# Unobtrusively Enhancing Reflection-in-Action of Teachers through Spatially Distributed Ambient Information

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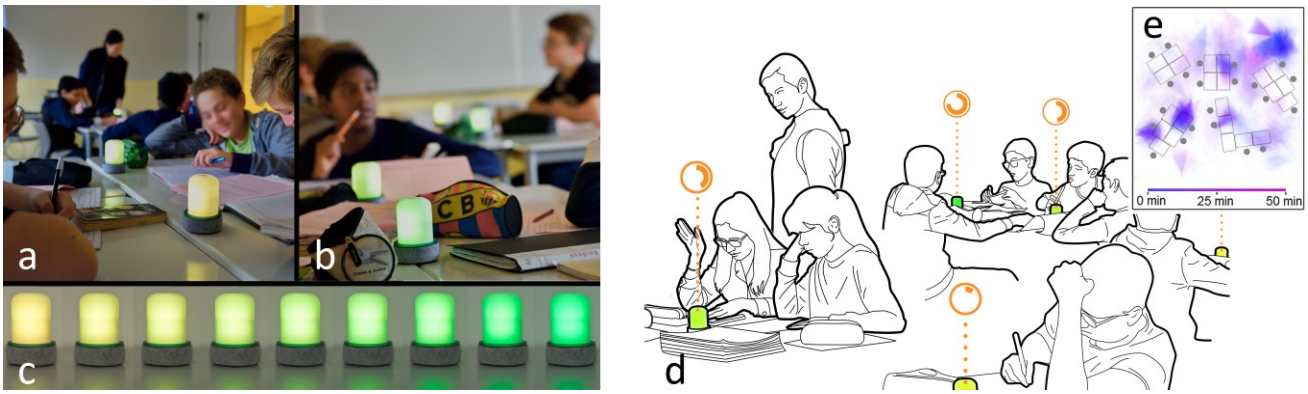


**Figure 1. (a)(b): ClassBeacons system (c): each lamp depicts how long the teacher has been around it by changing from yellow (no time spent) to green (440 seconds spent) (d): the system supports teachers' reflection-in-action on how they have divided time and attention over students in the classroom (e): the display is based on teachers' real-time positioning data.**

## ABSTRACT

Reflecting on their performance during classroom-teaching is an important competence for teachers. Such *reflection-in-action* (RiA) enables them to optimize teaching on the spot. But RiA is also challenging, demanding extra thinking in teachers' already intensive routines. Little is known on how HCI systems can facilitate teachers' RiA during classroom-teaching. To fill in this gap, we evaluate ClassBeacons, a system that uses spatially distributed lamps to depict teachers' ongoing performance on how they have divided their time and attention over students in the classroom. Empirical qualitative data from eleven teachers in 22 class periods show that this ambient information facilitated teachers' RiA without burdening teaching in progress. Based on our theoretical grounding and field evaluation, we contribute empirical knowledge about how an HCI system enhanced teachers' process of RiA as well as a set of design principles for unobtrusively supporting RiA.


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## CCS CONCEPTS

• **Applied computing~Computer-assisted instruction** • Human-centered computing~Field studies; Displays and imagers

## KEYWORDS

Reflection-in-action; periphery of attention; teacher; reflective practitioner; distributed cognition; ambient information system.

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## 1 INTRODUCTION

While teaching, teachers are expected to momentarily reflect on their performance (e.g. "Am I explaining things clearly?" or "Am I having enough interactions with individual students?"). Such reflection during the action of classroom-teaching is referred to as *reflection-in-action* [46]. Reflection-in-action (RiA) is widely considered as a significant competence for teachers [19]: it helps them optimize their teaching behaviors on the spot. However, RiA is challenging in practice, due to the intensive and

complex routines of teaching [12]. There simply is often no time and attention left to deliberately reflect on classroom performance while in the midst of it.

In the domain of teacher education, many in-service training techniques aim to make teachers more reflective in teaching [19]. Most of these techniques rely on teachers to reflect upon their performance *after*, rather than *during* the lesson. While leading to helpful insights for future teaching, such techniques do not enable teachers to adjust their actions while teaching. Little is known on how technology could, in real time, support RiA process, in both education and other application domains of HCI [50].

This paper explores the use of an ambient information system to facilitate teacher's RiA. Specifically, we evaluated the ambient system 'ClassBeacons' [6] whose design features are considered to be supportive to the characteristics of RiA. ClassBeacons uses spatially distributed lamps to portray teachers' performance on *teacher proximity* [26]: their division of time and attention over different students in the classroom (see Figure 1). We analyzed rich empirical data from eleven secondary school teachers in 22 class periods. The results show how the ambient information was thought about by the teachers on the spot, which enhanced their process of RiA, without burdening their ongoing teaching tasks. Based on related theories of RiA, as well as our empirical findings, we propose and contextualize four design principles to inform future design for supporting teachers' RiA.

This paper contributes (i) empirical understandings on how an ambient information system enhanced teachers' process of reflection-in-action including sense-making of ongoing performance and modification of upcoming actions; and (ii) four design principles to inform HCI design for supporting teachers' reflection-in-action.

## 2 THEORETICAL FRAMING: WHAT IS REFLECTION-IN-ACTION?

The theoretical notion of *reflection-in-action* was originally proposed by Schön in his work on professional practitioners [46]. Teachers are considered as typical professional practitioners in Schön's theory. Although his theory has been highly influential across domains [50,56], various interpretations of the term RiA exist [15,57]. We examined both Schön's original work [46,47] and that of his successors and critics studying the teaching profession [3,15,19,57], to summarize our interpretation of RiA.

RiA refers to reflection of practitioners in the midst of a performance to inform the action currently in progress. Therefore, it is distinguished from *reflection-on-action* [46]: the type of reflection performed *out of* or *away from* action [15], and intended to impact action in future episodes of practice. Professionals commonly rely on routinized and spontaneous performance in their workaday practice. But 'over-routinized' performance may lead to rigidity. RiA is therefore crucial for promoting professionals' responsiveness and improvisation in each (often unique) episode of practice. RiA can be explained by the following ***core characteristics***:

**C1.** ***Concerning ongoing performance***. The content of RiA concerns the ongoing performance and helps practitioners make sense of the situation at hand, or modify upcoming actions accordingly [19,46].

**C2.** ***Context-dependent***. RiA is highly context dependent. It relies on teachers' practical understanding of their own practice context [46,47]. Thus different teachers can give different interpretations of a similar phenomenon [46,57].

**C3.** ***Occurring in action***. RiA occurs *in* action. It is interleaved with and beneficial to the ongoing performance, rather than interfering with it [46,47].

**C4.** ***Short time-frame***. RiA happens at the moment that "action can still make a difference to the situation" [46 p.62]. Due to the rapid pace of teaching, teachers' time-frame for each RiA is relatively short [15,57].

**C5.** ***Both conscious and intuitive***. Due to their intensive actions and limited time and attentional resources, teachers' RiA is conscious but often not very elaborate [15,46]. It somewhat relies on their intuitive '*feel for*' things or *tacit know-how* [46,47]. Thereby they can assess the situation quickly, avoiding their reflections interrupting the flow of practice.

As suggested by related works, RiA can be shaped by media such as practitioners' repertoire, artefacts, or materials [46,57]. But little is known about how such media (e.g. HCI systems) mediate RiA [46,50,57]. This has been a motivation of our inquiry.

## 3 RELATED WORK

### 3.1 Techniques to Support Teachers' Reflection

Reflection-in-action is seen as a significant competence for teachers [19]. It helps teachers in the midst of teaching to deliberate on the (unique) situation at hand and adjust their performance accordingly. RiA is known to help avoid rigidity in teachers' intensive workaday routines, to enable self-renewal of teaching behavior, and to promote learner-centered pedagogy [2,22,56].

The ALACT model [28] is widely used by studies in *teacher education* to describe and train teachers' reflections. It is named after five stages that comprise an ideal circular process of teachers' reflection: ***A**ction*, ***L**ooking back on the action*, ***A**wareness of essential aspects*, ***C**reating alternative methods of action*, and ***T**rial*. Although the ALACT model applies to reflections both *in* and *away from* teaching, it is developed with the ultimate goal to help teachers incorporate such a reflective process *in* teaching, i.e. reflection-*in*-action [28]. We have used the ALACT model to interpret our empirical data to assess how the evaluated ambient information system supported teachers' RiA at different stages in the reflection process.

Classroom-teaching is characterized by intensive tasks, interruptions and multitasking [7,12]. As RiA means simultaneous reflecting and teaching, it is a skill that requires years of teaching practice [19,45]. In *teacher education* realm, many techniques are known to train teachers' reflectiveness [19]. For example, *video-cases* [2,11,22,26,51,56] help teachers relate their practice to video examples. *Keeping journals* and *oral interviews* [3,19,47] help teachers explicitly reflect on their teaching. Although the ultimate aim of such training techniques is to enable teachers' RiA [19,28], they rely on triggering teachers' reflections *out of* their lessons, i.e. reflection-*on*-action [46]. Contrarily, *synchronous coaching* [21], in which a coach remotely monitors and directly instructs a teacher via an earpiece, enables teachers to optimize performance during teaching. While effective, these techniques are costly and time-consuming and may thus only be accessible for teachers in a training program.

Little is known on how technologies can, in real time, enhance teachers' RiA during their intensive routines. At the intersection of HCI and education, a large body of work focuses on learners' use of technology (e.g., [25,30,31,40–42,52]). Design explorations on how technology can support teachers in the classroom are underrepresented. While some designs aim at supporting teachers' in-lesson routines (e.g. orchestration or using digital resources) [4,8,9,14,17,43,53], only very few of them aim to support teacher's reflection. E.g. *Lernanto* [5] visualizes real-time performance of students on the back-wall of the classroom to support teachers' deliberation on differentiated instruction. *Group Spinner* [27] supports teachers' reflection by enabling them to log and visualize observed learner behaviors via a graphical interface.

While these related works may suggest an emerging interest in supporting teachers' reflection, there still lacks empirical knowledge about whether and how such designs support RiA. This reflects a more general challenge in HCI: despite an increasing interest in designing for reflection [50], little is known about how technology can support the process of RiA, to inform future designs [50]. With rich empirical data, this paper aims to shed light on how technology can mediate teachers' RiA.

### 3.2 Leverage the Periphery of Teachers' Attention

Given the characteristics of RiA, we argue that a technology designed to support teachers' RiA must be *unobtrusive*: it should be used without interfering with the ongoing performance of teaching or overburdening teachers' thoughts. We believe this can be achieved by leveraging the *periphery* of teachers' attention.

The idea to leverage the periphery of users' attention in HCI was first proposed by Weiser and Brown [55], and inspired a large body of research under various terms including *calm technology* [58], *ambient information systems* [37], and *peripheral displays* [34]. A number of studies on leveraging the periphery in a classroom context are known. For example, some studies have explored using peripheral information displays to create group awareness of the learning activities of fellow students [5,29,35]. These peripheral displays show information on a central display on the wall of a classroom. Ambient information can also be shown through multiple devices that are physically *distributed* over the classroom. E.g., *FireFlies* [9,54] uses small light-object on individual students' desks to communicate simple and silent information to primary school pupils. *Lantern* [4] supports communication between learner-teams and university teaching assistants by showing work progress and help-requests of teams on light-objects. *Lantern* is proven to effectively ease help-seeking and tutoring processes.

These studies revealed that distributed displays can enable teachers' direct (peripheral) perception of relevant information. No interpretation was needed to figure out which information belongs to which group (or individual). Based on these related works, we consider distributed ambient information systems a promising paradigm for unobtrusively supporting teachers' RiA. Therefore, our work evaluates such a distributed system called ClassBeacons [6], to examined how its spatial distribution could *offload* [24,44] teachers' cognitive task of RiA.

## 4 HYPOTHESIZING DESIGN PRINCIPLES

Our empirical study explores how teachers' reflection-in-action can be supported by designed system in order to contribute practical understandings that can inform related

HCI designs in the future. To do so, we formulated four design principles (**P1-4**) which we hypothesize to support teachers' RiA [15]. These principles are deduced from the core characteristics (**C1-5**) of RiA summarized earlier and are contextually examined by means of a field study reported in this paper. Our hypothesized design principles are formulated as follows:

**P1.** ***Informing ongoing performance.*** RiA concerns ongoing performance (C1). Thus, system supporting reflection-in-action should provide information that is relevant to teachers' ongoing teaching activities.

**P2.** ***Being open to interpretations.*** RiA is highly context-dependent and based on teachers' personal experiences (C2). To support RiA, information interfaces should encourage teachers' own interpretations of the displayed information.

**P3.** ***Supporting use in the midst of actions.*** RiA happens in action (C3). Therefore, information systems to support such reflection should be usable in parallel with other ongoing tasks, without interfering with these ongoing actions.

**P4.** ***Enabling short-term, effortless, easy-to-discard engagements.*** Teachers' RiA happens in short time-frames (C4) with limited involvement of attentional resources (C5). Therefore information systems should support quick, effortless engagements, which do not demand continuously focused attention and can be discarded easily.

## 5 INTRODUCING CLASSBEACONS

This paper aims to study how an ambient information system can support teachers' reflection-in-action. To this end we conducted a field-evaluation in which eleven secondary school teachers used an ambient information system called ClassBeacons. The ClassBeacons design was selected because it embodies our four design principles (**P1-4**), which we believe to support RiA. This section introduces ClassBeacons and explicates why we believe this design to be a suitable tool to gather empirical data on how a technology can mediate teachers' RiA and contextually examine our hypothesized design principles.

### 5.1 The Functioning of ClassBeacons

ClassBeacons is an ambient information system consisting of small lamps that are distributed over the classroom: one is located on the desk of each student-group or pair (see Figure 3). These lamps simply use color to show information that is relevant for teachers to reflect upon during a lesson. Specifically, ClassBeacons depicts *teacher proximity* [26] information: how the teacher has divided his/her time and attention over different students during the lesson. This system is designed for differentiated instruction scenarios in secondary school: situations where (usually around 25) students are working on exercises independently while the teacher walks around to observe and give feedback. In the beginning of a lesson all lights are yellow. Over a course of a lesson, each lamp can gradually change from yellow to green to indicate how much time the teacher has spent around it (helping the student to whom the lamp belongs). The longer the teacher has been around it, the greener a lamp will turn (see Figure 1 (c)). This display is intended to help teachers reflect on which students they have (not yet) helped, and how to divide time and attention throughout that lesson.

The ClassBeacons system (see Figure 2) uses a decimeter-level in-door tracking kit [38] which senses the teacher's position and orientation (i.e. heading direction) via a wearable unit on his/her upper-back (Figure 2). The unit is attached to a garment worn by the teacher, and communicates with four positioning anchors placed in four corners of the room (Figure 2). During the system's use, the teacher's position and orientation is gathered every two seconds. Thus, the system can represent the teacher's accumulated whereabouts in a lesson, which is in real time translated as the colors of the lamps.

Each lamp reacts to the teacher's presence in the range of *close proximity* (≈1.6m, also see [6]). When the teacher is within close proximity to a lamp, the system uses both positioning and orientation data of the teacher to interpret whether the teacher is (1) directly engaging with the students around the lamp, (2) standing adjacently without directly engaging with the students, or (3) walking by the students without direct engagement. Based on this

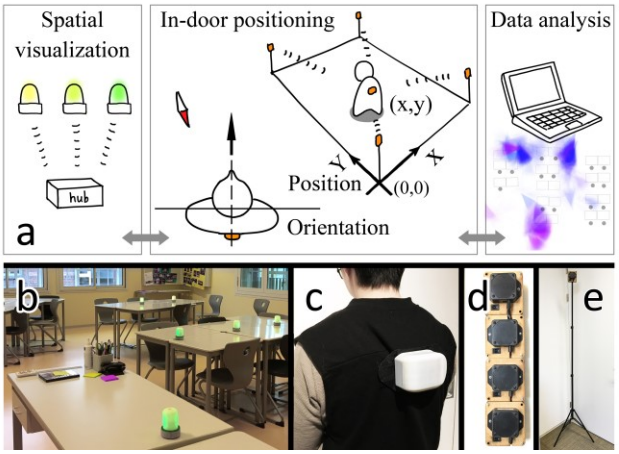


**Figure 2. (a): ClassBeacons system (b): its deployment in a classroom (c): wearable unit (d)(e): tracking anchors.**

information, each lamp changes color to indicate the amount of proximity it has accumulatively received from the teacher. It takes 440 seconds for a lamp to change from yellow to fully green in the condition that the teacher has been directly engaging with the students around it. In this way, each lamp is yellow at the beginning of a lesson and can only turn greener over the course of one lesson. Before a new lesson starts, the visualization is reset.

### 5.2 Teacher Proximity

*Teacher proximity* is a relevant but challenging aspect to reflect on during teaching. Although being implicit in teaching, teacher proximity is increasingly suggested to have major influence on learning behaviors and teacher-student interactions [26,32,33,36,49]. For example, students sitting near the teacher may be more engaged with learning tasks or receive more caring. For this reason, a number of studies [13,18,48] propose teachers to deliberately reflect on and manage proximity as a resource to positively influence learning behaviors. However, in practice, due to the intensity of teaching, it is often challenging for teachers to deliberately monitor their whereabouts, and provide proper amount of proximity to each student [6]. For example, a teacher might spend too much time with active or loud students while subconsciously ignoring others. On top of that, teachers usually only receive feedback on their proximity distribution in training settings when an observer is present in their classroom. In these cases the feedback is given *after* the lesson [6,26,49]. As a result, teacher proximity provides a specific opportunity for us to study how technology can support teachers' reflection-in-action.

### 5.3 ClassBeacons and RiA design principles

We selected ClassBeacons for our evaluation because we believe the design embodies the design principles (**P1-4**) that we hypothesized to support RiA. Here we detail how each design principle is represented by ClassBeacons.

*P1. Informing ongoing performance*: ClassBeacons depicts teacher proximity during a lesson in order to help teachers to deliberately think about or optimize their performance. The display depicts real-time information and can therefore inform ongoing performance.

*P2. Being open to interpretations*: An ideal distribution of teacher proximity does not mean staying with each student for equal amount of time each lesson; it depends on the particular context of a lesson and the professional beliefs of the teacher [6]. Thus, ClassBeacons aims to ease teachers' awareness of and reflection on their proximity to pupils, instead of steering them toward certain behavior. Hence, no red colors, which may contain negative connotations, were used and the data was presented as neutrally and objectively as possible (e.g. with only minimal data processing). Teachers may therefore form their own interpretations of what actions to undertake as a result of the information depicted by ClassBeacons.

*P3. Supporting use in the midst of actions*: In classroom teaching, teachers regularly look around at each of their students to observe their activities and see whether they understand the contents or need help [7]. Since the lamps of ClassBeacons are located on the students' desks, they are easily seen by teachers in their regular observational actions and may thus be used in the midst of actions.

*P4. Enabling short-term, effortless, easy-to-discard engagements*: Each lamp as a 'tangible pixel' displays only a minimal amount of information. The colors change in a slow and subtle manner to make the display unremarkable and easy-to-ignore. Therefore, the whole distributed display is intended to be perceived effortlessly at a glance.

## 6 EVALUATION METHODS

Our evaluation of ClassBeacons focuses on gaining empirical understandings which could inform future HCI design for supporting teachers' reflection-in-action. To do so, we deployed the ClassBeacons system during 22 lesson periods of eleven secondary school teachers. Semi-structured in-depth interviews were conducted after each lesson to gather data with two specific research aims: (i) to gather lived experiences about if and how ClassBeacons supported teachers' process of RiA, and (ii) to contextually examine the hypothesized design principles.

### 6.1 Participants and Implementation

The eleven teachers were recruited from four different secondary schools in the Netherlands. These participants are referred to as T1 to T11, numbered by their teaching experience in years from low to high (Mean=14.1, SD=8.7). The participating teachers were diverse in gender (M=4, F=7), and teaching subjects, which was intended for gathering a wide range of user experiences. Their teaching subjects include Computer Science (T4, T8), Chemistry (T2), English Language (T1, T3, T7, T10, T11), Humanities (T5), Mathematics (T6), and Music (T9).

Each teacher used ClassBeacons in two separate lesson periods. These lessons took place in their regular classrooms and were taught according to their existing teaching plans. As Figure 3 illustrates, ClassBeacons was implemented according to the existing layout of each

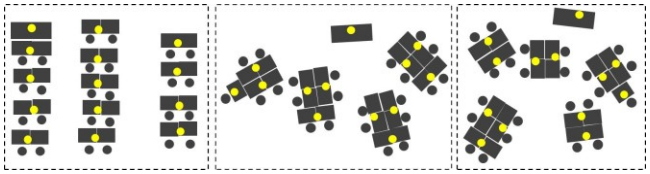

**Figure 3. Examples of how ClassBeacons (yellow dots) were implemented in classrooms with different layout.**

classroom; a lamp was placed close to a small group of two or three students. Before each lesson, researchers had installed and calibrated the system, but no researchers were present in the classroom during the lessons. Before first using the system, each teacher was given a leaflet briefly introducing ClassBeacons' display rules. They were also encouraged to ask for further explanations if they needed. Each teacher had confirmed with researchers that they understood the display rules after reading the leaflet.

### 6.2 Data Gathering and Analysis

Reflection-in-action is difficult to be directly captured by existing data gathering methods, since it is a cognitive activity and happens at the moment that a practice is unfolding. For this reason, qualitative interviews have been commonly used to study RiA [19,57], in which professional practitioners were asked to recall and describe the reflective thoughts that went through their minds when they were performing tasks [19]. Therefore, our evaluation uses qualitative data gathered through semi-structured in-depth interviews with the teachers. After each lesson, a semi-structured interview was conducted as soon as possible (at most in two hours) so that the teacher still had fresh memory about using the system in that lesson. During the interview, to sensitize the teachers and gather rich details from their lived experiences, we first asked them to recall and describe specific moments in which the participants consciously engaged with ClassBeacons in that lesson. When describing such a moment, the participants were asked to detail their situation or task at hand, and the physical (bodily) and mental activities they performed. This way, we intended to gather in-depth data with thick descriptions and rich contextual information.

After reporting these vivid examples of using ClassBeacons at a particular moment, each participating teacher was also asked to more generally talk about their experiences of using this system: e.g. whether it hindered their classroom activities, or whether its display was clear to them. The teachers were encouraged to freely and broadly comment on any aspects of their experiences with ClassBeacons. For instance, some of them compared their use of ClassBeacons with the use of existing classroom technologies (e.g. computer, or smart phone).

All the interviews were audio-recorded and transcribed verbatim. These data were subjected to a *conventional qualitative content analysis* [23], a standard and systematic approach to interpret content and contextual meaning of textual data. Our analysis followed its procedure detailed by Hsieh and Shannon [23]; and 324 quotes (in 14992 words) were selected from the data and clustered into a hierarchical categorization to formulate our findings concerning our research aims. We now present and discuss these empirical results in the two separate sections to address our research aims: (i) how ClassBeacons supported RiA and (ii) examining the design principles.

## 7 FINDINGS 1: HOW CLASSBEACONS SUPPORTED REFLECTION-IN-ACTION

The first aim of our study was to assess whether and how ClassBeacons supported teacher's reflection-in-action. The qualitative interviews conducted revealed numerous examples of situations in which ClassBeacons triggered teachers to reflect on their ongoing proximity distribution during teaching. In this section, we report these examples clustered by three recurrent types of reflections-in-action that occurred: (1) *confirming ongoing performance*, (2) *making new sense of ongoing performance*, and (3) *modifying upcoming actions*. These three types of reflection overlap with three stages of teachers' reflective process described in the earlier mentioned ALACT model [28], see Figure 4 for an overview.

### 7.1 Confirming Ongoing Performance - "*My thoughts were: yes, it's correct*"

One benefit of reflection-in-action is to help practitioners consciously confirm "that you have been doing something right" [46 p.55], so they can maintain the quality of their ongoing performance. As reported by our participants, ClassBeacons helped them to confirm that they had been distributing proximity in accordance with what they

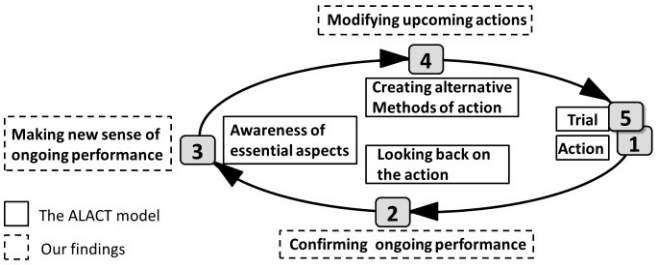


**Figure 4. Three types of reported RiA echo three stages of teachers' reflective process in ALACT model.**

thought was right based on their own professional opinion. A telling example is given by T2, regarding the lesson of which a heatmap of T2's indoor positioning data is shown in Figure 5 (L). In this lesson, T2 had a student group A sitting in one side of his classroom and working on a different topic from other students. T2 wanted to make sure that group A received extra attention from him throughout the lesson. ClassBeacons helped him visually confirm this during teaching: "*So when their [A] lights were greener than the others. That for me was like: that's good, that's how it should be. It's a confirmation. It always feels like I'm not giving them [A] enough attention, because they find it [the topic A was working on] hard. And I was glad to see that I gave them extra attention.*" T6 described a similar moment in which her thought was triggered by the lamps as a confirmation of her performance: "*[The lamps] was as I expected: The students with the most questions became green. And there were a few [yellow lamps] I never visited and they are the best students. My thoughts were: yes, it's correct.*" She felt that such confirmation was "*functional*" although she did not change her actions. These examples show that ClassBeacons enabled teachers to confirm their ongoing performance on the spot. This type of reflections echoes the stage of ***L****ooking back on the action* of teachers' reflective process in the ALACT model (Figure 4).

### 7.2 Making New Sense of Ongoing Performance - "*Oh, apparently I haven't been that much at that table*"

Reflection-in-action can turn practitioners to "a researcher in the practice context" [46 p.68] who make new sense of their ongoing performance, and thus can discover or criticize implicit aspects in their actions. Our gathered examples show how ClassBeacons helped teachers make new sense of their ongoing proximity distribution.

First, teachers reported that ClassBeacons helped them notice unwanted patterns of their proximity distribution. For instance, at a certain moment in T3's lesson, ClassBeacons' display made her notice: "*Oh, apparently I haven't been that much at that table.*" Also, T4 reported a moment in which he noticed from ClassBeacons that "*I haven't given that student any attention.*" As he felt, the display showed how different his proximity distribution was from his expectation: "*I was like: I've got no clue at all about how much time I spent with each student.*" Hence "*I find ClassBeacons useful, because it gave me some insight into what students I haven't given any attention yet.*"

Second, teachers indicated that ClassBeacons gave them insight into how their unfolding patterns of proximity

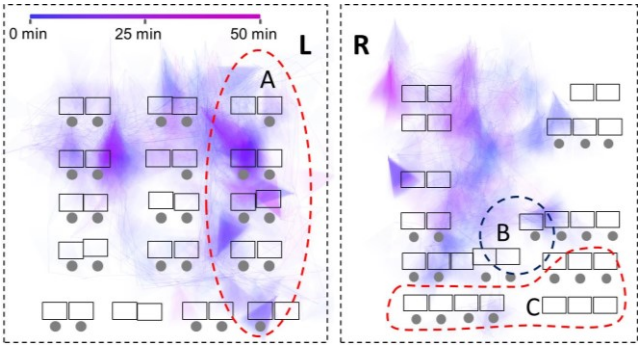


**Figure 5. Heatmaps of positioning data from a lesson of T2 (L) and T5 (R) for illustrating their reported examples.**

distribution were tacitly led by their routinized or subconscious actions. For instance, ClassBeacons triggered T3 to criticize her own action that she had been subconsciously ignoring a student: "*this group is a tricky group […] to put it mildly […] with the boy who refuses help basically. ClassBeacons made me aware of the fact that I shouldn't ignore him and that I should help him*" Also, T7 indicated that ClassBeacons helped her notice the routinized way of delivering proximity: "*[ClassBeacons] makes you more conscious that you tend to stay with the naughty children, you don't do very much walking.*"

Third, ClassBeacons revealed how teachers' patterns of proximity distribution were implicitly shaped by their physical context: i.e. the (desk) layout of their classrooms. As the heatmap in Figure 5 (R) shows, in T5's classroom, she had to pass area B to visit students in C. As T5 reported, ClassBeacons' distributed display made her consciously notice that because B is difficult to pass, students in C inherently got less attention from her during a lesson. "*My classroom has a different setting. And now I noticed: when I was walking around, because it's closed there [B], I can't pass very easily there [B]. So now I noticed that those students who are in the back [in C] don't get much attention [from the teacher] than others. [Interviewer: how did you notice that?] By looking at the lamps and then thinking: oh I should go there [C] as well, but it wasn't possible.*" Similarly, T9 once noticed from the lamps: "*I wasn't very free to go this way [so] I had some problems getting round there.*"

In summary, the participating teachers thought the ClassBeacons system helped them make new sense of their ongoing performance, notice unwanted patterns in their behavior and spot potential causes for these unwanted patterns. Such type of reflections echoes the reflective stage of ***A****wareness of essential aspects* in the ALACT model (see Figure 4).

### 7.3 Modifying Upcoming Actions - "*It really makes you think your actions through*"

Reflection-in-action is not only about making sense of the ongoing performance, but also about modifying upcoming actions accordingly [46,47]. It helps practitioners in "thinking what they are doing and, in the process, evolving their way of doing it" [46 p.56]. Correspondingly, rich examples were reported by the participating teachers in which they modified their upcoming actions with the aid of ClassBeacons' displayed information.

Several teachers gave examples in which ClassBeacons helped them make decisions about which students to help next and for how long. T1, for example mentioned "*It makes you think a bit more critically about the choices […] It really makes you think your actions through.*" For instance, in some cases, teachers decided to go to certain students, when realizing that the students had not received enough attention from them: e.g. "*I saw the lights were still yellow, I walked to the students and paid some attention* (T10)." Or "*Maybe I didn't pay enough attention to that student, so I went there* (T7)." In some other cases, teachers decided to stop giving attention to particular students when their lamps were bright green. For example, "*These [lamps] were dark-green. I felt: okay, maybe these boys should write their own essay instead of me taking their hand. […] if I help them too much they never get their own skills. Sometimes you can help students as well by not helping them* (T3)." Likewise, T7 was once reminded by ClassBeacons that "*now I have to go to the other one [so that] I don't stay too long with one group.*" Similarly, T9 once noticed a lamp while talking with some students: "*It's dark green. Maybe I should move.*"

Moreover, some teachers indicated that ClassBeacons triggered them to "*break free*" (T4) from their certain existing plans or conventions and deliberately try alternative actions. A telling example from T4: "*It did help me to get away from my initial prediction: So before I start the lesson I can already envision: Okay, today I'm going to have to spend some extra time with these students and these students […] And ClassBeacons helped me to, not completely, but slightly break free from that thought, from that mindset. So I think: okay I know I have to spend a lot of time here, but I should also spend some time over there.*" A similar example was given by T2, when talking about the lesson illustrated in Figure 5 (L). T2 wanted to spend much time with group A, but because of ClassBeacons, he improvised a decision to drop by some other students: "*I did at one point specifically ask them how it was going because […] I saw the lights […] and I was like: okay, maybe just check with them if everything is going alright.*". T5 indicated that in her usual lessons, students would come to her desk if they had a question. ClassBeacons triggered her to try the other way around: "*A student had a question and he wanted to come to me and I said, 'no I have to come to you, because then the lamps are responding to that.'*" And she considered this as a benefit, "*because if I go to the students I can also check on the other students.*"

In summary, teachers explained how ClassBeacons helped them modify upcoming actions: it supported them to responsively make decisions for their upcoming interactions with students, and triggered them to deliberately try actions alternative to their planed or conventional way of teaching. This type of reflections echoes the stage of ***C**reating alternative methods of action* in the reflective process in the ALACT model (Figure 4).

## 8 FINDINGS 2: CONTEXTUALLY EXAMINING THE FOUR DESIGN PRINCIPLES

The second aim of our study was to contextually examine the four hypothesized design principles (**P1**, **P2**, **P3**, and **P4**) which were deduced from the theories of reflection-in-action. By contextualizing these design principles in the case of ClassBeacons we aim to inform future designs for supporting teachers' RiA. In the previous section we have presented qualitative data revealing that ClassBeacons triggered various types of RiA. This section presents and discusses qualitative findings from our interview data to show how each of these design principles was embodied in the use of ClassBeacons, and experienced to be supportive during teaching.

### 8.1 P1. Informing Ongoing Performance - "*You can immediately reflect on how you're doing*"

Our design principle P1 proposes that in order to support teachers' reflection-in-action, a system should provide information that is relevant to their ongoing performance. As confirmed by the presented examples in previous section, ClassBeacons' real-time feedback of teacher proximity indeed supported teachers' reflection-in-action. Here we further present teachers' opinions on how having such real-time feedback to reflect upon could meaningfully support them during teaching. Specifically, most of the teachers (10 out of 11) explicitly mentioned that during teaching, ClassBeacons' feedback had increased their deliberate thinking. For instance, T1 described his feelings of how ClassBeacons' "*immediate*" feedback meaningfully increased his reflectiveness in performance: "*You get immediate feedback and you can immediately reflect on how you're doing, on how you're moving […] So what I was doing was reflecting at the moment: Do I need to go there or not?*

*Why haven't I been there? So you're consciously thinking about the choices you make in the classroom.*" Similarly, T3 mentioned, "*Because of the lights I'm more aware of what is going on or what I actually do.*" Hence, she considered ClassBeacons to be an "*effective tool for you as a teacher*". T6 also felt such feedback was meaningful to be reflected upon on the spot, "*because next lesson it will be forgotten.*" A similar experience was also described by T8: "*[with ClassBeacons] you can always reflect on your own patterns during the hour, to see where you have been, yes or no. So you can think: do I need to go to that student more often next time? Is my attention divided over all students? That's an advantage that you can see that.*" Therefore, teachers' opinions further confirmed that having real-time feedback to reflect upon could meaningfully support them during teaching, which confirms the value of design principle P1.

### 8.2 P2. Being Open to Interpretations - "*I'm still in control, I mean, I make the decision*"

Our second design principle P2 proposes that information presented to teachers should encourage their own interpretations. This is because reflection-in-action highly depends on the particular context and the teacher's own practical understandings. As revealed in our evaluation, proximity distribution indeed seemed an aspect of teaching which is open to interpretation: how a teacher should distribute his/her proximity in a lesson depends highly on the context (e.g. the particular students in that lesson) and his/her professional beliefs (e.g. understandings of the students' needs). As T11 put it, "*I think it's fairly obvious to teachers that they should try and distribute their attention fairly. But what's fair? So fair means letting the ones who can do things on their own alone, and giving more attention to the ones that need help.*" As a result, the objective and neutral display of ClassBeacons was appreciated: e.g. "*I am glad that red is not a part of the spectrum, because of the negative-ness* (T2)." And as shown by the earlier presented examples of reported reflections-in-action, the teachers were able to interpret ClassBeacons' display based on their own beliefs: e.g. a yellow lamp in one situation could be perceived as "*correct*" (T6) since it was next to the students who did not need help; while in another situation it could also be perceived as lack of attention to particular students. For this reason, ClassBeacons were appreciated to encourage teachers' own interpretations of what action to undertake. For instance, as T4 experienced, "*It gives me some awareness, and I'm still in control, I mean, I make the decision to what student I attend first. So I like that a lot.*" Similarly, as commented by T8, "*It's just an evaluation of where your attention has been and then you can make the right decisions.*"

Concluding, teachers' opinions confirmed the context-dependent nature of the reflection-in-action on proximity distribution. Teachers found it meaningful to have an objective and neutral visualization which encourages their own interpretations of their ongoing performance. This surfaces the value of design principle P2.

### 8.3 P3. Supporting Use In the Midst of Actions - "*You just do what you usually do*"

Design principle P3 proposes that a designed system supporting reflection-in-action should enable teachers to use it in the midst of actions. Examples reported by all the participating teachers show that they used ClassBeacons while simultaneously doing various primary teaching tasks at different locations in the classroom. For instance, T7 described that ClassBeacons system was visible in the whole room ("*It's visual in space*"), so that she did not have to "sit behind the screen" to see the displayed information. Similarly, T2 commented, "*I think the advantage of ClassBeacons is that I'm not stuck on my desk. Walking around and then I can have the information.*" Its placement on student desks was also considered to be convenient "*because that's where the children are, so that's where I'm looking*" (T6). For the above mentioned reasons, the teachers reported a variety of examples in which they consciously perceived information from ClasBeacons while they were in the midst of observing the classroom (T1-4,7-10), helping individuals (T2,4,5-6), giving group instructions (T1,2), or using the computer (T5,11). Moreover, as indicated in these examples, their use of ClassBeacons happened in different locations of the classroom, for example, when they were "*walking*" or "*wondering around*" the classroom (T2-3,5-6), "*standing in front*" (T2), or sitting at the teacher's desk (T5,11). It is thus shown that ClassBeacons seamlessly blended in teachers' nomadic routines. As T3 put it, "*In this case you don't have to do anything, you just do what you usually do and it immediately gives you feedback.*"

We furthermore found that ClassBeacons triggered both self-initiated and cued reflections in the midst of teachers' actions. T9, for instance, sometimes intentionally looked at ClassBeacons to get informed: "*I looked to see whether there were places that I hadn't really seemed to be at*", while at other moments she was cued to consciously think about the displayed information without initial intention: "*I was talking to one student and then as I turned around, just to see if anybody needed my help, I noticed that […] Not necessarily that I was looking at the lamps, but I just happened to notice* (T9)." As T6 pinpointed, with such cuing, teachers did not have to consciously plan when to reflect upon their

performance in teaching. And she assumed this to be a potential advantage of ClassBeacons over a screen-based display showing similar information: "*I'm busy with the children. So I would immediately forget to look at my screen.*"

In summary, ClassBeacons were reported to have been used by teachers while doing various teaching tasks in their nomadic routines, and enabled both self-initiated and cued reflections in teaching. Thus teachers did not have to interrupt or paralyze their ongoing tasks to access and reflect on their performance feedback, or to consciously plan when to initiate reflections in teaching. These findings therefore surface the value of design principle P3.

### 8.4 P4. Enabling Short-term, Effortless, Easy-to-Discard Engagements - "*Candles on the table*"

Design principle P4 proposes that a system designed to support teachers' reflection-in-action should enable short-term, effortless, easy-to-discard engagements, due to the limited time and mental resources available in teaching. Most of the teachers (10 out of 11) indicated that ClassBeacons' simple and low-resolution display enabled glanceable and effortless use. They considered the information display as "*intuitively*" (T2) "*clear*" (T4,6-7) and "*easy*" (T2,5,8-9) to interpret. For instance T2 mentioned "*I find it really easy because the colors are intuitively chosen*". During teaching, ClassBeacons informed T1 but "*did not cost any more energy or attention*". Likewise, T6 felt, "*It was clear. There was no effort at all*". As revealed from teachers' experiences, they perceived information from ClassBeacons in short time-frames: "*quick*" (T3) like "*a split second*" (T8) or "*a couple of seconds*" (T4). Both T11 and T3 pointed out that ClassBeacons' low-resolution display only required glancing rather than "*reading*", and therefore it was time-efficient in teaching: "*you don't have to interpret*" (T11), and "*It's so visual. Therefore you don't need to spend much time thinking about it* (T3)."

Another recurrent opinion from teachers' experiences was that ClassBeacons were easy-to-discard during classroom activities. Firstly, ClassBeacons' presence in the classroom was experienced to be unremarkable. Although ClassBeacons were present all around the classroom - "*I just saw them all the time out of the corner of my eye*" (T7) – they were not intrusive in the classroom: "*it's part of the table*" (T7). Similarly, for T9, ClassBeacons felt like "*candles on the table*". Also, T8 mentioned, "*It's very natural […] not distracting […] you don't always perceive it.*" Likewise, for T1, perceiving ClassBeacons was "*not always happening in the center of what I'm doing*". Secondly, ClassBeacons could be easily ignored when teachers' mental load was high: e.g. "*you just forget that it's there, if you really are involved with what you are doing*" (T9). This, according to participants' examples, happened when they were fully engaged in "*talking*" (T9) or "*working with students*" (T5), "*teaching or explaining something*" (T5), "*looking what they were writing*" (T7) or ensuring students' engagement (T1,11). Additionally, the teachers thought that ClassBeacons did not hinder learning activities. For instance, T5 described that despite the excitement of students when they first saw the lamps, they were not bothered during learning: "*In the beginning they were enthusiastic, and after that then it's okay*". Interestingly, T5 also experienced that both she and her students paid even less focused attention to ClassBeacons in the second lesson: "*It's getting less [noticeable] when you have it more often in your classroom.*"

In summary, ClassBeacons' display was experienced to be glanceable and effortless to use, which enabled teachers to interpret and reflect on the displayed information in short time-frames with limited involvement of attentional resources. It was also experienced to be easy-to-discard in classroom activities, which avoided teachers being overburdened during teaching. These findings concretize the value of design principle P4.

## 9 DISCUSSION

The work presented in the paper aims to study how an ambient information system can enhance secondary school teachers' reflection-in-action. Despite it being recognized as a crucial skill for teachers [3,19], RiA appears to be "the most demanding type of reflecting" [19 p.46] of teachers, since it requires thinking about their performance while in the midst of it. The current techniques to increase teachers' reflectiveness are costly, time-consuming and are therefore only sporadically implemented. Little is known about how technology can, in real-time, enhance RiA. Motivated by this, we conducted a field study with an ambient display called ClassBeacons, which we hypothesized to support teachers' RiA on teacher proximity: their division of time and attention over students in classroom teaching.

Reflection-in-action helps teachers to examine the *implicit* or *spontaneous* [46,47] aspects of their ongoing practice to avoid 'over-routinized' performance and promote responsiveness during classroom teaching [19,46]. Teacher proximity is such an implicit yet very relevant aspect to reflect upon in teaching [13,18,26,48,49]. As shown by our findings, ClassBeacons system facilitated three types of reflections-in-action, echoing three stages in teachers' reflective process described by the ALACT model [28] (see Figure 4). First, it supported the stage ***L****ooking back*

*on action*. RiA, at the very least, refers to practitioners' monitoring of action: "think about what they are doing while doing it" [46 p.275]. Teacher proximity is challenging to consciously keep track of in teaching. ClassBeacons enabled teachers to easily monitor and confirm their proximity distribution throughout a lesson. Second, ClassBeacons supported the stage ***A****wareness of essential aspects*. Much RiA emerges when practitioners notice certain unwanted outcomes of their actions [47]. As the teachers reported, ClassBeacons made them aware of certain unwanted patterns in their proximity distribution, which could further lead to insights in how their routinized or subconscious behaviors or physical context had been implicitly shaping their actions. In such way, the teachers indeed seemed to become "a researcher in the practice context" [46 p.68] who generates new understandings in their practice. Third, ClassBeacons supported the stage ***C****reating alternative methods of action*. RiA could yield not only "a new understanding" but also "a change in the situation" [46 p.68]. As reported by the participants, ClassBeacons helped them responsively modify upcoming interactions with students, and improvise actions alternative to their planned or conventional way of teaching. In summary, ClassBeacons seemed to help teachers transform teacher proximity from often an implicit consequence of their routines into an actionable resource for teaching, which they can easily reflect upon and responsively modify on the spot to potentially promote learner-centered pedagogy. Our empirical findings thereby shed light on how an ambient system could enhance teachers' RiA, and how such enhancement could benefit classroom teaching.

While using *teacher proximity* as a specific example for contextualizing and evaluating RiA, we note that there are many other areas that teachers can valuably reflect upon during classroom teaching. Our study suggests more future works to explore depicting *relevant* yet *implicit* aspects on the spot to enhance teachers' reflectiveness: e.g. imagine a system that depicts learners' cognitive load [1] in supervised self-studying, to support teachers' RiA on differentiated instruction (e.g. "Is this student's current task too hard/easy? Shall I give him less/more challenge?")

Our study revealed the context-dependent nature of reflection-in-action [46,47] in the specific case of teacher proximity distribution: what an ideal distribution looks like depends on both the context of a particular lesson and a teacher's practical knowing about individuals' needs. These contextual factors are currently impossible for a system to compute, but intuitive for the teacher to assess. Thus, it seems more meaningful for the system to objectively portray the data than to give arbitrary assessment. As shown in the results, an objective, neutral information display encouraged teachers to generate their own understandings of the practical situation. It is hence implied that practitioners' reflectiveness could be enhanced not only by presenting relevant information, but also by leaving space in the presented information for framing their own coherent interpretations.

It has been suggested that professionals' reflection-in-action can be embodied with and facilitated by their repertoire, artefacts, or materials [46,57]. Our study specifically surfaced how RiA can be offloaded by an augmented physical environment. In general, cognition can be offloaded by the surrounding [44]: it has been revealed that in daily contexts (super market, workshops, kitchen etc.), people commonly utilize space and environment as *external scaffolding* [20,24,44] to reduce the time and mental resources needed for cognitive tasks (e.g. to hide, highlight, or arrange objects in a space). Correspondingly, our results suggested that the spatial presence of ClassBeacons offloaded teachers' reflection: serving as an external representation of their proximity distribution, it transformed teachers' task of monitoring their whereabouts into a glance; and being spatially distributed, it offloaded teachers' task of remembering or planning when to initiate reflections. Therefore, while prior designs showed how distributed systems could support classroom orchestration [4,9], our study showed how such a system can also serve as a *cognitive ally* [20] to enhance teachers' reflectiveness.

Due to the limited time and mental resources in teaching, teachers' RiA cannot be highly elaborate [16] and has to rely on tacit know-how [46]. Thus an information interface to support RiA should also aim to be tacitly relied on rather than focally attended to by teachers during teaching, in order to avoid interfering with their actions or overburdening their mind. The low-res, unremarkable information display of ClassBeacons was experienced to enhance teachers' reflectiveness without getting in the way of their classroom activities. And some teachers indicated that they preferred glancing rather than reading during teaching in terms of using an information interface. It is therefore suggested that leveraging the *periphery* [55] of teachers' attention (e.g. through *ambient information system* [37], or *peripheral interaction* [10]) indeed seems a meaningful consideration for future designs to support teachers' RiA.

To be mentioned, our design principles that were originally generated from RiA theories, are not limited to

the specific design case of ClassBeacons that we used to contextually examine these principles. Our intention is to spur on more HCI works for supporting RiA. We believe that there are various possibilities to embody these principles in design, which are worth exploring in future: e.g. while P3 can be fulfilled by a spatial system, a tablet (if already used in a teacher's main tasks), smartwatch, earpiece, or AR lens could also arguably fit P3. While a glanceable display works for P4, ambient sonification or haptic display could also be promising to explore.

***Limitations and future work***: one limitation of this study concerns a common challenge of data gathering for studying RiA. Although interview is commonly used to study reflective behavior [19,57], an obvious issue is that this method relies on the practitioners' recall. To gain further insights in the process of using ambient information systems, future studies may consider combining measures such as eye-tracking [39] and cognitive load assessment [1], during the practice to compensate or triangulate teacher's recall. Another limitation, in terms of system design, is the large size of the wearable, which needs to improve in future iterations. Moreover, a longer-term field deployment would be needed in future studies to examine this systems' longitudinal mediation of teachers' reflectiveness. We also found that besides users' appreciation of the on-the-spot feedback, several users also would like to see their attention distribution over pupils across lessons. This suggests a future work on a combination of reflection-in-action and reflection-on-action.

## 10 CONCLUSION

In this paper, we explored how secondary school teachers' reflection-in-action (RiA) can be supported by an ambient information system. We examined related theories to summarize five core characteristics of teachers' RiA. Based on these, we hypothesized four design principles to support teachers' RiA, and evaluated the ambient information system ClassBeacons whose design features embodied these principles. Eleven teachers used ClassBeacons in two of their regular lessons. By presenting and discussing the rich empirical findings, we demonstrate both an overview and vivid examples about how teachers' process of RiA was supported by ClassBeacons. Moreover, we contextually surfaced how the four design principles were embodied in the actual use of ClassBeacons and how they can be valuable for HCI design to unobtrusively support teachers' RiA. We therefore contribute empirical knowledge about and a set of design principles for supporting practitioners' reflection-in-action.

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