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PENGCHENG AN, Eindhoven University of Technology, Eindhoven, Noord-Brabant, Netherlands

SASKIA BAKKER, Eindhoven University of Technology, Eindhoven, Noord-Brabant, Netherlands

SARA ORDANOVSKI, Utrecht University, Utrecht, Netherlands

RUURD TACONIS, Eindhoven University of Technology, Eindhoven, Noord-Brabant, Netherlands

BERRY H EGGEN, Eindhoven University of Technology, Eindhoven, Noord-Brabant, Netherlands

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ClassBeacons: Designing Distributed Visualization of Teachers' Physical Proximity in the Classroom

Pengcheng An [1] Saskia Bakker [1] Sara Ordanovski [3] Ruurd Taconis [2] Berry Eggen [1]
[1] Department of Industrial Design, Eindhoven University of Technology, the Netherlands
[2] Eindhoven School of Education, Eindhoven University of Technology, the Netherlands
[3] Department of Experimental Psychology & Helmholtz Institute, Utrecht University, the Netherlands
[1, 2] {p.an, s.bakker, r.taconis, j.h.eggen}@tue.nl; [3] s.ordanovski@students.uu.nl

ABSTRACT
As necessary for creating a learner-centered environment, nowadays teachers are expected to be more mindful about their proximity distribution: how to spend time in different locations of the classroom with individual learners. However feedback on this is only given to teachers by experts after classroom observation. In this paper we present the design and evaluation of ClassBeacons, a novel ambient information system that visualizes teachers' physical proximity through tangible devices distributed over the classroom. An expert review and a field evaluation with eight secondary school teachers were conducted to explore potential values of such a system and gather user experiences. Results revealed rich insights into how the system could influence teaching and learning, as well as how a distributed display can be seamlessly integrated into teachers' routines.

CCS Concepts
• Human-centered computing ~ Field studies • Human-centered computing ~ Displays and imagers • Applied computing ~ Computer-assisted instruction

Author Keywords
Ambient information system; distributed display; teacher proximity; learner-centered education; classroom.

INTRODUCTION
Secondary school teachers' work has been recognized as dynamic, complex and busy [3,10,17]. While teaching, with different students to serve, multiple goals to achieve, and unpredictable situations to deal with, a teacher often needs to perform tasks in quasi-parallel manner, or switch back and forth between tasks [3]. Thereby, their perceptual and cognitive resources are and continually occupied, making their attention precious and limited.

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The teaching practice in secondary schools is shifting from *teacher-centered* to *learner-centered* [15]. Today's educators are increasingly expected to function as facilitators who can provide differentiated instructions and punctual guidance [26] to each learner. This means more interpersonal interactions between teacher and students are needed in the classroom. As a result, teachers have to more mindfully distribute their time and spatial presence in a lesson to offer each student *closer physical proximity* [26]. This imposes even more mental load on teachers since it requires them to be more reflective [46] while working. Given already a lot of things to pay attention to in a lesson, keeping track of their distribution of proximity to students (i.e., how they wander in the classroom or how much time they have spent in different locations) cannot always be an explicit task in the center of teachers' minds. We hypothesize that this reflective task could be supported by an ambient information system [36] which can inform without overburdening teachers [45]. We developed ClassBeacons, a novel tangible ambient system visualizing teachers' physical proximity through wireless lamps distributed over the classroom (see Figure 1).

Figure 1. ClassBeacons: Each lamp on students' desks indicates how much time the teacher has spent around it through color ranging from yellow (no time spent) to green (440 seconds spent). ©Eindhoven University of Technology

Adopting a methodology inspired by *research-through-design* [49], we developed and evaluated ClassBeacons with two research goals. Firstly, since very limited research is known on physical proximity of teachers in classrooms [26], and no existing ambient information system is known to visualize teacher proximity, this study means to explore the potential values of tracking and visualizing teacher proximity to pedagogical activities. Secondly, by gathering and analyzing user experiences of ClassBeacons, this study aims to inform the design and development of tangible ambient information systems for the classroom. To achieve these research goals, an expert review with four educational researchers and a field evaluation, in which eight secondary school teachers used the ClassBeacons working prototype during two of their lessons, were conducted.

RELATED WORK

Ambient Information Systems for Classrooms

Besides interacting with individuals, or physical tools (pen, textbook, etc.), teachers also need to increasingly interact with computing devices (e.g., PC, smart phone, interactive whiteboard) [13] while teaching. Although technologies benefit pedagogical activities in many aspects [38], use of technologies in teaching seems to be restricted because the interaction is often time-consuming and effortful [4,8,16]. Today's computing devices usually require *focused attention* [7] from teachers, which means teachers need to visually attend to the graphical user interfaces (GUIs) of those devices continuously while interacting. This does not fit well in the teachers' complex and intensive routines. *Ambient information systems* [36], which display relevant but non-crucial information in an unobtrusive manner [45], are recognized as a promising direction to fit information more seamlessly into teachers' busy everyday routines [3].

A number of ambient information systems have been designed for classrooms. For example, Lamberty et al.'s [28] system displayed challenges different students were working on in the lesson to create peer awareness. ClassSearch [33] presented web search behaviors in the classroom to ease teacher-led discourse and group awareness. Lernanto [2] displayed students' real-time performance to inform the teacher during differentiated instruction. Sturm et al. [42] introduced a system to support lecturers by displaying attention/interest level of students.

Above mentioned related designs are *centralized* ambient information systems which present information through a single display on the wall of the classroom [2,28,33]. Given the distributed nature of proximity information, however, ClassBeacons is designed as a *distributed* ambient information system whose display media are physically distributed in a classroom. Few related studies on distributed ambient information systems are known in the classroom context. Lanterns [1] aim to support group working scenarios by showing the status of each group on multiple luminous devices. FireFlies [6] supports short and quiet teacher-student communication by enabling a teacher to control the color of each student's individual light-object. Although relatively fewer design explorations can be found in this sub-area, the mentioned studies have suggested that distributed display is a meaningful approach to present information in the classroom settings. Such displays enable a direct mapping between the information and the student (or location) in the large space of a classroom. According to the theory of *distributed cognition* [24], this way of displaying information makes perception intuitive and effortless. As a result, we aim to further explore the design of distributed ambient information systems in classrooms. Moreover, as the mentioned two studies targeted university level education [1] and primary schools [6], the secondary school classroom remains a new context to explore.

Teacher Proximity

A quantity of studies involving educator proximity can be found in educational research, targeting various educatee groups such as pre-school children [19,27,47], school-age learners in classrooms [11,12,18,48], or remote learners [9,43]. The term 'proximity' is used differently in different studies. An emerging cluster of studies addresses teacher proximity in virtual learning environments [9,43]. Alternatively, a relatively large body of work [11,12,18,48] has investigated teacher-student proximity through a subjective-report approach [48] to assess the quality of interpersonal relationships: i.e. how cooperating /opposing a teacher is to his/her students. Nearness between teachers and students in a classroom has not specifically been assessed in these studies. However, some studies on pedagogical interaction [29,30,35] suggest that physical proximity influences mental proximity. For example, students sitting near the teacher may have more opportunities to receive caring.

Rather than virtual proximity, or perceived closeness in relationships, this work focuses on a teacher's physical proximity to his/her students: the spatial distribution of the teacher's presence in the classroom over time. As recognized by [26], few studies can be found in this direction. However, research conducted in the second half of the 20th century [21,22,32] emphasized that physical proximity plays a significant role in communicating non-verbal messages to people (e.g. a feeling of rejection or acceptance), and therefore should be paid careful attention to by educators. A framework of proxemics patterns described in these works were used by [40] and [26] to study physical proximity of teachers for understanding different learning environments [40] and for evaluating online video-cases instructing preservice teachers [26] (to be mentioned, this framework was also utilized in HCI realm by *proxemic interaction* [31]). While these two studies directly analyzed physical proximity, a number of works [14,20,39] has studied teachers' intentional use of the *proximity-control technique* to achieve desired behavior changes of students (e.g. reduced inappropriate behavior, or increased engagement). These studies suggest that teachers' physical proximity to students can influence their behavior.

Although physical proximity between teacher and students has not been frequently studied, results of the studies mentioned above reveal its significance. However, teachers only get feedback on their proximity performance after a trained observer has attended their lesson. No technology is known to track teacher proximity and provide real-time feedback. Such technology could influence teaching and learning. Our work aims to explore the potential values of tracking and visualizing teacher's physical proximity to pedagogical activities, as well as to probe insights into how such displays can be successfully designed.

DESIGNING CLASSBEACONS

To study the value of, and design considerations for, tangible ambient information systems which reveal teachers' proximity information, ClassBeacons was designed, see Figure 1 and 2. ClassBeacons continuously collects data of a teacher's positioning and heading in the classroom through a wearable sensor, see Figure 3. Based on these data a set of small physical lighting devices distributed over the classroom shows the teacher's proximity distribution. Each lighting device changes gradually from yellow to green, indicating how long the teacher has been around that device: the more time the teacher has spent around it, the more towards green it will change (see Figure 2).

Figure 2. ClassBeacons in a classroom. ©Pengcheng An.

Beacons originally refer to the luminous objects signaling or guiding ships in the sea. ClassBeacons is also intended to provide supportive information to teachers in their intensive and complex journey of teaching in the classroom. In order to evaluate this concept in a real classroom setting, we developed a working prototype of ClassBeacons, presented in detail in the upcoming sections.

Wearable Tracking Technique

Teacher's physical proximity to students could be reflected by the teacher's location distribution in space over time. A wearable solution was designed to track teachers' real-time location. These location data were gathered using an indoor positioning sensor kit [37]. The kit consists of four 'anchors' placed on stands in four corners of the classroom and one 'tag' which is implemented in a garment worn by the teacher, see Figure 3. The tag and anchors communicate through ultra-wideband communication [25] to sense positioning of the tag in a constructed Cartesian space (coordinate value of X, Y). This kit was chosen because of its high accuracy (close to 10cm level [37]), compared to other approaches (e.g. Bluetooth, Wi-Fi, or RFID).

Next to location information, the tag also tracks teachers' heading (between 0 to 360 degrees in reference to the magnetic South), which informs the system of the direction the teacher is facing to. As Figure 3 shows, the wearable solution positions the tag on the upper-back of the teacher. The upper-back direction adequately reflects the teacher's facial direction, since we found that teachers' facial direction was mostly in accordance with their upper-body direction from informal observations on classroom videos. Additionally, comparing to other wearable approaches such as headsets, or harnesses, the present solution was expected to be less obtrusive, and therefore less distracting to teacher tasks and more socially acceptable in this context. An adjustable Velcro structure was added beneath the tag unit to tighten or loosen the garment for different teachers.

Figure 3. Left: the tag unit on the teacher garment. Middle: four anchors. Right: an anchor mounted on a stand.

Distributed Display

Inspired by studies of [6] and [1], which implemented distributed displays in educational contexts, we identified the value of leveraging distributed tangible devices for ambient display in secondary school classrooms. Therefore, we developed a set of LED devices (introduced in [44]) as the display media of ClassBeacons. As shown in Figure 2, each LED device, called a Beacon, has a frosted and semitransparent lampshade which enables an effect of color blending. All Beacons are wirelessly connected to a control hub. The control hub receives positioning and heading data transmitted by the wearable, and commands each Beacon to update its color accordingly. During deployment in classroom, Beacons were placed on the student desks. If the desks were located very close to each other, two students would share one Beacon put in the middle of the two desks, see Figure 2. Positions of the individual Beacons needed to be input into the system beforehand using the wearable tag.

Visualization of Teacher Proximity

The perception of brightness of the LEDs in a Beacon can be influenced by the existing natural or artificial light in a classroom. Therefore we decided not to indicate the amount of time a teacher spent around a Beacon by the brightness of that Beacon. Instead, we decided to use solely hue as indicator of proximity. To make the color code semantically understandable, we firstly used red-yellow-green spectrum. But to avoid connotations with positive and negative behavior, we avoided using red. Instead we chose to use a *yellow-green spectrum*, where yellow means the teacher has not spend time around that Beacon, while greener colors indicate the teacher has spent more time around that Beacon. This made the visualization less judgmental while still semantically intuitive (see Figure 2). The yellow-green color shifting of Beacons has been set in *nine discrete degrees*, which we experienced to be sufficient to enable gradual and subtle color changes while also retaining a certain level of ambiguity. Additionally, we chose to use discrete changes rather than a continuous change, because we wanted each change to be still subtly perceivable, potentially affording time awareness for the users.

Interpersonal proximity is defined in related literature [22,32] in four levels: *intimate* (0-1.5 ft ≈ 0-0.5 m), *personal* (1.5-4 ft ≈ 0.5-1.2 m), *social* (4-12 ft ≈ 1.2-3.7 m), and *public* (12-25 ft ≈ 3.7-7.6 m). Teacher proximity at the intimate and personal levels are considered as 'closer proximity' in [26]. Based on these works, as well as our informal observation, we defined the range of *close proximity* to be recognized by this system as 1.6m. Beacons within this *close proximity* range to the teacher will start to change color from yellow to green.

To determine at which speed the Beacons should change color, we decided to look closely at the types of interactions teachers might have with students when they are in close proximity. Next to being *engaged* in direct conversation, instruction or observation, more subtle interactions are also brought by teacher proximity. For example, when the teacher is walking around, he/she could glance at students close by to get an idea of their performance, while at the same time, knowing that the teacher is around, or that the teacher may be looking at them, students may also get more engaged in their activities or encouraged to initiate asking questions. Similarly, a study by [3] found that while performing a main task, teachers also try to listen to the students around or behind them to know their status. A review by [20] reported '*spill over*' effects which were found in several studies: a teacher's reinforcement or reprimands to a target student potentially influences non-targeted students sitting adjacently. To better portray teacher proximity, we argue that it is important to reflect various influences brought by teacher proximity including these non-verbal/implicit interactions. Therefore we designed the mechanism of display as follows, distinguishing three levels of interactions:

- *Engaging*: This level is activated when the teacher is standing still, one (or more) Beacon(s) is within *close proximity* to the teacher, and it is in the central area of the teacher's angle-of-view. At this level, a Beacon will take 55 seconds before changing from the current color to the next greener color on the preset nine-degree spectrum.
- *Surrounding*: This level is activated when the teacher is standing still, and one (or more) Beacon(s) is within *close proximity* and in the periphery of the teacher's angle-of-view. At this level, a Beacon will take 110 seconds before it changes to the next color.
- *Wandering*: This level is activated when either the teacher is standing still with one or more beacons in *close proximity* behind the teacher, or the teacher is walking with any Beacon in *close proximity.* At this level, a Beacon will take 220 seconds to change to the next color.

The Beacons change color from yellow to green over the course of one lesson and are reset to yellow before the start of a new lesson. This means that the Beacons can only become greener over the course of one lesson and the information is presented in a cumulative fashion.

METHODOLOGY

Adopting a research-through-design methodology [49], we developed and evaluated ClassBeacons, a distributed ambient information system visualizing teacher proximity in the classroom. Our exploration aims to answer two research questions:

- *RQ-1*: What could be the potential values of proximity visualization for pedagogical activities in the classroom?
- *RQ-2*: How will ClassBeacons be experienced by teachers and students in the secondary school classroom?

To answer these questions, we evaluated ClassBeacons using a mixed-method approach in which we conducted an expert review of ClassBeacons, and a field deployment with eight secondary school teachers. The conducting of both of them will be described in this section. The goal of the expert review is to address RQ-1, and to gather assumptions for RQ-2, while the field evaluation aims to address RQ-2.

Expert Review

We conducted an expert review of the ClassBeacons design with four educational experts (2 male, 2 female, ages 47 to 63), whom we will refer to as E1, E2, E3 and E4. They work at an educational research institute at a University in the Netherlands. All experts were conducting educational research targeting secondary school pedagogy. The jobs of E1, E2, and E3 also contained guiding and coaching preservice/novice secondary school teachers to help those teachers improve their teaching performance. All the experts had ample experiences of observing in secondary school classrooms for teacher performance improvement or research data gathering. All of them had worked as a secondary school teacher for between 6 and 30 years in their career. E2 and E4 were at the moment of the study still teaching part-time. Each expert participated in a semi-structured one-on-one interview of approximately 60 minutes, conducted in an office environment.

In the first part of the interview, the experts were asked to describe their understanding of the role of teacher proximity in secondary education. In the second part of the interview, the design of ClassBeacons was shown to them and they were asked to envision potential values of proximity display to pedagogical activities (RQ-1), and discuss possible user experiences of ClassBeacons (RQ-2). To stimulate the interviewees' imagination and to ensure they saw our design as a concept open for debate rather than as a finished product, we used a storyboard rather than the working prototype to convey the concept of ClassBeacons (see Figure 4). To trigger the experts to consciously speculate on the distributed nature of ClassBeacons, we created another storyboard presenting a screen-based display of the same information through a heatmap (see Figure 4). Experts were asked to give feedback on both and compare the two.

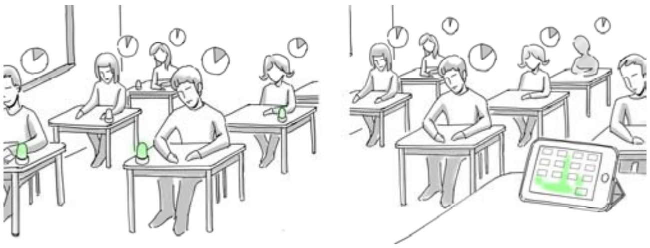

Figure 4. One frame of the storyboards. Left: ClassBeacons. Right: 'heatmap'. ©Pengcheng An.

The interviews were audio-recorded and transcribed verbatim for a *conventional qualitative content analysis* [23]. This standard qualitative analysis approach systematically analyzes textual data, in order to gain thorough and deep understandings about the data [23]. Following the detailed procedures described in [23], the analysis was carried out by two of the authors. 133 quotes were selected which related to (one of) the two research questions. The quotes were coded first individually and then jointly by the two researchers. Through discussion, a detailed categorization of quotes was finalized.

Field Deployments

To gather user experiences of ClassBeacons (RQ-2), the working prototype of ClassBeacons was deployed during lessons of 8 secondary school teachers from 4 different secondary schools. As Table 1 shows, we recruited a group of teachers that were diverse in gender, teaching experience and subject to cover a relatively wide range of pedagogical styles. The prototype was implemented in the classroom of each teacher for two lessons.

Teacher	Gender	School	Experience	Subject
T1	M	S1	8	Computing
T2	M	S1	17	Computing
T3	F	S2	32	English
T4	F	S2	8	English
T5	M	S2	3	English
T6	M	S3	5	Chemistry
T7	F	S4	12	Humanity
T8	F	S4	16	English

Table 1. Basic information about teachers recruited for field evaluation. 'Experience' indicates years of teaching.

Short 20-minute interviews were carried out right after each lesson: teachers were asked to quickly report specific moments in which they looked at or noticed the Beacons, and to indicate why they noticed them and which tasks they were engaged in at those moments. These short interviews aimed to capture detailed examples about how teachers used the ClassBeacons when they still kept a fresh memory about the lesson. After the last lesson of the deployment, each teacher participated in a longer interview of 30 to 60 minutes. These interviews included more in-depth questions on their experiences, such as why they felt the system had or had not helped them, how their students reacted to the system, why they thought the system had or had not brought extra workload to them, how they experienced the information display, and what other benefits, disadvantages, opportunities or risks they thought the system had. Some questions were based on assumptions we gained from the expert reviews (which will be discussed in the upcoming findings section). All the interviews were conducted in the secondary schools, and most of them took place in the classrooms where the prototype had been implemented.

The interviews were audio-recorded and then transcribed verbatim. A phenomenological approach [34] was used to analyze these textual data. This approach was chosen to understand the essence of peoples' experiences on studied phenomena [41], in accordance with the purpose of this field evaluation (to answer RQ-2). The analysis was carried out following the procedure described in [5]. The findings of the analysis will be addressed in next section.

FINDINGS AND DISCUSSION

Expert Review

After the analysis on the data from expert interviews, a categorization of the 133 selected quotes has emerged, under two main topics: the *potential values of proximity visualization* in classrooms (to address RQ-1), and the *possible benefits/challenges of ClassBeacons* (to address RQ-2*)*.

Potential Values of Proximity Visualization (RQ-1)

Reflecting personal interaction: All four experts mentioned that while observing a lesson, they paid considerable attention to the personal interaction between the teacher and individual students. As E4 mentioned, "*education is about interaction, tuning your behavior to the needs of the individuals in your classroom.*" And according to them, there are various types of interactions that are best achieved in close proximity to the students, such as talking (E1), observing a student's work, being around to show willingness of help (E2), or passing by to maintain students' engagement (E3). E1 and E3 pointed out that proper personal interaction could activate students in learning. As indicated by E1, "*if you can create a learning environment where you have more interactions, I think the learning process is more effective… the students are more activated to learn and they also like to learn.*" Moreover, E2 and E4 thought that having sufficient personal interaction helps the teacher keep track of a student's performance ("*what they've done*" (E4)), rather than only knowing the general status of the whole class (such as if "*they're quiet*" (E2)). Given the above mentioned reasons, the experts agreed that providing real-time feedback about the teachers' whereabouts is meaningful. As E1 concluded, "*It's very important from an educational perspective that the teachers get feedback on how they interact with their students.*"

Facilitating Attention distribution: The expert review revealed that it is highly relevant, but also difficult, for teachers to provide a proper amount of attention to each student. In principal, teachers try to "*give attention to all the students*" (E1) with no one left behind. However, it is challenging to "*see all the students*" (E2), especially for teachers who have *"a big classroom"* (E2), or "*30 children*" (E1); and there might be "*a blind spot*" (E2) which the teacher has not visited during the whole lesson. According to the experts, an ideal distribution of attention among students does not necessarily mean the teacher has to spend an equal amount of time with each student. "*Every student is different, so one needs perhaps more attention than the other*" (E4). It is natural that the teacher would "*give more attention to the students who have more problems with learning*" (E1). However, E1, E2 and E4 all noticed that teachers sometimes paid too much attention to some of the students while ignoring the others. "*You sometimes realize that you've paid a lot of attention to 1 or 2 students in the lesson, and the other students have not gotten your attention. That happens, for sure*" (E4). Two types of students normally capture more attention from the teacher: "*Pupils that are making a lot of noise*" (E4), and "*The children who ask questions*" (E2). Sometimes, these active students "*somehow end up in one side of the classroom and that means the other side of the classroom, they don't get so much attention*" (E2). Thusly, with attention caught by these louder or more active students, teachers may easily ignore those reticent students. "*A difficult problem is that sometimes students* [who] *have questions or* [who] *do not understand do not even realize that they should have a question. So asking* [for] *help is not something that all the students do.*" (E4) and therefore E1 identified the benefit of making teachers more aware of their attention assigned to students: "*I think that's very nice* […] *that you can see: where and what is the attention the teacher gives? That can be some feedback for the teacher, he can realize* […]"

Creating immediate awareness: The experts confirmed the complexity of teaching. As E4 reported, when interacting with a student, "*there was a lot more going on and you should keep your eyes and ears open to what's going on*". A teacher often needs to have multiple tasks in mind concurrently, Such as attending to "*sound levels*" (E4), having an "*overview*" (E3) of the class, or adapting teaching plans to changes (E2). All these tasks impose cognitive load on teachers. Therefore it is difficult for them to pay continuous attention to the details of their own performances while teaching, including keeping aware of their own "*movement*" (E3) in the classroom. As experienced by E4, "*usually when you're observing the classroom, you see other things* [more] *than the teacher sees* […] [Because] *you're not managing the class you have more time to observe*". Feedback about personal interaction or attention distribution of the teacher is often provided by the observers afterwards. The experts indicated that they thought a real-time visualization could disburden teachers' reflection and help them gain immediate awareness about their proximity distribution so far. For example, a teacher could easily notice that he/she has spent too much time with a group of students: "*if I get the feedback then I realize that I have to stop* [offering] *the feedback or the intervention for that group and I have to go to the other group*"(E1). The experts thought that a real-time visualization of proximity information could help teachers improve their performances immediately. "*When you have real time feedback you can adjust your behavior instantly, not afterwards* […] *wait for a second lesson* […] *So that's valuable.*" (E3)

Possible Benefits and Challenges of ClassBeacons (RQ-2)

Benefits: The most mentioned benefit by the experts was that as a public visualization ClassBeacons might create self-awareness among the students, especially for those who "*are not even aware that they should ask a question*" (E4) With this awareness, they might be encouraged to ask more attention from the teacher. Furthermore, a public display is expected to create transparency. "*I like to have a transparent situation and all students can see how much time there is given to the other students.*" (E1) As a result, the lights could be a justification for the teacher to go on to the next student, "*if you are explaining something to one student and you can say: 'Sorry, but I have to help the other students as well'*" (E4). Unlike a single device, ClassBeacons is distributed (E2) and therefore can serve as a visual cue. Being distributed over the space, ClassBeacons "*would be easier* [to perceive] *because you just see whose light is brighter than the other*" (E2). Since "*it's visible right away*" (E3), there is no need to go back and forth. "*You don't have to walk to the* [teacher's] *desk to have a look.*" (E2) And the ClassBeacons offer flexibility in how to use them: "*you could just take 4 or 5 of these lights and then put the seats together and say okay this is one group and this is the other group* […]" (E2).

Challenges: There are also some concerns from experts about ClassBeacons. The lights might be a distraction or disruption to students, "*Maybe they give attention to the light and not* [to] *what they are doing*" (E1). Some students may complain if this feedback information is visible for them. E.g., "[a student might say:] '*His light is much brighter than mine; you should pay attention to me. It's unequal'*" (E4). Also students might have their own interpretation of the ClassBeacons with negative consequences. E.g., "*I cannot ask any questions anymore because my light is so bright*" (E3). E2 was concerned that "*if you would do this in lower* [grades of] *secondary education,*" those younger students might fiddle around with the Beacons. In a distributed manner, it can be more difficult "*to get some overview*" of the proximity distribution (E1). Comparing to a heatmap which shows the proximity information on screen, the experts expect that ClassBeacons is less beneficial for reflection afterwards (E2). And it was also estimated by E2 that with a centralized device, attention could be paid only when the teacher wanted to.

Field Evaluation (RQ-2)

In this sub-section we report the results of the analysis on eight teachers' experiences of using ClassBeacons in their classrooms to address RQ-2.

Influence on Teaching

All the teachers except T3 reported that ClassBeacons had brought them more awareness about their own proximity distribution. For instance, as T4 reported, "*I could actually see that I didn't spend that much time or I spent more time* [in this group] *than in another group*". The newly gained awareness seemed to have different meanings to them. T1 found it supportive to his decision-making: "*when multiple students were raising their hand, I checked the Beacons to see what color it was, so more towards yellow then that would be the first to go to*". T2 experienced the awareness triggered reflection: "*I saw there was the light* [that was] *a little bit yellow. Then you reflect to yourself: did that student need more attention? No, that student is okay.*" T6 reported that the information helped him to confirm his execution of plans "*In my head those* [students] *are the ones I want to give* [extra] *attention,* […] *and now I can actually see that they also get that extra attention.*" While T3 and T5 did not think that the display could make a difference in their teaching ("*I can't imagine that it would change my behavior at all*" (T3)), the other teachers indicated that it could potentially facilitate their attention distribution and personal interaction with the students. For example, T8 felt it was "*quite useful because* […] *you can be sure that you are dividing your time with everybody in the classroom.*" T7 thought ClassBeacons reminded her to wander more, which motivated students to ask for help.

Social Awareness

Teachers identified both benefits and risks of the social awareness created by the ClassBeacons' public visualization of the teacher's proximity. T7 found it "*a benefit for the students because some of them maybe are going to realize that they don't ask enough questions, so they don't ask for the attention of the teacher enough*". T4 experienced that it could activate students in a playful way, because they liked to have their lamps turned green: "*It's more like a reward and they become aware of their participation as well*". After being asked, no teacher reported that they had been stressed by the social awareness in their lessons (e.g., "*Does it give you any pressure?* [...] *No, it doesn't.*" (T4)). However, they could imagine that teachers might experience pressure in some occasions. One concern was that students might use it to complain about their teaching. For example, students might say: "*'my light is always yellow. I didn't get the attention I needed.'*" (T2) or "*students use it as a reason to say that the teacher is picking on me*" (T3). At the same time, T2 and T6 considered that it could also be justification for teachers: "*'I always spend time with you: look at the system, your light is always green.'*" (T2) Another possible pressure on teachers could be that the data of ClassBeacons might be abused by the school management or parents to (mis-)judge teachers. Therefore "*It would have to be made very clear to that teacher what the system was used for*" (T3).

Distraction Level

The participating teachers experienced that the students showed curiosity and interest at the beginning of the lessons when they first encountered ClassBeacons. "*At first they wanted to know why the lamps were on the table and what they were doing. So the first five minutes they were focused on the lamps* […] *after that, that was okay*" (T7). "*They were quite excited. After a bit they stopped bothering*" (T3). None of the teachers considered ClassBeacons as a serious distraction to the learning activity. As T4 indicated, "*they find it very interesting but it's not like they're constantly aware of it*". Some teachers tended to attribute this to the novelty effect of the system: "*it's the same with the mobile phones. Once they were used to seeing them all the time, they will not notice them.*" (T8) Contrarily, T6 reported that the lamp was quite distractive to one student who he knew to be quite sensitive to distractions in general.

Perception of Information

Teachers considered the perception of information from ClassBeacons as effortless and direct. T4 experienced her perception was "*quick, because it's got the color so unconsciously... I think it's a split-second or something that you actually think about it*". T6 found that the system could show an understandable pattern by color difference: "*when at first it was all a bit yellowish, all the same, but after a while I started to see patterns, and the patterns were for me an indication.*" Some teachers also reported that they could easily ignore the display when focusing on their main tasks. "*I kind of deliberately forgot them* […] *I was busy looking what they were writing*" (T8) Examples described by teachers indicate that they could obtain relevant information from ClassBeacons while performing other teaching tasks, sequentially or in quasi-parallel. "*You look around: is everybody okay? And then you can see, then you look at the lights and think: okay, do I have to go somewhere?*" (T2). "*So I try to observe some obvious clues: students raising their hands or students talking to each other and not working* […] [looking at] *ClassBeacons are also part of that observation*" (T1). This seamless integration of the perception into teaching routines was appreciated by teachers. "*I think that's the best point, that you can use it at the moment.* […] *you are just doing regular things, what you're used to do*" (T7). And compared to a visualization on a screen, *"it's direct, and it doesn't require a lot of reading."* (T4) Additionally, a benefit brought by physicality was mentioned. As T7 experienced, her teaching was influenced not only because of the information presented to her, but also because of the physical presence of the Beacons served as a cue. "*In the first place because the system is there, it's not like this light is orange so I have to go.*" T8 had a similar comment: "*if they weren't there, there is no visual sign* [reminding me to] *go to the back* […]"

DISCUSSION

To assess what the value of showing real-time proximity information might be to educational practice and to study the user experience of the ClassBeacons' implementation, we conducted an expert review and a field deployment.

From the expert review it became clear that close teacher-student proximity is beneficial for individual support, and activating students, which confirms views from related educational research [29,30,35]. Knowing how much time teachers have spent in different areas could help them to more mindfully distribute proximity. However, in current practice, feedback on teacher proximity is only subjectively and sporadically provided by professional observers. The experts considered objective real-time feedback as a valuable addition, which could enable teachers to reflect more often and more directly on their time and attention distribution over students. As a confirmation to this, most of the participating teachers experienced that the immediate feedback given by ClassBeacons could benefit them during teaching. They indicated that it helped them in decision-making (e.g. which students to help first) or reflection (e.g. to check if they were doing the right thing). Such reflective activities are considered important for teachers [46], especially in the context of learner-centered education [15]. Both findings indicate that teacher proximity visualization can be meaningful to classroom pedagogy. Nonetheless, T3 perceived little usefulness from the system. And she also happens to have the longest career among the teachers (see Table 1). This may suggest that a future study could focus on the differences of the system's perceived usefulness to and actual impact on the teachers with different levels of teaching experience and technology acceptance.

The ClassBeacons' distributed display makes proximity information visible to everyone in the classroom. We therefore explored the possible social effects of ClassBeacons. The experts and the participating teachers identified both benefits and risks of the design. Both experts and teachers addressed that teacher choices could be justified by the display, that information about teacher proximity could encourage 'reticent' students to ask the teacher for support, and that the engagement of students could be increased as a result of knowing that the teacher is wandering more. This echoes some findings in educational science literature [14,20,39] which show that a teacher's physical proximity positively influences student engagement. Although the number of participants in our field-study was limited and experts merely voices expected effects of ClassBeacons, a display like ClassBeacons might be able to extend the effect proximity has on student engagement. When the teacher is no longer close to the student, but a display reminds the student of a teacher's proximity earlier in the lesson, or of upcoming teacher's proximity, this might also result in increased engagement. Longer and more elaborate field evaluations would be needed to further examine such an effect of ClassBeacons.

With the ClassBeacons' display accessible to all, some experts were concerned by its distraction to students. However, through observation, none of the participating teachers found it a serious distraction to the students despite the "curiosity" during the first minutes of use. Some teachers attributed this extra attention from students at the beginning as novelty effect of a new technology. Moreover, both experts and teachers were concerned that students might complain to the teacher for receiving too much or too little attention, or misinterpret the display. Besides this, teachers also expressed the concern that the data from the system might be abused by schools or parents. Hence a careful consideration of possible social effects is needed when designing similar systems. Given that privacy concerns are appropriately dealt with, we believe to make this feedback also visible to the students is constructive for creating learner-centered dynamics in the classroom.

Teachers considered the display to be effortless and direct. Although E1 estimated that it might be difficult to have "*some overview*" of the displayed data with this distributed system, T6 experienced that an understandable pattern emerged in the space through the colors. Different from what E2 had assumed, the display was not experienced as demanding: Beacons could be easily discarded when the teachers were busy. Because of its distributed nature, a location and its related information were co-located. Teachers indicated they could use the system sequentially or in quasi-parallel with student observation (which commonly exists in teacher routines [3]). As compared to centralized displays, ClassBeacons did not require teachers to go back and forth, or read information from a screen. Therefore it seems less interrupting to the task flow of teaching. The teachers' experiences of ClassBeacons confirmed our assumption that distributed tangible displays have the potential to seamlessly integrate relevant information into teachers' everyday routines.

CONCLUSION

We presented the design, expert review, and field evaluation of ClassBeacons, a distributed ambient tangible display that visualized teacher proximity in secondary school classrooms. Our findings show that access to real-time information about the teacher's proximity over the duration of a lesson could be valuable for both teachers (to support decision-making and immediate reflection) and students (to possibly increase engagement and encourage active participation). Furthermore, the distributed and ambient nature of ClassBeacons enabled the design to potentially seamlessly blend into the classroom routines.

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