"I Spent More Time with that Team": Making Spatial Pedagogy Visible Using Positioning Sensors

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ABSTRACT

Teachers are often encouraged to adopt different positioning strategies at various stages of a classroom lesson as each can influence learners in different ways. However, little work has been done to make evidence of the use of classrooms visible to teachers and students. As sensors drop in price, it is becoming more viable to capture traces of the use of the physical classroom space automatically. In this paper, we build on the notion of *spatial pedagogy* to propose an approach to visualise digital traces of teacher positioning in the classroom. We illustrate our approach through an authentic case study of a teacher enacting three distinctive learning designs. We document the teacher's and students' reactions to visual representations of positioning data to explore their potential as proxies of spatial pedagogy.

CCS CONCEPTS

• **Information systems** → Data analytics; • **Human-centered computing** → Visualization design and evaluation methods

KEYWORDS

mobility tracking; classroom; wearables; IoT; learning spaces

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1 INTRODUCTION

Educational research literature has identified the critical role that teacher movement, circulation, proximity control and active supervision can have in developing effective practices for orchestrating the classroom (see review in [17]). For instance, some authors have identified teaching *proximity zones* that can strongly influence student engagement [12]; and *embodied strategies* that teachers enact to orchestrate a classroom effectively [11]. The term *classroom proxemics* can be used to refer to the study of how teachers and students use the space, and the impact of the spatial design on learning activities [16]. Several teaching guides (e.g. [1; 12; 21]) encourage novice teachers to adopt certain proxemic communication strategies at various stages of a classroom lesson depending on the task being enacted (e.g. standing at the front of the class, circulating, getting closer to students, remaining mobile, etc.) as each can influence learners in different ways. Novice teachers can also get feedback on their classroom positioning from peers or experienced teachers observing their classes [4]. However, a large number of educators, particularly in higher education, receive no pedagogical training, nor receive feedback on classroom proxemics [8; 9]. This is a problem given that teachers' positioning can have a strong effect on learners [17].

Indoor-location and movement sensors have dropped steeply in price whilst improving in accuracy [3], and the corresponding uptake across many industries has given data-driven insights into existing operations (e.g. shoppers' movements in a store; pedestrian traffic; usage of office spaces). This opens up the opportunity for making evidence about the use of classroom space visible to teachers to promote self-reflection.

In this paper, we build on the notion of spatial pedagogy [13] to propose an approach to investigate and visualise digital traces of teachers positioning in the classroom (Figure 1). We illustrate our approach through a case study of a teacher enacting three distinctive learning designs as part of an authentic university unit of study. We investigate the teacher's and students' reactions to visual representations of these data, during and after the classroom sessions. We particularly foreground how the teacher gives meaning to her classroom positioning data based on the intended learning design, the location of the classroom furniture, and her proximity to the students.

The rest of the paper is organised as follows. Next section describes the principles of spatial pedagogy underpinning our approach and an overview of the state-of-the-art in the area of physical learning analytics. In Section 3, we describe the study that serves to illustrate our approach. In Section 4 we present the

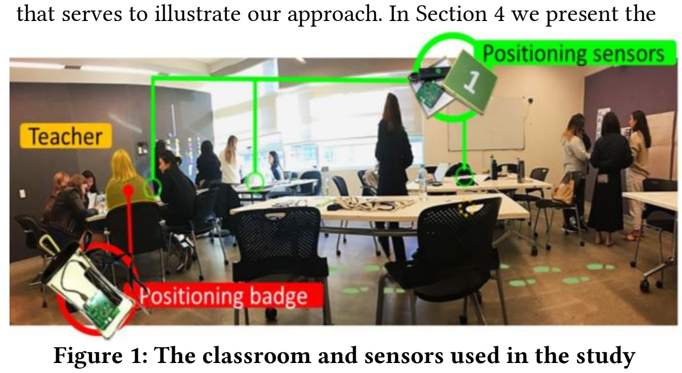

Figure 1: The classroom and sensors used in the study

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teacher's and students' reactions to visual representations of positioning data. The paper concludes with a brief discussion of current and future implications of our work in Section 5.

2 BACKGROUND

2.1 Spatial Pedagogy

Qualitative studies have demonstrated that certain zones in the classroom can have multiple meanings based on the kind of activities unfolding on the site [18] and the relative proxemics among teachers, students and objects (e.g. teaching materials, furniture, devices) [16; 24]. Lim et al. [13] coined the term "spatial pedagogy" to refer to the *meaning* that can be given to spaces in the classroom in terms of teacher's positioning, which can reflect the active use of other pedagogical resources such as language, gestures and teaching materials. The following types of classroom zones (spaces) are defined based on this notion: i) *authoritative*, where the teacher conducts formal teaching or provides instructions; ii) *personal*, where the teacher prepares materials for the next stage of the class; iii) *supervisory*, where the teacher moves, supervising, without offering consultation to students; and iv) *interactional*, where the teacher comes in closer proximity to the students to interact with them. Any given physical zones in the classroom can have more than one meaning at different times. Lim et al. [13] suggested that visualising how teachers use the classroom space through digital graphical methods can have critical implications for teaching and learning as well as for teacher training and development. In this paper we address this by leveraging the automated analysis of teachers' classroom proxemics using positioning sensors and contextual information from the learning design.

2.2 Related Work: Physical Learning Analytics

There has been a growing interest in exploring physical aspects of learning using multimodal analytics techniques [15]. For example, video analysis has been used as a way to identify students' affective states during a lecture (e.g. [20]) or quantify the number of interactions between lecturers and students (e.g. [23]). Other data sources have been used to model teachers' activity in the classroom using microphones [6], eye trackers [5] and movement sensors [10]. However, the work by Prieto et al. [19] is the closest to ours, since authors aimed at modelling teacher's activity based on multimodal wearable sensors (an eye tracker, an accelerometer, an electroencephalogram device and a camera). However, authors did not look at positioning strategies nor explored how the data can facilitate teacher's reflection. Other related work was presented by Bosch et al. [2] who modelled teacher's behaviours (such as walking or gesturing) during a lecture using video data. The limitation of this study is that it only works for lecture-based classroom sessions. In terms of positioning analytics, some preliminary work has recently highlighted the potential of using sensors to track students in nursing education scenarios [7] and firefighting training [22].

Overall, the studies discussed above show how multimodal data can serve to complement the analysis of teacher's activity in the classroom. It also shows the growing interest in physical aspects of the classroom such as proxemics and interactions between teachers and students. Our work goes beyond previous work, and complements previous research in teaching analytics, by documenting the teacher's and students' reactions to visual representations of positioning data in order to explore their potential as proxies of spatial pedagogy.

3 LEARNING CONTEXT AND STUDY DESIGN

We illustrate our approach to visualise digital traces of teachers positioning through a classroom study. The study was conducted in a fully authentic setting as part of the regular classes of a third-year undergraduate unit, titled Socially Responsive Design, which fully immerses students in a problem-based learning experience. The unit includes weekly 3-hours tutorial classes in which students work individually or in small teams advised by a supervising teacher. Each class typically has 15-20 students working in small teams of 4-5 students. The study focused on three randomly chosen tutorial classes (A, B and C) conducted in weeks 3, 4 and 6 of semester 2, 2018, led by the coordinator of the unit of study. The classes were conducted with the same students (15 females organised in three teams -1, 2 and 3 - of 5 students each) in the same classroom (see Figure 1).

The (8 x 10 meters) classroom is equipped with moveable tables, a projector and pinnable walls. Students arranged the tables in a similar way at the beginning of each class, forming three large tables to facilitate groupwork. Each team used the same table in each class. Each class exhibited a very distinctive learning design. Class A involved 3 hours of continuous small team design work. Class B was equally divided into two parts: i) group oral presentations in which each team, in turns, used the classroom projector to report on their progress; and ii) team meetings. Class C was also divided in two parts: i) poster presentations, in which all the class would move to each table in turns for students to present prototypes pinned on the walls close to their table (2 hours); and ii) team meetings (1 hour).

4 APPARATUS AND METHODOLOGY

Teacher's positioning in the classroom was automatically captured through a custom-made wearable badge based on the Pozyx.io ultra-wide band sensor system. This provides an error rate of 10 cm. To automatically detect the proximity between the teacher and each student table, we located additional sensors above each table inside a casing that the teacher could move and also use to identify each table with a number (see Figure 1). We recorded x and y positions of the teacher and each table at 2Hz.

Positioning data was presented to the teacher in 2 ways. First, a short debrief was conducted after classes A and B in which the teacher was asked a series of questions about positioning visual representations printed on paper. These were presented to the teacher in the following order: 1) heatmaps summarising positioning data of both classes; the same heatmaps with added information of the time the teacher spent with each team (e.g. see Figure 2); the same data for both classes divided into quartiles (of 40-45 minutes each). This means 2 sets of 4 heatmap visualisations (see the set of Class B in Figure 4).

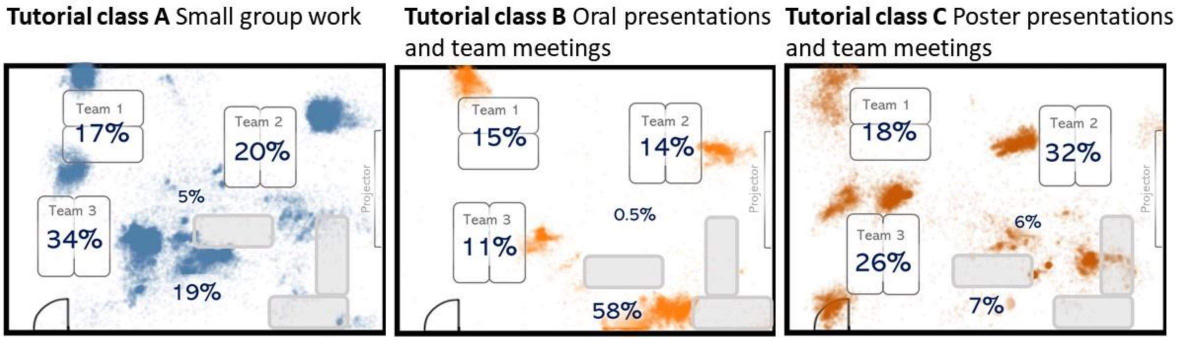

Figure 2: Visual heatmap representations summarising positioning data of a teacher in three tutorial classes

Second, for Class C a teacher's dashboard, showing a heatmap of her positioning, was made available on a stationary computer located at the teacher's table (see Figure 3). The position of each team table was depicted as a hexagon based on live sensors data. The real-time position of the teacher is represented by a blue circle. Proximity data was used to estimate the time the teacher attended specific groups working at the tables (measured as whether the teacher was within a maximum range of 2.5 meters from the table sensor, considering the dimension of each table was $2m^2$). The least attended tables that have not been attended in the last t minutes (t=20 in our study) are highlighted (e.g. see team 1 coloured in orange). The teacher was asked to reflect on the visualisations through a think-aloud protocol. Additionally, she was asked to respond to questions about the use of the data by others and for her own practice (explained in detail in section 4). Two volunteering students were asked to provide their opinion about the use of these data after facing the summarised heatmaps of their classes (Figure 2).

4 TEACHER'S AND STUDENTS' REACTIONS

Based on the notion of spatial pedagogy, in this section we present and discuss the teacher's and students' reactions while facing the visual representations of the positioning data.

Heatmaps without quantitative information. The first task posed to the teacher during the debrief was to comment on the raw heatmaps for each classroom session. After inspecting the visualisation for Class A (Figure 2, left, shown to the teacher without the percentages) the teacher explained the following: "*This is pretty accurate because I was standing in this area, at the centre, and I was talking a lot at the beginning. The sizes of the dots for each table are pretty even'. I hung around closer to the tables instead of being at the centre of the class to be near the students. I made sure I was not necessarily speaking from the front of the classroom all the time*". This initial reflection hints that the teacher spatially partitioned the classroom in two zones for the first learning design: an *authoritative* zone for lecturing at the centre, (which she called the 'front of the classroom'), and *interactional* zones in very close proximity to the student tables.

In this first reflection, the teacher did not put much emphasis on the other two kinds of zones (*supervisory and personal),* but these were made more explicit while reflecting on the second class (B- Figure 2, centre), as follows: "*This is obviously the one where I was speaking to everyone around this area (below the teacher's desk in the figure). Oh! Students were doing the presentations, so I sat dawn, looking at the screen and speaking from there".* Influenced by the quite different learning design, the *authoritative* zone may have shifted from the centre to an extreme of the room, where she spent more than half of the class time. This zone was also her *personal* zone at times.

Then, the teacher reflected about the time dedicated to each team in Class A. Based on her experience and the data, she believed that she spent more time with Team 1 and stated this as follows: "*I spent more time with Team 1, because, I think, they were having more issues. This (Team 2) was probably the least attended one. But the attention was not that disproportionate*".

Heatmaps with quantitative information. In the second task the teacher was asked to comment on the numerical information presented to her (shown to the teacher as they appear in Figure 2). To her surprise, she realised her own hypothesis about the least attended team in Class A was incorrect. This is illustrated through the following dialogue with the facilitator of the session:

Teacher: For the first week, how come I attended this group (3) for 34%? Is it picking up the time when I was sitting in my chair (her personal zone) or just with the group?
Facilitator: just with the group
Teacher: Wow! Then maybe I was spending all that time. But don't you think that's odd because I kept saying that I have been spending more time with Team 1 when I only spent 17%. I thought I spent more time with that group, but the data doesn't represent what I believed. Having said that, I agree with this because I think [Team 1] was going more ahead. So, I think I agree with that. In general, I don't think I am favouring any group but attending them according to their needs.

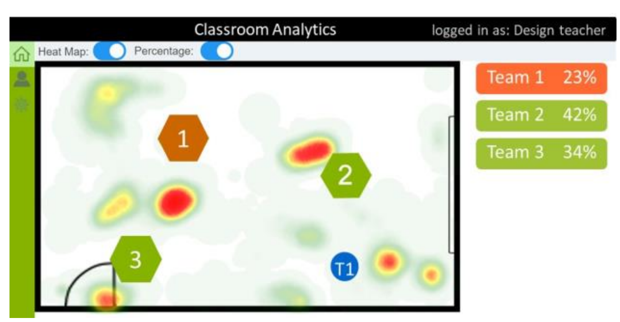

Figure 3: Dashboard showing live teacher's position (blue circle) and student tables (hexagons). Teacher-student time ratios are shown at the right. The least attended team is highlighted in orange.

Heatmaps divided into quartiles. The third task for the teacher was to comment on the same data divided into quartiles of 40-45 min each. This allowed the teacher to re-construct the structure of her classes and justify her positioning strategy and the meaning she gave to different zones in the classroom. For example, for Class B the change in the meaning of the physical zones of the classroom was evident compared with Class A.

While inspecting the first two quartiles in Figure 4 (top) the teacher stated the following: "*When students were doing the presentations I obviously sat down in the same spot for half of the class. I think the data is pretty good".* Classroom observations confirmed that this zone, which was her *personal zone* (in other classes) became an *authoritative zone in Class B* since she listened and provided feedback to students using the projected screen located at one wall of the room (right edge in the figures). The teacher stated the following after inspecting the third quartile (Figure 4, bottom-left): "*After the presentations I hung around and spent time with each group. I think the data shows it was pretty even. So, I went with these two groups first (Teams 2 and 3 in quartile 3) and spent the rest of the class with this group (Team 1 in quartile 4). So, I think I spent slightly more time with the group in the top left, but mostly at the end".* This shows how the rest of the classroom space became into her *supervising zone* (the space she used to move between tables) and *interactional zone* (the space she used when sitting at each table seat as in Figure 1). She concluded her reflection referring to the positioning data representation as a proxy of the enactment of her lesson plan: "*I think this was a good structure for my class and the attention was pretty even".*

Real-time dashboard. The teacher was asked to reflect on how she used the dashboard during Class C. In this case, the student-teacher ratio was not as accurate as for Classes A and B because the learning design was different. During the poster presentations the teacher and all students gathered around each table. In this way, the teacher was sometimes positioned further away from the tables. This particularly affected the calculation of time for Team 2. The teacher reflected on this as follows: *"I did look at the screen and I would like to justify my percentages. I spent more time with Team 2 than what the dashboard picked, but because they were doing the presentations I was standing further away from their table. I do think you are aware of the need for tuning the tool according to the activities for each week".* The teacher also reflected on how the dashboard may have influenced her behaviour as follows: "*It also made me aware that I am being tracked. I don't mind being tracked if it is for my own reflection. It just made more mindful about the time*". This suggests that the mere presence of the dashboard can have a self-regulatory effect. This can bring design implications as to what extend and in which ways teachers may want to adopt or adapt the tool for their practice.

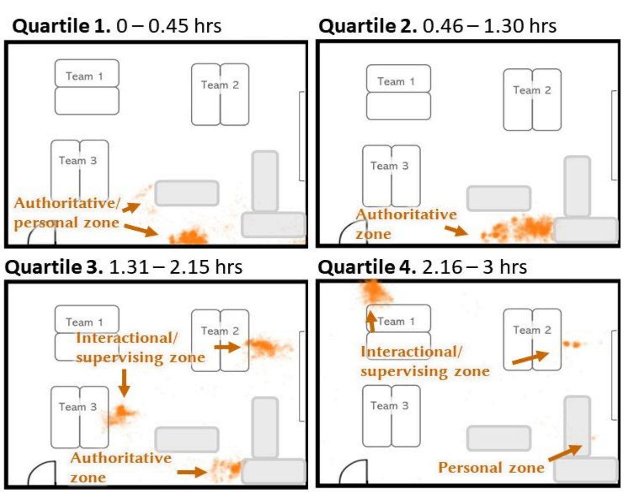

Figure 4: Visual representations of positioning data from Class B divided in quartiles of 45 minutes

Usage and accountability. After conducting the think-aloud protocol, the teacher was asked the following four direct questions about usage and accountability: *Who should look at these data? What would you do with the data if available for each class? Should these data be used for measuring teacher's performance? How would you use these data as the coordinator of the unit?*

The teacher identified a key group of stakeholders who should be the main target of the positioning data: casual academics. Consistently with the literature [9], this group teaches a large proportion of university classes and usually have little pedagogical training. The teacher highlighted the potential of these data as follows: "*I think it would be good to show this to casual academics who are probably less experienced. This would be a quick way to show them how to 'work the room' and how be conscious about the time. I wonder if students would be interested on this... maybe".*

The teacher commented on the potential usefulness of these data for her own professional development and linked it to her current practice. This was stated as follows: "*If I had it for each class it would make me reflect about how much time I am spending with each group. I didn't do it this time, but sometimes I put a timer on my phone to avoid being carried away by interesting conversations and then needing to rush towards the end*". However, the teacher raised a concern about potential misuse of these data as follows: *"this should not be used as a performance metric*". Yet, she offered a potential strategy as follows: "*It should be used as a teaching aid to make you become more aware".* For example, in her role as unit coordinator she "*would use it for [their] weekly meetings with [her] other tutors*". But she hinted that further work would need to be done to design the mechanisms to provide support to her casual teachers: "*...you have to be very sensitive about how you show these data. If I was one casual academic I wouldn't like to feel like I am not doing my job properly or that I am being tracked*".

Students' reactions to the positioning data. The two students who looked at the heatmaps were curious and interested about the tracking. One of them stated that, while these data is not of her direct interest, she recognises that it can depict teachers' behaviours that may have an effect on their learning experience. She stated this as follows: *"I am sure some students would care about how much time the teacher spends with them. Personally, I don't. I think it would be interesting for the university though, on our behalf, to motivate teachers that* *are doing a good job".* The second student added that the use of these data may be more helpful for some teachers than for others. She reflected on this as follows: "*I am getting enough attention from this teacher when I need her help so I guess if she attends more to others it doesn't really affect me, but in classes where [other] teachers spend most of the time with only one group, it would be good for them to look at these data and think about the other students".* These preliminary reactions suggest that students should have a very active voice in analytics that they may not directly use but that can influence their activity in the classroom or the attention they receive form their teachers.

5 CONCLUSION AND FUTURE WORK

The growth in the market of sensors and wearables [3] is generating new ways to make different aspects of the physical classroom visible and available for computational analysis. Classroom proxemics is just one of many other important aspects of the classroom design that can affect students' learning. Positioning data is therefore incomplete, but it can contribute to generate a more complete view of what happens in the classroom if intertwined with other types of evidence [14], such as multimodal data sources [19] and observations [13].

The contribution of this paper is an approach for visualising teachers' use of physical learning spaces. We illustrated how this approach can be operationalised to provide dynamic visualisations that can serve as a proxy of teacher's spatial pedagogy and to support real-time feedback, post-lesson reflection, and, academic development. This work should be seen as an initial exploration of much more work that needs to be done to empower teachers with evidence about their classes. The discussion of teacher's and students' reactions shed some light into topics of interest that should be investigated more deeply in the future. For example, the teacher pointed at particular ethical issues that can emerge as a result of applying physical learning analytics pervasively in the classroom. The teacher hinted that there is room for the use of this technology for particular purposes and for the right stakeholders. A careful strategy needs to be defined along with the technology development. The teacher also related her reactions with her actual practice and that of academics under her supervision. This calls for the use of participatory methods to co-design further visual representations of positioning and other kinds of classroom analytics with multiple stakeholders, including students.

Finally, this initial exploration suggests that positioning data about teachers and students positioning can help to address further interesting questions, computationally. Some of these questions include: how do novice teachers can learn from more experienced teachers to position themselves in the classroom? how do teachers, in different domains and with different levels of experience, use the same classroom space? how different configurations of the furniture affect the classroom proxemics? or how do teachers and students use new spaces architected to afford 'novel pedagogies'? Each of these questions can motivate future research avenues that can be explored using positioning technologies and enriched visual representations similar to the ones presented in his paper.

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