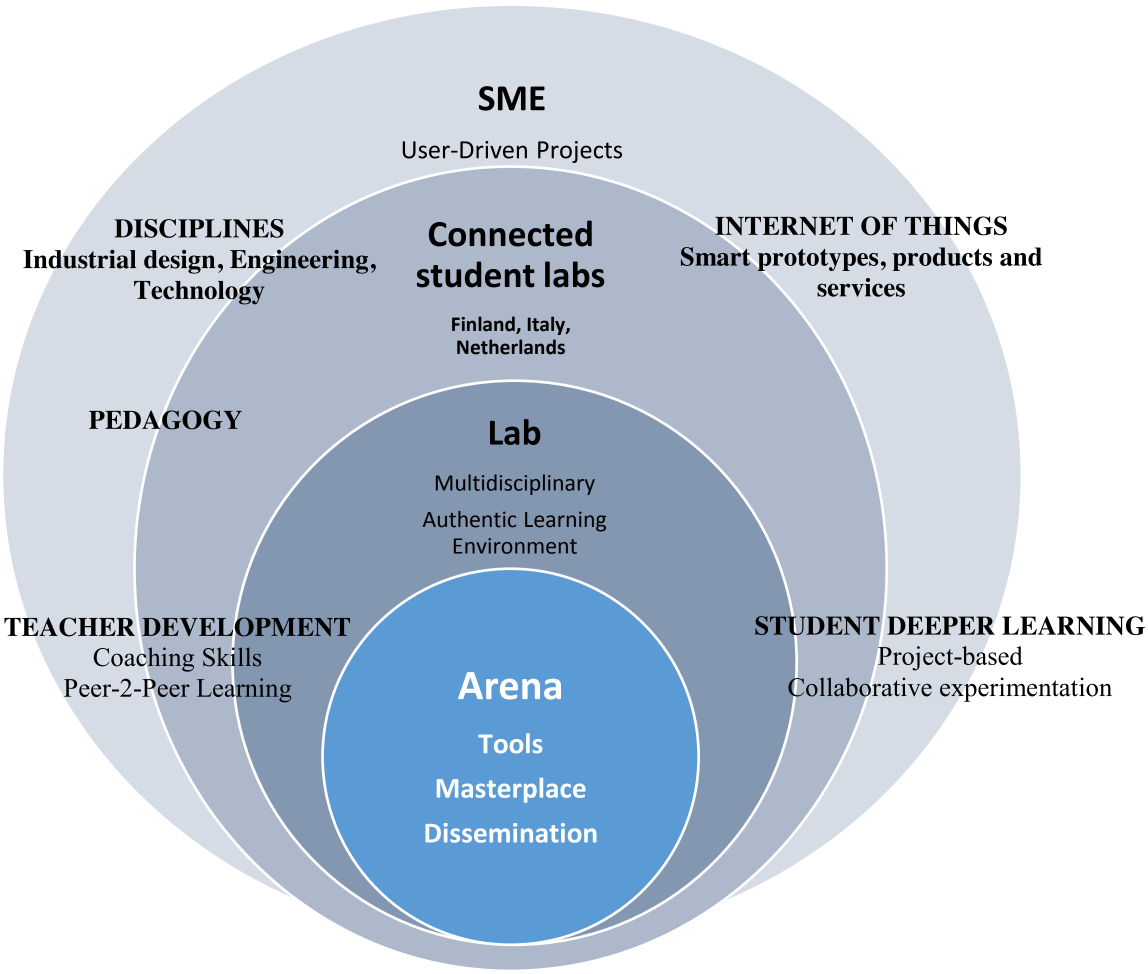

Figure 2. Design of IoT Rapid Proto Labs

Three examples of authentic task for IoT Rapid Proto Labs are summarized in Table 4.

Table 4. Three examples of authentic tasks of the IoT Rapid Proto Labs

1. Smart ski boots	**2. Wearable devices for affective computing**	**3. Smart devices for wheelchair user well-being**
A local company manufactures sport equipment and is particularly keen to innovate their line of ski boots. They are interested to innovate their product and add functionalities to attract customers. The company would like to develop a "smart boot" by adding sensing capabilities to it and provide the user with data analyzing of the skiing performance. In this case the project will cope with the search for existing solutions for sport motion analysis (e.g. inertial wearable sensors) and develop a solution which can be integrated within a ski boot and plan how it will be used. The project represents a real-life product development scenario and faces several multidisciplinary problems: • Product design: add-on for boot or integrate it; • Service design: just give the user sensors and data or provide an app and services to track/compare/share data; • Algorithms: which high-level information the system provide to the user; • Design: design of the product, ergonomic, usability, and • Business: existing solutions, market analysis, marketing approach.	Lab participants receive the assignment to study the development of a wearable device for implicit (no user interaction required) recognition of the user's activities and emotional state (affective computing). The device is worn by the user and it is accompanied by a smartphone app. There is a social component with friends connecting through social networks to compare activities and to exchange information/suggestions. The activities of the project include: • Study of requirements and technical specifications; • Development of hardware and software; • Data collection and development of algorithms for motion analysis; • Integration with smartphone app and backend for data storage and processing; • Integration with existing social solutions and development of a platform to share results/progress, and • Design of the product, design of its user experience, user acceptance evaluation.	Health and mobility are important pillars of well-being. Lab participants receive the assignment to design smart products and services for an internet-connected wheelchair using a domain-specific design platform. This platform is composed of standard hardware components only (Arduino, Raspberry Pi, Wi-Fi, Bluetooth, sensor) and communicates with the Data-Centric Design Hub via standards such as HTTP and MQTT. It comes with a step-by-step, get started guideline for designers without previous experience on IoT and a set of examples for sensing, processing and actuating. The platform supports students to inform, rapid-prototype and evaluate their design concepts in three phases: • Discovering: students receive a bare wheelchair to be transformed into a design platform learning about sensors, actuators and communication; • Experiencing: students use the wheelchair to collect and analyze data and try pre-set algorithms to control actuators, and • Designing: students design and prototype a product or service by extending or leveraging the design platform. For more information, see Bourgeois, Liu, Kortuem, and Lomas (2018).

Concluding Remarks

IoT Rapid Proto Labs are examples of student-learning labs in higher education in the STEM domain developing and improving cross-border, multidisciplinary collaboration, communication and problem solving. In addition to hardware and software tools for design and testing prototypes, various tools for student collaboration and collaborative learning are used supporting sharing files, screens and posts, editing documents, design, presentations and drawings and communication through email, video- and audio conferencing, instant messaging, online discussion, and live chatting (c.f., Al-Sammarraie & Saeed, 2018). These forms of collaborative learning in authentic productive learning environments might offer as effective ways to prepare students as future workers in the STEM domain.

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