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Guiding the design and implementation of interactive public displays in educational settings

Maximilian Müller[1] · **Nuno Otero**[2,3] · **Marcelo Milrad**[1]

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Abstract

Interactive Public Displays (IPD) enable new ways of interaction as well as communication channels, extending online communities into physical places and supporting a culture of participation. While educational environments have seen how new digital technologies can enhance learning activities beyond the traditional classroom context, the use of IPDs is still an area insufficiently explored. This paper proposes a set of design goals for the implementation and deployment of engaging interactive public display applications in educational settings. Based on findings from a series of design workshops and two deployment studies in authentic settings, seven design goals were identified and defined. The design goals provide clear guidelines for the design of IPDs for schools by making design teams and stakeholders focus on factors fostering user adoption, social interactions and collaboration. The design goals also opened up paths for further explorations regarding display awareness, level of commitment in interactions, the displays' integration into structured activities, and display management at the educational institutions.

Keywords Interactive public displays · Informal learning · Design guidelines · Technology-enhanced learning · User engagement

✉ Maximilian Müller
maximilian.muller.extern@lnu.se

Nuno Otero
N.R.PalmeiroOtero@greenwich.ac.uk

Marcelo Milrad
marcelo.milrad@lnu.se

[1] Department of Computer Science and Media Technology, Linnaeus University (LNU), Växjö, Sweden

[2] School of Computing and Mathematical Sciences, University of Greenwich, London, UK

[3] ITI/LARSYS, IST-U. Lisbon, Lisbon, Portugal

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Introduction

Digital technologies are providing new means for creating, disseminating and interacting with digital content in a variety of contexts: we are experiencing a shift from a culture of one-to-many media consumption to a culture of many-to-many media creation and participation, with lowering barriers to artistic expression and civic engagement (Jenkins et al., 2009). Young people are becoming more technologically savvy, but empirical results also suggest that they need to master a wider range of so-called *New Media Literacies* (NMLs) (Jenkins et al., 2009). NMLs can be seen as a set of cultural competencies and social skills that people need to be able to master in our emerging new media landscapes, extending aspects already taught in the traditional educational institutions, such as conventional literacy, technical skills, and critical analysis (Dede, 2010; Jenkins et al., 2009). Educational institutions are asked to emphasize understanding the challenges involved in using the novel interactive features and ways of publishing of new digital media channels: students need to comprehend the underlying purpose of the content, the message to be delivered, target audiences and the dissemination context (Jenkins et al., 2009).

Digital public displays are part of this new media landscape and enable interactive content dissemination allowing the audience to engage with content directly and can thus facilitate a participatory culture (Churchill et al., 2004; Jurmu et al., 2014; Memarovic, 2015). Digital public displays can extend students online communities' participation into the schools' physical contexts. Moreover, a network of displays connecting several spots, can facilitate a new communication medium (Davies et al., 2012), engaging distributed communities (J. Müller et al., 2014). However, research has shown that the display systems often see lower than expected acceptance and attention (Müller et al., 2010). And while the importance of how to convey a system's interactivity and engage users to interact has been investigated in a variety of settings (Agamanolis, 2003; Akpan et al., 2013; Michelis & Müller, 2011; Parra & Duval, 2014), only few works investigated interactive public displays in educational settings specifically, e.g. (John & Rist, 2012; M. Müller et al., 2014). In terms of the content that can be displayed in digital public displays in educational contexts, video and multimedia repositories for educational purposes have experienced wide popularity over the last years (e.g. TED, NeoK12, WatchKnowLearn[1]).

This paper reflects about the potential of using interactive public displays (IPDs) to convey educational videos and associated activities at public locations in schools. Moreover, based on an ongoing line of research that includes several empirical studies investigating the design and interactivity of IPDs, this present contribution proposes a set of design goals that should be able to facilitate the definition of the design space of IPDs for educational contexts. Designing public displays for such settings needs a well-informed understanding of contextual factors that will influence their adoption and actual use. Studies around public display systems often seem opportunistic without defining clear design goals or addressing the requirements for

[1] www.ted.com; www.neok12.com; www.watchknowlearn.org.

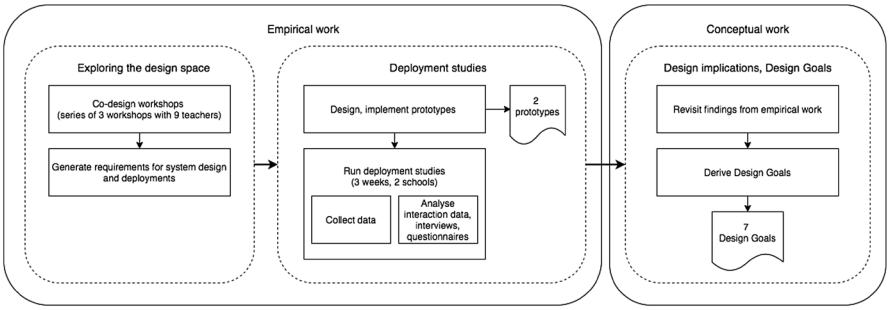

Fig. 1 Overview of steps taken to address the research objectives of this article

the specific context. To get insights into this complex weave of factors, a multi-step research process was conducted, as can be seen in Fig. 1. Overall, this comprehensive process comprised design workshops, prototype implementations, deployment studies, as well as the definition of a set of seven design goals.

As an initial step, during the course of eight months, three co-design workshops with nine teachers were run focusing on possible features and interaction techniques as well as infrastructure and ethical considerations (Otero et al., 2013a, 2013b). The sessions aimed to define a set of requirements that would help to guide the design of IPD applications. We then designed and developed two prototype applications around educational videos. Two deployment studies introduced the prototypes into authentic educational settings which allowed to investigate the users' adoption and behavior around them (M. Müller et al., 2014). The current article extends the first two steps by looking back at the findings from these empirical studies and derive and discuss seven design goals based on them. This allows to abstract knowledge aiding the design of future IPD systems, for a similar generic goal see (Höök & Löwgren, 2012). The work was guided by the following research questions:

- What are the central challenges related to the design and implementation of engaging interactive public displays for educational environments?
- Which features and functionalities need to be taken into account when designing and developing such systems?
- How can the integration of interactive public displays in educational environments be facilitated?
- How do these aspects influence the adoption and use of such systems?

The remaining of the paper is organized and structured as follows. In the coming section we present a discussion of related work regarding the use of public displays in educational settings. We analyze those efforts to identify which features and processes have been supported. This analysis identified challenges of IPDs as well as a gap in knowledge of implementing IPDs for educational settings. The following sections describe (see Fig. 1): the co-design process leading to the definition of requirements and implementation of prototypes, a description of the evaluative studies of

our display system as well as their findings, and finally a presentation and discussion of seven design goals for IPDs in educational settings.

Related work

The related work discussed in this section will focus on digital public displays that were either only tested in educational environments or designed for educational purposes, which will be presented in two separate sections below. Several research projects have investigated (large) shared digital displays in classroom settings used for more formal teaching activities. In such settings, shared displays allow for increased participation in collaboration and group work (Liu et al., 2009) and supported keeping track of other's work and class discussions (Lamberty et al., 2011; Verbert et al., 2014). Still, characteristics of such systems and settings do not necessarily apply in the more open settings outside the classroom, e.g. in corridors, communal shared spaces or schoolyards, which potentially hinders to utilize such systems to their full potential.

Interactive public displays in educational settings

Some projects addressed specific characteristics of universities, aiming to provide helpful information for students or visitors (John & Rist, 2012; Müller et al., 2007) or care for the student audience and community interactions (Day et al., 2007; Memarovic et al., 2012, 2016; Ostermann et al., 2015). But others often seem to be deployed or tested in university settings as a matter of accessibility and convenience, being an obvious choice for research groups working at universities and thus making use of their place as a testbed. This regards especially cases in which no reason for choosing an educational environment was given and no specific implications for the settings were made, e.g. (Alt et al., 2011; Greis et al., 2014; J. Müller et al., 2014; Paay et al., 2017).

Dynamo (Brignull et al., 2004) was a large multi-user interactive display system for sharing and showing multimedia content deployed in a communal room of a high school. Dynamo provides access from mouse and keyboard pairs allowing multiple users to interact with it simultaneously. Even though the students had experience with similar applications on single-user devices, the introduction of Dynamo into the common place engaged them in group discussions and interactions, reshaping their existing social practices. The display application by Tang et al. (Tang et al., 2008) allowed to submit votes and opinions on non-educational topics by sending a SMS with specific coding. A study in a hallway at a university allowed to identify three different types of bystanders: passers-by; standers-by that have time to explore the system, but do not interact; and engaged bystanders that are interested in the content and consume it, with a chance that they will interact. These three types of bystanders suggested features that regarded engagements based on distance, low-barriers for interactions and covert interactions to avoid social embarrassment.

Being deployed at schools and universities, the displays are usually publicly accessible, which entails a risk of posting inappropriate content in general. Instant Places (José et al., 2008) has been deployed in different educational settings. Some of the studies conducted involved several months-long deployments at a university's campus bar (José et al., 2008) and a common area at a secondary school (Otero et al., 2012). Instant Places allowed users to contribute and adapt photo and text content. Otero et al. (2012) investigated ways for approval of user contributions in a high school. Centralized approval practices were necessary due to organizational constraints, but the study found that such practices lowered the users' actual exploration and use of the system (Otero et al., 2012). The UniDisplay investigated expectations towards public display applications regarding posting behaviors and the impact of waiting times due to content moderation and approval (Alt et al., 2014; Greis et al., 2014). Users were able to post text messages and photos via a twitter user handle. A two-month long deployment study showed that user-added content decreased with an extended waiting time, but also that the waiting time did not influence their decision to post at all.

Public display installations can foster community interactions at a place. Applications around shared interests and activities aim to increase the sense of belonging and connectedness among the student audience (Memarovic et al., 2016), or prevent students on a university campus from feeling isolated and cut off from the outside world (Day et al., 2007). Day et al.'s (Day et al., 2007) study around the UniVote public display application informed students about campus- and worldwide news/events in the form of votings, allowing students to engage with content outside their own bubble on campus. Contextually relevant content and polls that do not relate to or repeat class work and lecture content were also investigated by CommunityConnect (Ostermann et al., 2015), a display application specifically designed for a residence hall for undergraduate students at a university. Memarovic et al. (Memarovic et al., 2016) deployed the Moment Machine 2.0 on four displays on a university campus that allowed to take situated snapshots. The application connected known and unknown groups of people, recognizing that they are part of the same community.

Müller et al. (Müller et al., 2007) installed several non-interactive "iDisplays" on a university campus informing the audience about news and events taking place on their campus. Even though the researchers provided means for the creation of the content, they found challenges for the staff to integrate the generation of content into their general workflow. Similar challenges of finding content or involving people to generate content were reported by John and Rist (John & Rist, 2012): students generally had lower interest in entertainment content and higher interest in news on their displays. Placing the displays at main entrances and the cafeteria was beneficial for attracting students towards the content.

The e-Campus project at Lancaster University has deployed displays in foyers of colleges, departments and lecture halls (Friday et al., 2012). Besides being a research testbed, the display system is used by the university as general digital signage and emergency alert solution (Almutairi et al., 2019). Besides interaction techniques with dedicated apps on mobile devices, the system also supports implicit interactions to personalize display content (Davies et al., 2009; Mikusz et al., 2021). Long-term findings suggest that universities have their own way of adopting such

digital signage system into their practices (Clinch et al., 2011). For example, sophisticated mechanisms for controlling timings and sequences of showing content can be counterproductive. Images were most popular content types, because they were easy and fast to create for the university staff.

Patterson and Clinch (Patterson & Clinch, 2018) added interactivity to public displays at their university showing slides with aggregated information from university social media accounts and department newsletters. The added interactivities were text commenting and the ability to switch slides. Commenting was not a well-received feature of the application, while viewing the comments was a popular activity done by users. The feature of switching slides was liked and made use of: the users liked to be in control of what was shown, but active contribution to the display content remained a challenge for the design.

Interactive public displays with educational purpose

Ambient displays embedded in their context of use can support learning activities of users and their effect depends on the level of situational awareness required (Börner et al., 2013). Work by Börner et al. (Börner et al., 2011, 2013) suggests a value of such devices in the context of technology-enhanced learning since they allow "learners to view, access, and interact with contextualized digital content presented in an ambient way" (Börner et al., 2011) opening up new possibilities for educational scenarios. For example, they deployed an ambient learning display at a university campus with information and guidelines for first responders in emergency situations (Börner et al., 2014). Their results suggest that the public display system was able to attract and retain the attention needed for the comprehension of the presented information. Less positive results were reported by Mikusz et al. (Mikusz et al., 2018) who deployed an educational application with "memory cues" on their network of displays. The memory cue contained a slide and an image of the lecture in which the lecturer talks about this slide/topic. The idea was that students would be exposed to non-interactive bits from lectures while being at the university to improve student recall. But a longitudinal study could not show any impact on the student performance and the creation of educational content proved to be difficult. Interviews revealed that students did not remember seeing their content and did not pay attention to the displays.

With an emphasis on interactivity, gamification and direct manipulation of display content, Barth and Müller (Barth & Müller, 2017) report technical explorations and initial implementations of a technical framework for interactive public displays for informal learning. Initial findings showed that gamification seems to be a beneficial component for the user experience of educational applications on public displays in educational environments. Madeira (Madeira, 2010) presents a technical framework for ubiquitous learning on public displays where users would interact with their mobile phones. While these projects seem promising and fit our efforts described in this article, both lack evaluations to this point and have not been deployed in authentic settings.

Herczeg et al. (Herczeg, 2022; Herczeg et al., 2021) present their Ambient Learning Spaces for teaching and learning with interactive digital media in context. Their system entails several educational applications accessible on public displays—media gallery, timeline and semantic networks. The authors also only focus on presentation of system architecture as well as scenarios and examples of the applications.

Ahn et al. (Ahn et al., 2018) aimed to connect learning experiences over different settings making use of public displays deployed in schools, church and afterschool programs. Students created posts about their science projects on a mobile app that are then shown on the public touch displays, which allowed the broader public to interact with them. The display app allowed to filter and scroll through these posts on the display and also to select posts and give feedback in form of badges to them. Field studies with the display system showed benefits for the students as their work was noticed in the community and engagements around the display allowed to reflect on their prior learning activities on their own and with parents. Still, crucial for the success of the system was an "institutional infrastructure" including volunteers, facilitators and events (Ahn et al., 2018).

Summary of related work: Opportunities and challenges

The overview presented suggests that more research is needed especially regarding the application of IPDs for collaborative learning and edutainment environments. IPDs introduced new and also reshaped existing social practices, mediated by the display and its content (Brignull et al., 2004). They further could support a sense of belonging and being connected as part of the student community (Day et al., 2007; Memarovic et al., 2016; Tang et al., 2008). Showing visual content such as photos (Clinch et al., 2011; Greis et al., 2014; José et al., 2008) and providing smaller, simple interactions such as polls (Day et al., 2007), games (Barth & Müller, 2017), tweets (Greis et al., 2014) and posting photos (José et al., 2008; Memarovic et al., 2016) showed to be beneficial. But it needs to be further investigated how these qualities could be exploited for the design of educational applications for IPDs. The projects actually having an educational purpose were mostly non-interactive (Börner et al., 2014; Mikusz et al., 2018).

Identified challenges are: (a) the different roles in the audience and designs addressing them (Brignull et al., 2004; Tang et al., 2008), (b) content creation and contribution by staff as well as students (Clinch et al., 2011; Friday et al., 2012; Müller et al., 2007), (c) content moderation (Greis et al., 2014; Otero et al., 2012), and (d) the importance of the integration at the institution, including staff and organizational aspects but also activities and events (Ahn et al., 2018). An overarching concern raised in the related work was a lower than expected user engagement and generally low usage of the systems (Clinch et al., 2011; John & Rist, 2012; Mikusz et al., 2018; Müller et al., 2007; Patterson & Clinch, 2018).

Although the examples show the promise and the potential for large screen IPDs in educational settings, many challenges lay ahead regarding the way the affordances of this technology can be harnessed. To address matters regarding the integration

and organizational aspects as well as instructional means it is important to integrate stakeholders at schools into the design process (Roschelle et al., 2006).

Design approach: Towards the creation of design goals

In order to explore the design space concerning IPDs for educational settings, three co-design workshops with nine secondary school teachers of two schools were conducted. From a methodological perspective, such design activities in accordance with design research (Edelson, 2002; Muller & Kuhn, 1993) provide a productive approach for knowledge development. In this case, this regards design goals, a form of intermediate-level knowledge residing between theory and practice (Höök & Löwgren, 2012). The goals and constraints of the design challenge set in these activities guide the process and are beneficial in dealing with the complex factors when designing technologies for educational settings (Roschelle et al., 2006). The main objective of these workshops was to explore the design space and understand the expectations of the teachers/stakeholders. The workshops elicited sensitivities towards possible features and interaction techniques as well as inquired about expectations and technology adoption.

Teachers and school administration are important stakeholders in the design process of digital technologies for schools. Although students are the main user group and audience of the display applications, ensuring that teachers and the school administration are engaged with the design process is key to enable adoption at school level and foster the integration in the overall school's activities. Teachers are eventually responsible for most of the activities and corresponding content. Input from the teachers allowed to focus on the design of features that could be integrated into learning activities at the schools and facilitate adoption. However, the technology of interactive public displays was novel for the teachers and the students and an important challenge of the design process was to manage expectations concerning what was possible and understand how this user group can contribute to the design (Scaife et al., 1997).

Methodology of the workshops

The first two sessions included hands-on activities in which the teachers expressed their understanding of the displays' potential and created paper prototypes and usage scenarios of display applications (Fig. 2). To finalize the sessions, teachers received questionnaires inquiring about advantages and disadvantages of the technology, potential ethical issues and the design process itself. In the third workshop our first developed prototypes based on the teachers' designs were discussed and approved. The data collected at the workshops included: (a) notes from the conversations taken by the researchers; (b) scenarios and paper prototypes developed by the teachers; (c) answers to questionnaires.

The main outcomes of these workshops can be divided into: requirements regarding the application functionalities, interaction design, infrastructure and

Fig. 2 Workshop session with teachers

ethical considerations. These findings emerged from a qualitative analysis approach in which the researchers and design team together discussed the data collected (notes taken during workshops, outcomes of the paper prototyping, submitted questionnaires) generating meaningful interpretations of it. The following section will present the prototypes developed based on the results of the workshops.

Features of the prototypes

The public display system focused on interactions with educational videos picked by the teachers in accordance with their planned learning activities. All teachers confirmed they would usually show such videos during classes or ask the students to watch them as homework. Showing them on the public display at the schools would allow learners to consume and engage with the content in more informal settings in a collaborative fashion.

Creating opportunities for further interaction was considered important and the idea of providing and creating quizzes related to course material was mentioned in all the workshops conducted. It was discussed that quizzes have the potential to fill the gaps between lectures with educational content in a playful way. They provide a familiar concept for students, but in contrast to tests, they are more light-hearted and for entertainment. These interactions provide challenges that could motivate the students to pay attention to the content on the public displays and learn about topics in a less formal way (Ryan & Deci, 2000). With the applications the students were able to actively engage with the educational video content shown on the public displays through video-based quizzes and video ratings. Quizzes and tests in schools have been mostly individual activities, as was consuming (educational) videos on desktop computers and mobile phones. Personal mobile phones can be used to interact with the applications on the public displays, which allows synchronous single and multi-user interactions. Enabling multi-user interactions highlights one of the main value propositions of IPDs that is creating shared experiences. The system comprises a mobile endpoint (mobile website) with web apps showing a multiple-choice quiz

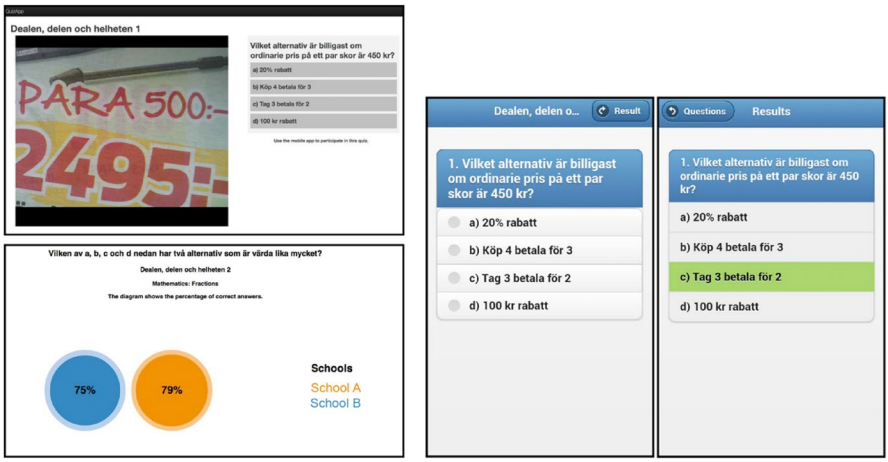

Fig. 3 Display application showing video, quiz question and result visualization; and mobile views with multiple choice answers and direct feedback provided

as well as a five-point rating scale interface which facilitated user participation. The public display also presented aggregated scores and results of the quiz to the students, i.e. a comparison of positive answers between schools and a comparison between classes of the schools. This comparative visualization aimed to explore the design of playful mechanisms. Screenshots of the mobile and display applications can be seen in Fig. 3.

The display system allowed the integration and presentation of other kinds of applications and content. For that, the browser-based application scheduler cycled through a list of applications. Making use of web-based applications running in the browser allowed to make use of the schools existing display infrastructure: large screen displays connected to a PC with internet access. Since our developed applications were meant to be integrated into the everyday practices at schools, other content provided by the teachers was also part of the overall schedule of the display system. These items were general information posters (e.g., cafeteria menu, student projects). These posters were created by teachers using Microsoft PowerPoint, a tool they were used to for creating content with, and then converted into image files, so they could be integrated into an image gallery.

The display system utilizes the "displr" public display platform (José et al., 2015). This system is based on the concept of check-ins at a display via a smartphone app, which allows access to the display applications. Students would need to create an account to be able to interact with the application content. This guaranteed controlled contributions in the system, which could be checked by the teachers, as it was requested by them.

Evaluation: Deploying the system at secondary schools

Following up on the design workshops, we ran two deployment studies with the display systems evolving from the workshops. Deployment studies allow to investigate users' adoption and behavior around interactive systems in authentic settings and are an established method for system evaluation (Alt et al., 2012). The deployments of the IPDs aimed at investigating the usage, adoption and integration of IPDs into educational settings and practices and collect further information for their design. The three weeks long deployments took place at two schools in Växjö, Sweden, the Kronoberg Skola and Teknikum. Teachers from the two participating schools collaborated with the design team to choose the content for the public displays, which could then be incorporated into teaching activities actually taking place at their schools during the deployments. More specifically, teachers chose YouTube videos and created quiz questions with multiple choice answers. In total, 16 quizzes were collected and integrated into the system. The following sections will present the methodology followed during the studies and their findings.

Methodology of the deployment studies

As part of the deployment studies, different data collection methods were combined to address aspects of the system's usage and overall adoption: outcomes of interactions with and consumption of display content (questions answered, videos rated), in-situ observations, semi-structured interviews and questionnaires. The user logs on the mobile endpoints comprised answers to quizzes, quiz visits, video ratings, rating app visits, created accounts, check-ins and number of total users. The observations were conducted to get a clear picture of what students were doing around the display and how they were using the system deployed. Overall, activities at schools follow a clear schedule that also affects possible usage scenarios of the IPDs, such as time in classes, break between classes, school events. In order to cover different situations and scenarios, we considered these timings for the observation sessions at the schools. Due to ethical and privacy considerations no tracking of "passive users" was implemented using e.g. cameras. The semi-structured interviews were conducted at the schools on the final day of the deployment. For this, 16 students were picked randomly on a voluntary basis and in coordination with the teachers. The students were asked to elaborate on their consumption of the applications, elements fostering and hindering their interaction, as well as their general impression of the technology, interactivities and content. In addition, a post-deployment questionnaire with similar content was sent out to all participating students and teachers. We were able to collect 19 questionnaires from students and 2 from teachers.

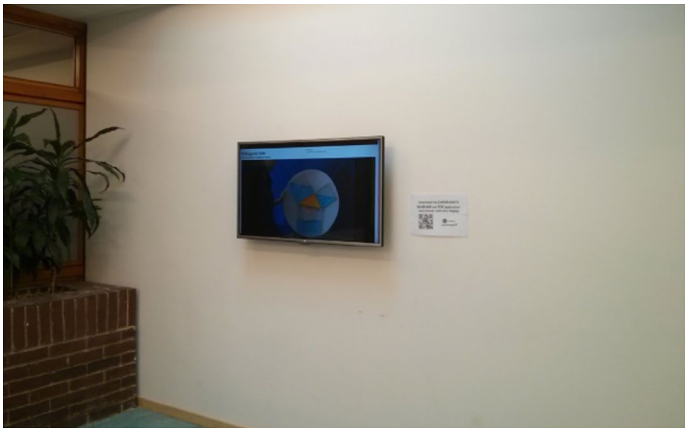

Fig. 4 Public display at Kronoberg Skola

Deployment at Kronoberg Skola

Settings and display environment

Kronoberg Skola comprises grades 4 to 9 (10 to 16 years old), with around 240 students in total attending the school. The two classes directly involved in the deployment study comprised 58 students (29 female and 29 male). The display used for the study was situated in a common area mostly used by students from the grades 7 to 9 (between 13 and 16 years old). In this area we can find several benches, chairs, tables, and a sofa, which allow the students to gather and socialize in the school before, after, and in between classes. Considering the nature of the place, the videos were played with the sound on, because it was expected not disturb other activities. The school installed two new digital displays with one being used in this study (see Fig. 4). Given this recent procurement, the students and the teachers were not familiar with it.

Results

Logs: students' usage and interactions Looking at the interaction logs, 48 students and 3 teachers created user accounts during the deployment. The logs revealed that most of the registrations happened during the first week of the deployment (see Fig. 5). Only 43 of the 48 users actually opened one of the two interactive applications (quiz, rating), and only 37 actually answered a quiz question and 15 students rated a video. This means that around a fifth of the students that created an account were lost in the interaction process.

The distribution of interactions throughout the deployment shows a higher number of check-ins and interactions in the beginning of the deployment (the first half), which dropped in the scope of the following two weeks. The overall schedule for the content in the quiz and video applications was designed in a way to serve new

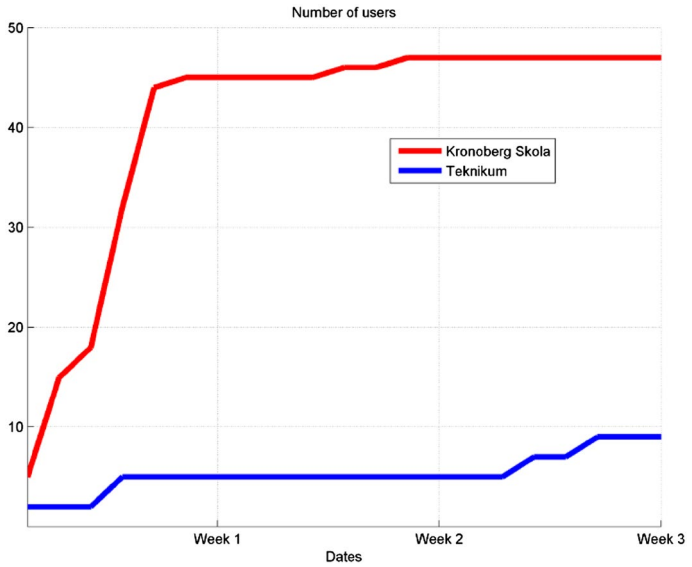

Fig. 5 Registered users over the three-week period of the deployment

content throughout the deployment time and avoid that students would e.g. answer all the questions in a day (or in one session).

Teachers' engagement The main contact person from Kronoberg Skola was a teacher that was engaged in design workshops and took a very pro-active stance. He was very positive towards the project and the public display, promoting it to colleagues and especially students: when setting up the display at the school, ten students were present in the common area around the display and curious how to use it. The teacher took his time to explain the applications and the on-going deployment to all the students and encouraged them to take out their phones, register to the system, and interact. Besides this example of his engagement, he further: ran introduction sessions to the display system, its applications and their features in his class; shared similar information via email to the students; and informal talks to students in the corridor during break time.

Additionally, three teachers organized an introduction event for their classes of 8th graders as part of their math lecture. During this event at the end of the first week of the deployment, around 50 students gathered in the common area. With the applications running on the public display, one teacher explained the applications and how one can interact with them. Then the students were asked to create accounts on their mobile phones and started to explore the applications and features, while the teachers (and two researchers) were present for further assistance. As can be seen in Fig. 5 this event led to a substantial increase in users, with only a few accounts created the weeks afterwards.

Observed user behaviors and interactions The observations suggest that the students noticed the display during their activities at the school and paid attention to the content. However, in line with the technical logs, the observations revealed that students seemed to have lost interest in later stages of the deployment.

The observations revealed that different types students' groups gathered around the display. Common group sizes were composed of three to five students. Some groups placed themselves away from the display and did not consistently pay attention to the display, while other groups chose to be close to the display, interacting with it and discussing about the quizzes shown. In some cases, students stood in front of the display watching the videos play and talked about the video content and the questions—with and without answering quiz questions and rating videos. Sometimes they did not answer the quizzes or rate the videos when still clearly engaged with the display. In other occasions, a single individual's mobile device was shared and used as a "group interface". When groups did not occupy the space in front of the display, single users would approach and watch the videos and look at the quiz questions displayed next to them. For example, in one occasion two groups of students were not paying attention to the public display, while another group was sitting directly in front of the display. All of the students of the latter group had mobile phones and were clearly discussing about the video and quiz displayed on the public display. Checking the interactions logs of the system, it could be confirmed that this group was answering questions as a group, which in this case led to 16 new quiz results from five users.

Our observations allowed us to identify the important role of the display location. The display was located in a common space for students, which invites the students to gather and socialize. Based on the observed user behaviors in the vicinity, the space around the display could be divided into three areas: close by where students paid attention and actively interacted with the applications; passage connecting two adjacent corridors with people mostly only looking at the display but not stopping or watching; and the benches further away with students socializing without appreciation or awareness of the display.

Inquiring the students about usage The interviews and the questionnaires complemented the observations described above, especially regarding the group constellations and lack of interactions. The interview and survey data confirmed that students mostly were around the display in groups discussing about the content as a group. But they rather answered for themselves without submitting an answer via the mobile application.

In several cases, the interactivity of the display applications was not clear for the students. Communicating about the interactivity capabilities proved to be a challenge, similar to (Dix & Sas, 2010; Müller et al., 2011, 2012), even though the students were introduced to the system by their teachers. Additionally, some students indicated that the content itself did not seem to be appealing, the videos did not seem to be fun or interesting enough for the students. Nevertheless, students reported positive aspects of the system: the competitive nature of the quiz application, the visualization of the quiz results, and the fact that as soon as the interactive nature of the display was understood the system was easy to use.

Fig. 6 Public display at Teknikum

Deployment at Teknikum

Settings and display environment

The display used for the study at Teknikum (covering grades 10 to 12, with most of the students between 17 and 19 years old; around 800 students in total), was situated in the hallway, next to the entrance of the school's main cafeteria (see Fig. 6). This hallway is one of the main traffic routes connecting several departments and areas of the school. The videos on this display were played without sound. The school has additional non-interactive displays installed at several locations throughout the buildings. Due to the teachers' participation in the project (prior design workshops) one class of 31 students was directly involved in the deployment study.

Results

Logs: Students' usage and interactions The logging shows nine registrations for students and one registration for teachers, with the registrations taking place along the three weeks of deployment. Similar to Kronoberg Skola, the logs showed that some students did not complete a single interaction. Out of the nine registered users, seven accessed at least one of the interactive apps' items on their mobile phone. Further, only six answered a quiz question and three rated a video.

A similar picture could be observed for the overall check-ins at the school's display, as shown in Fig. 7: the check-ins were more evenly distributed throughout the deployment time. Further, the logs showed that the users were more consistent in their usage, checking for interactive items in the mobile app. Given that a higher amount of the registered users regularly checked-in at the display, the users seemed to have had a different approach in engaging with the system. Besides the general low adoption during this deployment, the logs helped to identify three "power

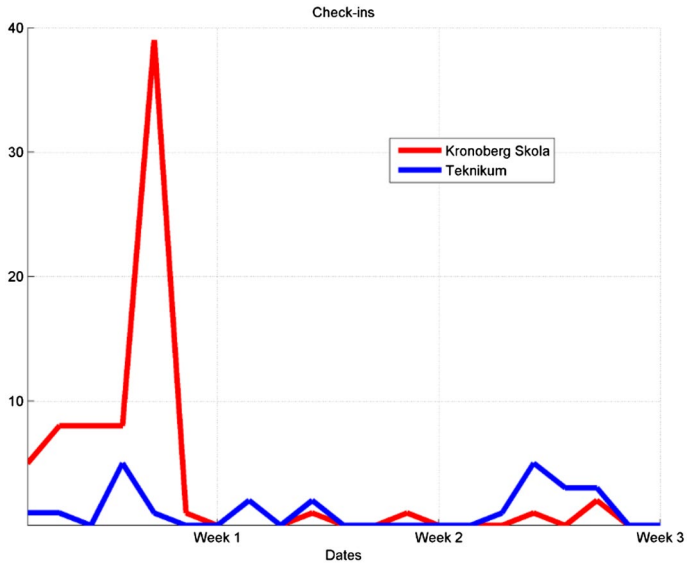

Fig. 7 Check-ins at the display over the three-week period

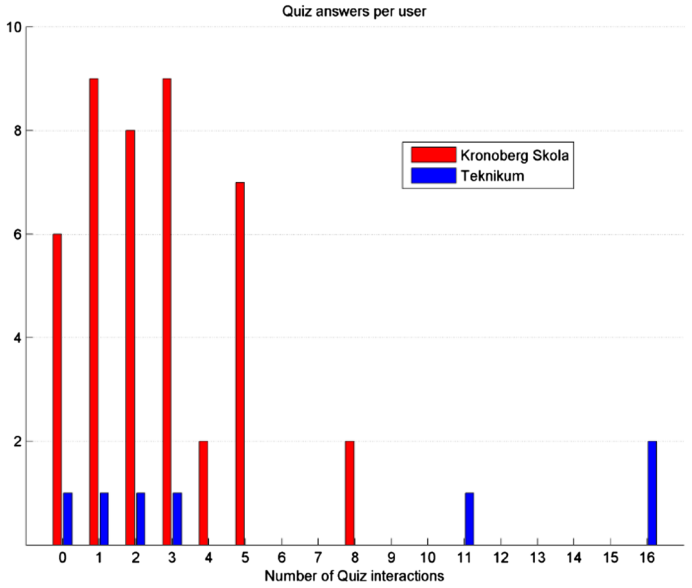

Fig. 8 Amounts of quiz interactions done by users

users", whose interactions were far above the main group, as can be seen in Fig. 8. These users checked in at the display regularly to see if new videos were available and then immediately answered the newly released quiz questions.

Observed influence of the location on user behaviors The four observation sessions demonstrated a consistent situation: a low number of students in the hallway around the display seemed to be aware of the display and/or did not seem to be interested in what it had to offer. The data showed that most of the students were only passing by the display or standing in the vicinity of it without paying further attention to it. Here, the distance to the display did not seem to matter so even students walking or standing in a close radius of 1–2 m could not be observed taking an actual look at the display. Given it was situated in the hallway, not many students socialized close to it. When directly targeting periods of expected high traffic, i.e. lunch time when students queue and wait in front of the cafeteria entrance, several different constellations of groups (usually 3–5 students) could be observed talking and discussing in front of the display. Still, the display did not seem to play a part in their activities.

During the last observation session, we counted students and categorized them regarding their actions for one hour: passing by public display: ~ 165; spending time near to it: ~ 20; taking a look: ~ 17 (these were also either counted as "passing by" or "spending time"); actually paying attention: 0. This data clearly represents that the area around the display was rather busy in terms of traffic and potential users, but also supports the observations from the earlier days and general findings from the interaction logs that the display and its applications did not attract students to interacting or consuming content.

Besides the insights into students' interactions and behaviors in the space around the display, the visits and observations at the school also revealed some organizsational challenges connected to the deployment study: in one instance the cafeteria personnel had removed the info leaflet next to the public display informing about the project and the interactive applications (also QR code to app stores); and at another occasion the display was switched off when we arrived which required a consultation with the school IT. These circumstances highlight the importance of the teachers' but also whole school's engagement on the successful integration of interactive public displays into activities at the schools.

Inquiring the students about usage The students at Teknikum also reported to like the competitive nature of the applications and the visualizations that enticed comparisons. In fact, the students suggested that these should even be extended to local and more personal lists of users and scores. They clearly referred to the fact of having paid attention to scores of both schools on the displays and that this triggered their will to participate in the quizzes. Furthermore, students that did interact with the system reported being motivated to engage after hearing about the system from their friends and emphasized that such way of communicating educational content could be helpful to learn about topics, especially while bridging time at school.

Interviews revealed some privacy concerns that were pointed out to be a reason for low participation. The mobile application required the students to sign up with their name, a nick name, birthday, and an email address (while it was possible to use their school email address, without exposing their private address). This seems to have triggered apprehensions regarding tracking of interactions and responses. The students mentioning these issues were not willing the go through the steps of registration before even having explored the functionality of the display system.

Looking more in detail into the answers to the questionnaire and interviews, it seems that none of the students at Teknikum, who noticed the display and answered the questionnaire, actually paid attention to the videos being shown on the display (i.e. watched them). When inquired about why they did not pay attention to the videos the most common answers were: wrong location of the display and uninteresting ("boring") content. As the observations had shown, the location of the public display seemed influential, even though promising at first given its centrality. This was confirmed by the data from the interviews and surveys which showed that most participating students usually do not spend time in this area.

Furthermore, students were expecting more dynamic and also motivating content. Additionally, a more reactive behavior of the display to user interactions and happenings in the surroundings would be interesting. This seems to be connected with the "display blindness" (Memarovic et al., 2015; Müller et al., 2009) effect: the students did not expect any interesting content and avoided them, and this happened although they were told about the project and new interactive applications. Although all relevant and reasonable, several of the students' comments need to be evaluated carefully, since most of them actually did not make use or pay attention to the display system even though they were informed about it by their teachers.

Discussion: Defining design goals

The comprehensive findings from the workshops and studies provide opportunities to define and discuss Design Goals defined for IPDs in educational settings. The discussion of the design goals in relation to the findings and related work allows to abstract knowledge from them that can aid designers of future IPD systems. A summary of the results of this process can be seen in Table 1.

DG1—combining the formal and informal settings and activities

The teachers were quite aware of the potential of the digital public displays to be used to foster students' curiosity to particular learning content. The technology would allow bridging the gap between teaching inside the classroom and activities occurring in school but outside the classroom. Short trailers, teaser videos, animations, or still images could be shown on the public displays for such approach. The interviews at the schools confirmed that some students found it interesting to extend content discussed and worked on during lectures to the informal and casual settings surrounding the public displays. However, it is important to ensure that these communal spaces within the schools and universities are not bound to classroom rules—they should be mainly perceived and treated as spaces of socialization, avoiding invasions with traditional classroom activities.

Additionally, users liked to see their contributions towards the overall system, opening up the potential to seek new ways to extend content creation for the displays. As promising examples, Hoppe et al. and Müller et al. had students pick videos and create quizzes (Müller et al., 2015a) and also even create the video content

Table 1 Overview of the Design Goals, their advice and their initial application features

Design Goal	Advice	Initial features of the prototypes
DG1 "Combining the formal and informal settings and activities"	Support/Utilize student-/user-generated content	Educational videos consumed collaboratively in informal settings
DG2 "Educational and playful experiences"	Combine opportunistic and structured activities	Quizzes related to videos
DG3 "Appropriate playful mechanisms"		Quizzes and comparative visualizations
DG4 "Single and multi-user interactions"	Support collaboration and competition; Facilitate audience awareness	Shared display for "group/audience" access; mobile devices for participation
DG5 "Controlled contributions"	Right balance of "control" and "low hurdle" interactions	User accounts; constrained contributions with defined quiz answers and rating scale
DG6 "Integration and extension of existing usage"		Use videos that teachers were used to using as e.g. home-work; combination with info posters
DG7 "Utilize existing technological infrastructure"	Location needs to match expected interactions	Browser based applications allow to use existing display infrastructure; utilize students' mobile devices

for the public displays (Hoppe et al., 2016). The studies showed that the notion of ownership towards the display content increased students' interest for the systems. They observed that students were excited about sharing their created videos and quizzes in public settings, enabling them opening-up for a wider audience than only their course peers.

Looking at the video content more specifically, the videos chosen by the teachers were not specifically designed for public displays. The discussions with the teachers and the students revealed that they were aware of special requirements for the video content: video duration due to limited time in front of the display as well as the role of audio (or its absence) in the videos. However, it seems that this awareness did not translate into fitting alternatives.

Challenges exist to bridge the formal settings and activities into the informal settings around the public display. Our studies revealed that teachers acted as important facilitators towards the interactions with the display systems. The role of the teachers proved to be essential in the students' awareness, behavior and willingness to make use of the system. Especially at Kronoberg Skola the pro-active involvement of the teachers showed to be a decisive element to trigger adoption. Positive effects of facilitator roles have also been reported in prior work by Brignull and Rogers (Brignull & Rogers, 2003) and recently in educational settings by Ahn et al. (Ahn et al., 2018). Still, the collected data also showed that motivating the students through teachers was not sufficient and that specific constraints exist in educational environments. Different organizational levels in schools (school's director, teacher leaders, teachers, etc.) need to be aware of their potential roles especially in the initial stages of display deployments and how their engagement can influence the students' adoption.

DG2—educational and playful experiences

The prototypes created and the results from the studies show how educational videos can be repurposed for use in informal settings and provide opportunities for further interactions: the video-based quizzes motivated students to engage around the content and proved to be a casual and playful way to reflect on topics worked on during other learning activities.

Some additional interactivities can be designed to entice the students to sign-in and be regular users of the system. However, students need to see a value in using the system to avoid having them elude contact with educational content in their leisure time. Additionally, the costs associated with the initiation of an interaction with the system need to be evaluated. Interactions with public displays usually are opportunistic, spontaneous and voluntary (Agamanolis, 2003; Rogers & Rodden, 2003), so people need to be aware of the displays, their interactivity and they probably need to be convinced to interact (by the system itself) (Müller et al., 2010).

The results showed that only few people from outside the group of participants interacted with the display system during the study time (i.e. nobody engaged through the app with content). In another study students outside the study activity perceived the public display as a "closed system" only usable by specific people

(Müller et al., 2015a). For a broader adoption of the display system, the systems need to be opened up to a wider audience and opportunistic use must be supported and promoted. Similar to how McDonald et al. (McDonald et al., 2008) discuss the tension between peripheral and productivity-oriented (groupware) display systems in office settings, one has to find a balance between opportunistic, casual interactions and structured activities/interactions in the educational settings. Public displays might attract attention for the students who are not involved in a specific task or learning activity. This creates opportunities for a wider use, but also challenges if people consider it to be a more productivity-oriented system. The tension also exists between the attention they attract and the focused attention necessary to interact. If the displays attract no attention, they would not be useful, but if they attract too much attention, they would not be peripheral. Potential users also need to understand that the display content is not always informative or educational for them (suitable for their level of education or courses), but also not always just entertaining, and educational/serious content is also provided. Structured activities should attract opportunistic users and interactions and serve as facilitators for more interactions. As other studies show (Hoppe et al., 2016; Müller et al., 2015a), students liked to have their videos shared on the public displays and also to challenge others in their quizzes. It needs to be investigated how the momentum and facilitation can be exploited more.

DG3—appropriate playful mechanisms

Playful mechanisms in learning activities help students to develop an understanding of collaboration, problem-solving and communication (Dicheva et al., 2015). The distinct characteristics of interactions around public displays, being often short-lived and opportunistic, demand appropriate playful mechanisms. For example, quizzes would allow the learners to engage in activities that test their knowledge among peers from own and remote schools. Results from questionnaires and interviews showed that scores and visualizations were evaluated very positively and considered to be motivating (in fact, some participants emphasized that these could be even more salient). The visualizations provided feedback to their interactions and performance, which helped them to identify with the results shown. More feedback in the applications could further scaffold this identification and assurance that their interactions led to a contribution. The stated requests to integrate more individual scores and results on the public display (instead of only non-personalized group comparisons) support this conclusion.

DG4—single and multi-user interactions

This setup of a shared public display and mobile devices was implemented as direct result from the design workshops. Mobile phones are perceived as ideal by users for creating content on the go, especially when maintaining privacy and concealing is a concern (Alt et al., 2011). Furthermore, they facilitate synchronous single and multi-user interaction (Dix & Sas, 2010; Finke et al., 2008), which, for example,

allows several students simultaneously to answer a quiz question without exposing their answers to others and without individuals occupying the display system.

The IPD scenarios in our studies led to discussions around the content and interactions among the users and bystanders. The quiz questions around the videos fostered collaboration as well as competition among the students and this feature was considered favorable by the participants. Students who met in front of the display would engage in spontaneous collaboration discussing about the quiz questions and the video content, using their mobile devices individually to log an answer or one device as "group interface". Compared to other settings for public displays, at schools students know each other and more easily gather in groups, which could be further exploited in the system design, so it drives adoption.

Still, communicating about the interactivity capabilities proved to be a challenge, similar to (Dix & Sas, 2010; Müller et al., 2011, 2012), even though the students were introduced to the system by their teachers. Making interactive features easily understandable and providing information about them seems crucial. One promising way to increase the engagement is to further explore how to promote awareness of peers interacting with the applications. In a study targeting this challenge (Müller et al., 2015a), the authors investigated the effect of pop-ups informing about other users' interactions. The results showed that this cared for an increased social awareness and contributed to a "remote honey-pot effect" (J. Müller et al., 2014, Müller et al., 2015a), which increased the attractiveness of the system. However, knowing that the application features can facilitate collaboration as well as competition research needs to pinpoint which aspects used care for one or the other. Collaboration and competition seemed to be split into local and remote settings: locally, students mostly collaborated around the display, while competing with students from other spots/schools.

DG5—controlled contributions

Personal accounts on the mobile phones for interacting with the public displays would allow to track performance and improvements for both the students as well as the teachers, as this was mentioned to be a requirement by the teachers during the workshops. This would further allow to control who is interacting and what is contributed. Teachers explicitly mentioned potential ethical issues with the main concern being to find appropriate content control mechanisms. Any incident of somehow offensive episodes could jeopardize the deployment of interactive public displays. In order to care for controlled contributions in our applications, users needed to create an account to access the interactive features of the public display system and take part. As it was discussed above, we could see that this seems be a hindrance for people and eventually prevent them from further usage of the display system ("too high hurdle with registration" was a common comment in our studies). These issues can be classified as entry-cost and seem to have implications for the students' adoption and usage.

The logins are meant to be constructive for the educational settings, allowing to track student participation and to lower the risk of offensive contributions. But they

seem a deterrent for potential users that are not part of the integrated learning activities. Prior work that utilized Bluetooth names to share text on a public display in high school settings (Otero et al., 2012) had also shown that teachers want control over contributions, but too much control also could mean too much effort for teachers in maintaining content. If teachers then are overwhelmed with providing responsive moderation and it comes to delays, students would lose interest in the system. This circumstance presents a too high cost especially for initial interactions and opportunistic users. Especially for educational settings one needs to find the right balance of "control" and "low hurdle" interactions. Another possibility is to create a reputation system that decentralizes control but maintains a high level of accountability for the usage (José et al., 2013).

DG6—integration and extension of existing usage

Two of the participating schools already had several public displays installed in their buildings, the third was about to do so. Therefore, one obvious application feature for the displays emerged from their current use of communicating information about school activities, e.g. projects, group work, cafeteria menu, and sport events. This allows to combine educational content/games with everyday school info to serve a wider audience being present at the school. The design team discussed and encouraged the teachers of both schools to publish posters and photos. However, although at the beginning the teachers showed interest in such feature, the fact is that the opportunity was not actively pursued. Teachers were also free to change the applications/content as they wanted (adopt and adapt them for their educational goals), but did not do it after the initial setup. Some possible explanations are: the design team was not able to explain the full potential of the feature and the benefits it could bring; people did not find the feature interesting enough to put some effort to organize relevant information; the schools' work processes were not adjusted to the need of feeding relevant content to the system. As such, there is a clear need to investigate how the display utilization can be promoted at the schools. For example, teachers seem to need guidance on how to integrate the displays into their teaching activities if they want to create engaging activities for the students. Furthermore, teachers play a distinct role as facilitators for the students' adoption of the display system and thus their engagement with the applications. At both schools, teachers promoted the display system and its content and functionalities. But major differences between the schools could be seen. While at Teknikum the teachers kept with a generic introduction of the system in classes and talking to some individual students in the hallway, teachers at Kronoberg Skola did all of this plus a dedicated introduction session as part of a class. This led to an early understanding of the system and prepared the students for the interactions with it.

DG7—utilize existing technological infrastructure

The fact that several of the participating schools already had public displays installed led to the goal of utilizing the technology/displays that are available and

incorporating them into activities taking place at the schools. Therefore, the applications were developed having in mind the display infrastructures available at the participating schools. Due to this, we developed web-based display applications and a browser-based application scheduler that could easily be incorporated into the schools' display systems. Furthermore, this eased logistics of conducting the deployments as well as acceptance of the technology from teachers and schools.

Different locations for the displays in our studies uncovered aspects for the design of public display applications. The studies showed how the display location plays a crucial role in the general adoption and the students' engagement. Further investigations are needed to create ways to inform students in the vicinity and passers-by about the system's features. For example, promising results were gathered in studies that explored the effect of notifications about others interactions with the display on the audience engagement (J. Müller et al., 2014, Müller et al., 2015a, 2015b).

The deployments worked with existing displays, so the choice of displays' placement was predetermined. Regarding the display location, Parker and Tomitsch (Parker & Tomitsch, 2017) recently suggested that the importance of positioning the display in the correct height to get attention (see (Huang et al., 2008)) needs to be combined with the permeability of the space, which allows to position displays on people's main paths and orient them towards them. Similarly, Brignull and Rogers (Brignull & Rogers, 2003) recommended to place a public display at a location with constant traffic/flow of people, e.g. people queuing next to the display anyway. The results from our studies have shown that these considerations might not be enough. This regards especially the display location at Teknikum, where the display was located at a wall next to the cafeteria with regularly high traffic. Based on our findings, the considerations regarding the expected traffic need to be extended with considerations around expected (social) interactions at the place. The display and its applications need to fit to the practices that are tied to the location. It proved to be a challenge to introduce new interactions into a place that do not blend with existing activities. In our results, this regarded both, the nature of the applications and interactive features provided, and the steps necessary to take part. If one wishes to foster collaboration and discussions around the educational display application content, the location needs to allow such interactions: our studies highlight the differences in interactions between a display in a common area at a school and a display placed in a hallway, even though the deployments contained the same application functionalities. The placement of the display needs to be considered in relation with the application purpose(s) and expectations of potential users.

Challenges for the interactions with public displays

The two studies with their very different display locations pointed out general challenges that exist in the design of interactive public displays. The display location at Teknikum led to students avoiding it and or simply not being aware of it, even though it was located at a promising spot initially. This is a classic example of "display blindness" (Müller et al., 2009) or difficulties triggering interest (Brignull et al., 2004; Huang et al., 2008). Prior research has documented this problem due to which

people tend to ignore public displays, because they do not expect relevant content (Huang et al., 2008; Memarovic et al., 2015; Müller et al., 2009). However, a recent study (Dalton et al., 2015) demonstrated that people actually do look at public displays more than assumed. In this study, participants had to do a shopping task at a mall wearing head-mounted eye-tracking devices. The results showed that participants actually looked at displays, but only for a short amount of time and from far away. It is unclear what stops them from approaching as well as eventually interacting with the displays. Furthermore, given the results from our studies we assume that display blindness cannot always only be linked to the expectation of uninteresting content, which would be a usual explanation. The content in the different deployments conducted was tailored for the students' learning activities and the environment that should have increased the interest for the students, yet they avoided them.

The displays at the schools were available before the test-deployment, but without any interactive features. As it was mentioned by the interviewees, more dynamic content and direct feedback to happenings around the display would have engaged them more to interact with the system. This goes along with findings of Müller et al. (Müller et al., 2012) conveying interactivity via visual feedback of movements. We will need to investigate how to better convey that the displays are interactive, especially to potential users who do not know about the system.

Understanding affordances that facilitate interactions with public displays can be difficult in general, with many different interaction modalities possible (e.g. touch or in-air gesture) and especially if interactions happen via mobile phones (Müller et al., 2011). This was also reported by students, even though they were introduced to the system and posters with instructions on how to interact were shared at the school. Remote control and mobile device interaction experience recurrent challenges regarding how to communicate to the public that they can use their own devices to interact with the content on the public display. They do not benefit as easily from the "honey-pot effect" as terminal or touch interactions do (Tang et al., 2008). And at an even earlier stage in the potential interaction process (Müller et al., 2010), people are not even aware of the interactivity of a display system itself since it is not conveyed sufficiently (Ackad et al., 2013; Grace et al., 2013; Müller et al., 2012). To address this issue, studies often investigate the effect of visual feedback to body movements in front of the display (Grace et al., 2013; Müller et al., 2012) and proxemics (Cheung & Scott, 2015). Such systems make use of in-air gestures or touch as interaction modality, which provides a direct mapping that users seem to be attracted to. With mobile devices users need to understand that an additional device is necessary for the interaction and this might create misunderstandings. Nevertheless, interactions via mobile devices support covert interactions to avoid social embarrassment (Tang et al., 2008).

Müller et al. (Müller et al., 2015a) have introduced several factors caring for more engagement with public displays: pop-ups and quiz result visualizations. Both provide feedback to the audience that interactions are possible and happening. The pop-ups regard a more immediate representation while the visualizations care for a long-term representation (i.e. as to be defined by the school) of the interactions happening with the applications. As a study around these specific features and their

impact showed, these dynamic representations care for an awareness of interaction opportunities even for passers-by and people not familiar with the display system.

Conclusions

The findings from the multi-step research process comprising co-design workshops, prototype implementations and deployment studies gave us valuable information for the design of interactive public display (IPD) applications for educational environments. We were able to define and discuss seven design goals (DGs) addressing interaction and application specifics as well as display locations and school engagement, which addressed our main research question ("What are the central challenges related to the design and implementation of engaging IPDs for educational environments?"). These design goals serve as grounded guidance describing aspects that need to be taken into account when designing and developing the IPDs (*Combining the Formal and Informal Settings and Activities*, *Educational and Playful Experiences*, *Appropriate Playful Mechanisms*, *Single and Multi-User Interactions*, *Controlled Contributions*), as well as how the integration of the IPDs at the places can be facilitated (*Integration and Extension of Existing Usage*, *Utilize Existing Technological Infrastructure*).

The evaluative deployment studies at the two schools gave a rich picture of how the students used the systems. More specifically, in regard to the research question "How do these aspects influence the adoption and use of such systems?", we could see that the public displays in our studies had potential to enhance the place and interactions in it. They were able to engage students in discussions around educational topics. The playful interactions with the system promoted collaboration as well as competition around the display as well as between the two schools. But the results also showed that the IPDs' integration into structured activities and the level of commitment in interactions provide challenges and need to be explored further.

Even though the IPDs could not be utilized yet to their full extent, they should not be neglected in the process of designing new activities at educational environments as well as enhancing such places. IPDs in schools should rather be considered as an added layer and channel for educational content, instead of utilizing them for purposes such as commercialization, advertisement, (redundant) information and entertainment, that could lead to negligence in the long run. Several interesting questions on how to better integrate them into activities were identified throughout the scope of our studies. These point to the challenges of display awareness, level of commitment in interactions, integration into structured activities, management at the institutions, and display location. Coordinating these factors is necessary to realize the full potential of IPDs engaging students in semi-formal activities at educational environments.

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Data availability The datasets collected, used and analyzed for the study at hand are available from the corresponding author on reasonable request.

Declarations

Conflict of interest All authors declare that there are no competing interests.

Ethical Statement We hereby declare that this manuscript is our own independent creation. This manuscript contains original work that has not been published before. The work complies with all ethical rules described in the Juxtalearn project handbook (EU FP7 project, grant agreement ID: 317964). All subjects participated voluntarily. Organizational and personal consent was obtained from all participants to ensure awareness and acceptance amongst participants of ethical, privacy and research activities.

Informed consent Informed consent was obtained from all individual participants included in the study.

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Maximilian Müller is a PhD candidate in Computer and Information Science at Linnaeus University, Sweden, working with the CeLeKT research group at the Department of Computer Science and Media Technology. His research projects are centered around interactive public displays. This divides into the development of applications and systems as well as the evaluation of the technology once applied. He has interests in the fields of interactive systems design including shared screen environments and mobile devices, as well as interaction technologies and HCI frameworks.

Nuno Otero holds a Ph.D. from Sussex University in the UK and he is a Senior Lecturer at the School of

Computing and Mathematical Sciences, University of Greenwich in the UK. He is interested in theories and conceptual frameworks in HCI, from more traditional approaches taking a user centered perspective to more recent trends focusing on user's experiences with technologies. His research has been mainly addressing the following topics: technology-enhanced learning, digital tools for everyday music making, Human–Robot Interaction, the design of large screen displays for public places.

Marcelo Milrad is a Full Professor of Media Technology at LNU. His current research interests include the areas of Technology-Enhanced Learning (TEL), advanced human-computer interaction and novel uses of Big Data techniques and mobile technologies in the fields of Education & Health Care. Since March 2020, he acts as the main scientific coordinator of LNU's cross-disciplinary knowledge environment called Digital Transformations. Dr Milrad is also actively involved in an initiative at LNU together with colleagues at the Faculty of Arts and Humanities called Digital Humanities. Professor Milrad conducts his research in very close collaboration with industrial partners and the public sector. Professor Milrad has published over 250 articles in international journals, refereed conferences, books, and technical reports. Dr Milrad has also been presenting and giving lectures about his work in more than 45 countries worldwide.