1 Scientific Contributions on Online Labs

1.1 General Topics and Organizational Issues

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Fundamental Organizational Aspects of Shared Lab-Networks: Trust, Business- and Maturity-Model Considerations in DigiLab4U

Abstract

Online labs form the basis of digital exchange in networks and are thus candidates for the use of shared knowledge, shared infrastructure, and shared facilities through the application of ICT technology. In addition to technical and didactic considerations, the importance of organizational considerations in this respect is increasing due to shared use. In this paper, the organizational foundations of digital sharing are highlighted, providing a long-term perspective on lab networks. To this end, three organizational aspects are addressed: (1) a platform business model for activating online lab sharing, (2) considerations on building initial and long-term trust between actors as a critical challenge of a lab sharing platform, and (3) a maturity model for capturing the organizational transformation of online labs for platform actors. Using the case study DigiLab4U, a time-limited, funded research project on online lab sharing, this paper shows how the three organizational considerations can contribute to sustainability over the funding period. The reader is thereby shown which success criteria and functional requirements are necessary for the sustainability of a lab-sharing network.

Keywords

Sharing economy, Online labs, Platform business model, Trust, Transformation maturity model

1 Introduction

Science, technology, engineering, and mathematics (STEM) education requires applied tasks and problems to promote conceptual understanding, practical knowledge, and experience (Feisel & Rosa, 2005). Laboratories (labs) provide students with a special hands-on engineering experience and allow them to explore systems and their real-world behavior in a protected environment (Zutin et al., 2010). However, for universities, these specialized

labs involve high investment and operating costs, their utilization is often low, access is limited to local user groups (students and researchers), and the labs are subject to rapid loss of innovation (Heradio et al., 2016). In addition, funding for the labs is solely dependent on budgetary resources and grants and is therefore subject to corresponding funding fluctuations.

Digitalization technologies can be used to transform traditional labs, making them available online, allowing access to labs across locations, eliminating the need for in-person lab attendance, and thus enabling the delivery of lab experiences via distance learning (Mani & Patvardhan, 2006). These online labs are experiments supported by information and communication technologies (ICT) in which manual efforts are eliminated and can be accessed via the Internet (Zutin et al., 2010). According to Zutin et al. (2010), online labs are divided into software simulations (or virtual labs) and labs with real hardware equipment (or remote labs), through which they achieve advantages in availability, observability, accessibility, and security (Heradio et al., 2016). Expanded availability, where users can access online labs from anywhere and at any time, offers universities wide-ranging opportunities to increase usage through new business areas created by the transformed labs, as they can be used outside class hours (Gardel et al., 2012).

By making the labs available online, they can be shared with other facilities and users, opening up a new area of business and thus a potential constant source of revenue. The sharing economy describes behavior that promotes the sharing of resources to benefit from increased resource utilization, cost advantages, and access to new knowledge (Goudin, 2016). The digital transformation of labs to online labs makes them good candidates for the sharing economy, which means additional users can be reached. Several didactic and technological studies have already been conducted to measure the transformation from real to online labs, such as in Brinson (2015) and García-Zubía (2021). Research by Uckelmann (2012) has shown that in addition to didactics and technology, an organizational element is required for online lab sharing, so this paper explores (**RQ**): What are the fundamental organizational aspects of shared lab networks?

Using a case study methodology, this study focuses on three key organizational aspects: (1) a platform business model for activating online lab sharing, (2) considerations for building initial and long-term trust between actors as a critical challenge of a lab sharing platform, and (3) a maturity model for capturing the organizational transformation of online labs for platform actors. The case study is described in Section 2 and introduces the DigiLab4U research project, which explores lab sharing as part of the research mission and, like most such research projects, faces the challenge

of being sustained through the adoption of a business model after the funding period (Esposito et al., 2021). Section 3 then describes the three fundamental organizational aspects of shared lab-networks, further possible approaches, and their interplay for sustainable online lab sharing. For the business model as the first aspect, the following problem is addressed. Labs involve high investment costs, utilization is often low, access is limited to local user groups, labs are subject to rapid loss of innovation, and funding is solely dependent on budget and grant funding and thus subject to corresponding fluctuations. While classic business models do not seem to work, the question of what success criteria and functional requirements should be placed on digital labs is outlined. The second aspect describes the success criterion of trust for the business model in more detail. Trust should be a core element in sharing digital goods such as online labs (Gossen et al., 2019). We, therefore, show how technology-based initial and long-term trust development is approached. Building on this, we show why this is a core element for the sustainability of the sharing business model and how initial and long-term trust can be leveraged for sharing labs. Finally, as a third aspect, it is clear that the effectiveness of the digital transformation of the lab should be made transparent to the user and the platform operator, as has been shown many times for both didactic and technical transformation (Heradio et al., 2016). This could be used by lab operators for design, implementation, or improvement and by users such as students for comparability to build trust. Section 4 then discusses the results, interplay, further approaches, open challenges, and a possible way forward for shared laboratory networks before Section 5 concludes the paper.

The authors point out that individual aspects of this publication have been published before, but the interaction of the aspects is new.

2 DigiLab4U as a Case Study for Shared Online Labs

The mission of the DigiLab4U research project is to make real labs accessible and shared online. Participating institutions work across international borders to achieve common goals for teaching, learning, and research. Collaboration among universities and research institutions allows resources to be pooled so that faculties, learners, and researchers have access to a greater variety of digital courses based on different labs. Currently, the project relies solely on budget and grant funding and is therefore subject to corresponding fluctuations. The inclusion of potential user fees is intended to open up a third pillar of funding and thus create a viable business model that enables sustainability beyond grant funding.

Many research projects, such as the DigiLab4U research project, can be seen as a virtual organization whose typical customer is the funding organization. Their common goal and vision are described in the project proposal and in the statement of work (Seifert, 2009). These are temporary and end when the funding ends. When the temporary lab network is transformed into a sustained, long-term form of collaboration, the goals of the participants may change from jointly meeting the needs of the funder to goals that fit into the long-term business strategy. In some cases, the goals will change only slightly. In other cases, the partners will have such different goals that they will end the collaboration. The corresponding business model will change, however, as the revenue streams will change because the interested funder will have to be replaced by a different type of customer.

Various technical and didactic measures have been taken to best meet the needs and preferences of DigiLab4U stakeholders. The success of operating shared resources in a collaborative network depends not only on business considerations that take into account the needs of all stakeholders, but also on trust between stakeholders and the maturity of the online lab transformation. The introduction of a user fee as a business model changes, among other things, the stakeholders and their goals and relationships.

3 Trust, Business and Maturity Models as Organizational Aspects

Students, researchers, professors, universities, and institutions need organizational measures that go beyond technical and didactic measures to organize and sustainably map the sharing between the stakeholders. These organizational aspects are outlined below and thus form the necessary framework for the successful introduction of a sharing business model. To this end, we first outline a business model that addresses stakeholder needs, initial and long-term technology-based trust to leverage the business model, and a maturity model that maps the effectiveness of transforming an online lab for users.

3.1 A Multi-Sided Platform to Activate the Sharing of Online Labs

Sharing is originally a private matter, but new concepts for sharing goods and services between individuals and companies are emerging worldwide (Beutin, 2018). Sharing is now taking on far-reaching new forms, such as car sharing, code sharing, file sharing or food sharing, and is conquering new business areas with innovative business models. The underlying concept

of the sharing economy describes behavior in which either individuals or organizations seek to share existing resources, such as human, tangible, and intangible resources (Goudin, 2016). At first glance, the sharing economy for digital labs offers benefits to providers through increased utilization, and the customer side gains access to a greater supply of labs.

According to Eikaas et al. (2003), a major obstacle to a sustainable business model is "*the willingness of customers to buy access to laboratory resources*". The benefits of sharing must be demonstrated over direct access, and the real benefits are the selling point. Customers expect valuable content, ease of use, affordable services, access to otherwise inaccessible materials and equipment, and customer support (Kammerlohr et al., 2021). In addition, sharing must be trustworthy. This point relates to both the functional and success criteria of sharing. Compared to physical markets, where trust is built through relationships, the digital environment currently uses transparent rating systems that consider the quality and reliability of the actors (Schallmo et al., 2017). Nevertheless, this does not achieve the interpersonal trust that comes into play in social contacts, as discussed in more detail in Section 3.2. However, a closer look at possible user groups, such as industry and students, also shows that they have different requirements (Kammerlohr et al., 2021). For industry, for example, integration into the corporate structure, data security, and the protection of intellectual property are of great importance. For students, on the other hand, the added value must be recognizable in comparison to or in addition to their regular lectures.

Thus, a business model for online labs is needed that is tailored to the needs of customers and providers while fulfilling the trust in network organizations. Following the business models of the leading providers in the sharing economy, a multi-sided platform would be suitable for the activation of the concept. A multi-sided platform is an intermediary for exchanging value between interested parties and providers from two or more markets (Zhao et al., 2019); for example, it is used by Airbnb (landlords and renters), eBay (buyers and sellers), and Facebook (users, advertisers, and content developers). In the DigiLab4U concept, the universities would offer various online labs, and students could meet their needs via a corresponding platform. Here, the interested parties are the students, and the providers are the universities. The marketplace is the DigiLab4U platform, where the joint exchange and coordination service takes place and supports matching providers with buyers (European Commission, 2013). The main difference with a traditional business model is that the DigiLab4U marketplace does not acquire ownership of the resource traded and therefore has no influence on the way it is presented or the price. The terms of sharing are therefore directly controlled by the provider and the buyer. The online lab provider

must therefore keep its offer and prices attractive to attract and retain buyers. More users on both sides (supply and demand) increase the benefits of the Digilab4U marketplace, the so-called network effect (Abdelkafi et al., 2019).

The challenges of a multi-sided platform, according to Henseling et al. (2018), are: (1) building user trust, (2) evolving what the marketplace offers, and (3) attracting new user groups. In addition, the life cycle of a marketplace is described as consisting of three phases (Abdelkafi et al., 2019 ; Otto & Jarke, 2019): (1) design: technological architecture and innovation of the platform (software and hardware), (2) dynamics: evolution of the platform and ecosystem by attracting users and adding new functionalities, and (3) performance: scaling, growth, and competitive success. The challenges for a multi-sided platform, such as developing trust, need to be addressed first, and depending on the current phase of the marketplace, the other goals and associated challenges afterward. Trust is extremely important for the development of the online lab, as a loss of trust could lead to the collapse of the network effect.

In the example of DigiLab4U, the user must trust that the online lab will be available at the right time and in the expected condition, while the operator, e.g. the university, trusts that the lab will be used correctly and under the conditions agreed upon and that no damage will occur. Particularly with online resources such as online labs, the parties involved may not know each other and must have confidence that each other's requirements will be met. Independent information from third parties can provide clues to this and help to build initial trust before one's own experience can be gained (Ba et al., 2003). Two further organizational aspects for the DigiLab4U shared lab network can be derived from the business model: first, a model for the marketplace that initially, but also in the long term, builds trust between the provider and customer to avoid disruptions in the network; second, a maturity model that allows providers to pre-evaluate the effectiveness of the online lab's transformation, and that provides a kind of trust reference for the user of a third actor that evaluates the effectiveness of the online lab's organizational transformation.

3.2 Trust to Leverage the Business Model and Increase Organizational Effectiveness

In general, trust arises from and in relationships, and therefore it can be created and destroyed (Flores & Solomon, 1998). A trust relationship involves two parties, there is uncertainty and risk, and the trust giver relies on the honesty and goodwill of the trust taker (Siau & Shen, 2003). A distinction

is made between weak and strong trust relationships, with a strong relationship characterized by feeling secure and trusting that our partner can rely on us and will respond to our needs (Rempel et al., 2001). Trust occurs in various social contexts and can arise both between individuals and between individuals and organizations as a hybrid form (Zaheer et al., 1998). A further distinction is made between trust that already arises on the basis of an existing trust relationship and trust that must first be established. In addition to initial trust, there are trust models that reflect the development of trust during the interaction of the parties, such as that of Lewicki and Bunker (2010). The transitional stages of their trust development model describe how two parties form and develop a new relationship and explain how trust and relationships change, develop, or decline over time and how trust can be restored. In doing so, the transitional stages of the trust model maps different benefits and different costs for each stage (sequential iteration) (Lewicki & Bunker, 2010).

In contrast to trust in a social context, online trust or technology-based trust is increasingly being studied, e.g., e-commerce (Gefen, 2000), trust in smart personal assistants (Zierau et al., 2020), in blockchain platforms (Zavolokina et al., 2020), or for entire research disciplines such as information systems (Söllner et al., 2016). The difference with online trust is that in an online situation, it is more difficult to reasonably assess the potential harm and goodwill intended by others (Friedman et al., 2000). To this end, new methods have been developed, such as a user-centered rating system, trusted third-party certifications, or trusted third-party recommendations. Long-term trust conditions have not yet been used in technology practice because the focus to date has been on initial trust rather than the impact of long-term development. Similar to Lewicki and Bunker's (2010) model, Williamson's (1993) transaction cost theory follows a parallel idea when parties begin to validate activities in terms of trust to build a knowledge base about their needs, preferences, and priorities. According to this theory, a transaction can be processed and organized more or less efficiently, which describes the transaction costs. An adaptation of this transaction concept for trust in a technology context could map trust interactions into a trust-level model and promote benevolent behavior through lower (transaction) costs. For example, a user with a higher level of trust will be more willing to accept a trusted online lab offer because they will expect the transaction costs to be lower. One way to provide information to users to build long-term trust is to develop technology maturity models, as described in the next section, which are enabled by a business model by influencing costs through trust levels. The combination of a business model and a maturity model, both of which promote long-term trust, should ensure that after

the initial trust, there is stakeholder interest in building a long-term trust relationship, thus underpinning the sharing.

3.3 Maturity Model for the Effectiveness of Digital Lab Transformation

Digital transformation is defined by Pousttchi et al. (2019) as a change process that companies undergo due to the emergence of new technologies and their social and economic impact. Digital transformation of labs is therefore defined as a continuous development process that goes beyond the emergence of new technologies and their social and economic impact to include the construction of a new business ecosystem. Various studies measure this transformation from a didactic and technical perspective in order to make its effectiveness transparent to stakeholders and to build trust. The pedagogical effectiveness of online labs at different stages of digital transformation as an indicator of the usefulness of an experiment to achieve the desired goal has been studied by various authors, e.g., Brinson (2015). Similarly, studies on technological effectiveness, such as the design, development, and implementation of different digital lab transformations have been pursued, as by Prada et al. (2015). Corresponding maturity models for both areas can also be found in research literature (Abbas, 2019), but a model that takes into account organizational change towards sharing between institutions and thus the needs of users and operators is currently lacking. The organizational effectiveness of digital lab transformation has not been further researched since then but has gained importance over time due to the changing requirements of lab sharing, such as building initial trust between different actors and organizations. Numerous international research projects involving online labs have failed to continue the environments developed after the project funding phase (Esposito et al., 2021), not least due to lack of effectiveness.

Digital lab transformation effectiveness is defined as the evaluation of the lab's digital transformation efforts with the goal of sharing (Kuntsman & Arenkov, 2019). In this study, effectiveness is specifically defined as the quality of the change process organizations undergo that involves technology and its social and economic impact. Specifically, effectiveness is about four dimensions: (1) universality and accessibility, (2) user management, (3) scalability and extensibility, and (4) learning support. These are aligned with Garcá-Zubía's (2021) structures for the requirements of a remote lab management system and the characteristics of a remote experiment. Universality and accessibility describe if and how a lab is accessible to the user in any technological scenario and refer to the original design of the experiment (García-Zubía, 2021). In this context, Prada et al. (2015) added easier

support and efficient management. The second requirement, user management, consists of four subsections that describe how users gain access to online labs, how their data is managed, what user rights they have, and how their experiment data set is stored (García-Zubía, 2021 ; Ying & Zhu, 2004). The third requirement is scalability and extensibility, which consists of five subcategories. Scalability and extensibility describe how easy it is to adapt the labs to new audiences, expand them to include more experiments, extend them to more facilities, certify the results, and ensure sustainability (García-Zubía, 2021). The fourth requirement is learning support or pedagogical effectiveness, i.e., whether and to what extent the online laboratory supports coursework (García-Zubía, 2021). As Kara et al. (2010) stated, "*effective learning in engineering education can only be achieved through approaches that link theoretical courses to the laboratory*." The lab supports not only experimentation, but also social coordination, the lab environment, and individual differences (Nickerson et al., 2007). We distinguish between learning environment, interactivity and realism, technical support and maintenance, and didactic support.

In terms of application in the DigiLab4U project, it should therefore be further investigated whether the effectiveness of digital lab transformation in support of the sharing economy can be mapped in a maturity model. The practical use of DigiLab4U promises comparability of the effectiveness of shared labs, both from the provider's perspective in terms of administrability and financial and personnel effort, and from the perspective of demand in terms of learning success. The theoretical perspective has shown that the effectiveness of digital lab transformation assumes that criteria are subject to multiple truths and that these are determined by the subject matter and the underlying use case. Therefore, a constructivist approach based on multi-stakeholder interaction should be used to gain insights into and build knowledge about the effectiveness of labs' digital transformation within the shared DigiLab4U network.

4 Discussion

Returning to the research questions, we can conclude that this research has provided an overview of the fundamental organizational aspects of shared lab networks through a general understanding of business models, trust, and maturity models for digital labs. Specifically, a business model that promotes sustainability by enabling online lab sharing. A maturity model that can determine the effectiveness of digital lab transformation, and a consideration of trust as a key element of platform business.

As described in the second phase dynamics of the life cycle of the multi-sided marketplace, the platform and the ecosystem should be further developed depending on the current situation (Otto & Jarke, 2019). In addition to the three organizational aspects already described, there are numerous other ways to further develop the business model marketplace and keep it attractive to customers, which we divide into central services, individual services, and community services. By central services, we mean applications that are offered centrally from the marketplace to improve matching, for example. We think of cooperative resource management, from which a common booking and billing process, work properties and resources, and common and standardized terms of use emerge, but also a booking system that is able to cover the different needs of user roles, such as a recurring event for a lecture series. Associated with this should be a flexible billing system on a transaction basis to map the described levels of trust, individual but also standardized, national and international, and billing for companies and universities. Individual services are services provided by the marketplace on an individual basis, such as lab didactic or transformation services, research services, or the sale of processed research data. Community services are actions taken to build and sustain the community as an ecosystem around the marketplace. Simple things like a shared vision, or mission statement can help, but so can conferences, awards, badges linked to learning paths for external visibility of learning success, or individualized advertising for job openings or research contracts.

Generalizations can be applied to related application areas such as vocational training, but also to broader areas such as shared infrastructures and digital transformation, e.g., the business model of shared resources, as in research facilities for industry and research, or the effectiveness of transforming the digital infrastructure of government agencies or universities. Technology-based initial trust and long-term trust could be generalized in order to build trust in new technologies.

Limitations arise from differences in the education system, such as regional differences in the willingness to pay for education and the degree of digitalization. One problematic issue is the willingness to pay; traditionally, education in Europe has been free. Students accept that the cost of a digital lab must be paid, but there is considerable dispute about whether the state, the university, or the students themselves should pay for it. Another limitation is the language and cultural differences that affect the type of education (practical vs. theoretical) and the level of education (BA, MS, PHD). In addition, regional taxes and public sector billing may impose limitations.

5 Conclusion

This paper addresses the problem of sharing online digital education resources for STEM subjects. Lab exercises to gain hands-on experience and practical knowledge play an important role in the education of future engineers and scientists. Online labs can be used to gain this experience online. However, sharing online labs is currently insufficient; in fact, a large percentage of lab providers fail to keep them running (profitably) after research funding. This paper addresses this problem by highlighting the organizational aspects of online lab sharing to provide a long-term perspective for lab networks and to serve as a foundation for online lab sharing between providers and buyer. The analysis includes three different organizational proposals for improving the sharing of these labs to increase sustainability, using DigiLab4U as an example. The research potential, generalizations, and limitations were highlighted.

The next step is to further explore the organizational aspects scientifically and put them into practice using DigiLab4U as an example to gain insights and experience. This will provide a more detailed insight into the community, further elaborate on buyer and provider demand, make different online lab transformations organizationally comparable, clarify dependencies in more detail, and test the initial but also the long-term trust network. In addition, experience can be gained from later life cycle phases of the multi-sided platform business model for sharing online labs.

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