Classroom Dandelions: Visualising Participant Position, Trajectory and Body Orientation Augments Teachers' Sensemaking

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Figure 1: Dandelion diagrams of teachers' positioning data in a physics lab (left) and nursing students in a simulated ward (right).

ABSTRACT

Despite the digital revolution, *physical space* remains the site for teaching and learning *embodied* knowledge and skills. Both teachers and students must develop spatial competencies to effectively use classroom spaces, enabling fluid verbal and non-verbal interaction. While video permits rich activity capture, it provides no support for quickly seeing *activity patterns* that can assist learning. In contrast, position tracking systems permit the automated modelling of spatial behaviour, opening new possibilities for feedback. This paper introduces the design rationale for "Dandelion Diagrams" that integrate participant *location*, *trajectory* and *body orientation* over a variable period. Applied in two authentic teaching contexts (a science laboratory, and a nursing simulation) we show how heatmaps showing only teacher/student location led to misinterpretations that were resolved by overlaying Dandelion Diagrams. Teachers also identified a variety of ways they could aid professional development. We conclude Dandelion Diagrams assisted sensemaking, but discuss the ethical risks of over-interpretation.

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CCS CONCEPTS

• **Applied computing** → **Learning management systems**; • **Human-centered computing** → *Walkthrough evaluations.*

KEYWORDS

Learning analytics, Indoor positioning, Teamwork, Multimodal, Teaching

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1 INTRODUCTION

The term 'spatial competency' refers to the capacity that humans have to identify and understand spatial relations among objects, people and the environment [45]. This competency enables individuals to navigate the environment and exploit its affordances to complete their tasks. In education, teachers and students demonstrate this competency in the form of *spatial behaviours*: the ways they make use of and behave in physical learning spaces [46]. Observational studies have investigated how teachers' spatial behaviours, in relation to the classroom architectural design and their physical proximity to students, can strongly influence learning (see review in [60]) For example, researchers have explored the role of proximity between teachers and students in improving students' written work [73]; reducing misbehaviour [32]; and increasing the effectiveness of student-teacher interactions [84], motivation [25] and engagement [22]. The excessive presence of teachers by students can negatively affect their self-efficacy and sense of ownership of their own work [27], while studies of student seating arrangements all report inconsistent results [29, 35].

However, the study of student spatial behaviour is much more complex in dynamic learning spaces, often with authentic activities requiring students to move around different spaces in the classroom to interact with various resources and people (e.g., see classrooms in Figure 1). This is the case with simulation-based learning in professional fields such as healthcare, where students are expected to develop specific spatial competencies that are required of registered practitioners. These include having the ability to position themselves around the patient to timely accomplish a specific procedure [97]; knowing how and when to maintain close proximity to the patient [69] and other team members [58]; and forming particular spatial arrangements to enable collaboration with team members [34]. The development of analogous spatial competencies is required in other areas such as emergency response [62] and firefighting [1].

Spatial behaviours are ephemeral, making them hard to reflect on in detail, meaning more attention is given to other aspects of the tasks that teachers, students or trainees have to accomplish [67]. Key spatial competencies can be developed while the activity unfolds (Schön's notion of *reflection-in-action* [77]) as has been demonstrated in teaching, healthcare and team training [5, 79, 97]. However, Schön also emphasises the importance of *reflection-on-action* to recognise how our knowing-in-action may have contributed to unexpected outcomes or how it can contribute to the further development of competencies to be demonstrated in future events. For example, teachers commonly reflect on evidence after a class to understand how their actions may have impacted student's learning [75]. Paper-based checklists can support reflection on spatial behaviours, such as whether they were in continuous movement, standing in a specific area of the classroom or keeping close proximity to most students (e.g., [56]). Some teaching guides (e.g., [9, 38]) suggest that teachers should circulate through the classroom following various patterns and keeping specific distances to students. Unfortunately, most of these tools do not refer to the evidence used to prescribe such strategies, and they do not provide teachers with feedback about their own performance. The same happens with teachers and students in simulation-based learning activities. Although healthcare practitioners have dedicated debriefs after the simulation sessions to reflect on their actions [42], they rarely have evidence about spatial behaviours. Whilst these sessions may be video-recorded, in practice, teachers and students often do not have the time to watch full videos [65].

It is in this regard that emerging sensing and computer vision technologies could improve the timeliness and fidelity of feedback loops, as their capabilities to accurately and inexpensively track people and objects in indoor spaces improves [43]. Such technologies are now being used in educational settings to track teachers and learners in learning spaces such as makerspaces [16], lecture halls [11], specialised classrooms [51], collaborative classrooms [26] and schools [94]. In simulation-based contexts, such as healthcare education, there has also been a growing interest in using wearable devices to track how nurses move about training spaces. Yet, with a few exceptions [5, 50, 76], most of these works have focused on insights for researchers, and not provided visual mechanisms to support educational stakeholders' reflection. Critically, a key limitation to previous efforts to help teachers and students visualise their spatial activity is the assumption that close proximity (e.g. to classroom resources or other people) is a reasonable proxy for *interaction*. However, theoretical foundations in proxemics [71] challenge this assumption, since the *body orientation* of people strongly indicates the *focus of their attention* in the space [10]. Information about body orientation of teachers and students is key to detect what are termed *f-formations*: spatial patterns used by people to arrange themselves so that they can have easy and preferential access to one another during social interactions [81].

This paper investigates the extent to which granular information about teachers' and students' positioning and body orientation can be integrated and visualised effectively, thus mapping from low-level sensor traces to higher-order, contextualised spatial behaviours. An innovative visualisation technique called the *Dandelion Diagram* was used to visualise digital traces of the body's *movement trajectory, position and orientation* (see examples in Figure 1). The design goal was to augment positional heatmaps with trajectory and body orientation cues, without losing the intuitive, engaging attributes of heatmaps. These visualisations are evolving prototypes to generate a deeper understanding about teachers' sensemaking of their classroom activity and the kind of questions that they would be able to respond based on positioning and body orientation data. In-depth interviews were conducted with teachers in two authentic studies involving (i) collaborative teaching in a science lab, and (ii) teamwork simulation in nursing. Teachers were presented with visualisations of their own positioning data, and of other teachers and students. A thematic analysis of the reactions and reflections of teachers was conducted to determine the potential added value of the dandelion diagrams to (i) support reflection, (ii) envisage pedagogical uses of these visual representation and (iii) identify potential risks associated with bias and possible over-interpretation. In sum, this paper contributes to the growing body of evidence concerning the value of spatial learning analytics, by documenting teachers' perceptions of such visualisations, from which we derive a set of practical implications for professional development.

2 BACKGROUND AND RELATED WORK

2.1 Foundations of Proxemics

Proxemics is the study of communicative features of space such as how people consciously and unconsciously maintain physical distance during interpersonal interaction, how people arrange themselves in the space while performing a task, territoriality, crowding, and how the physical environment is culturally perceived [33]. A number of proxemics *constructs* have been used to study and give meaning to people's spatial behaviours. For example, the concept of *interactional space* refers to how people mutually adjust their bodies to enable close proximity and mutual attention for verbal interactions to unfold fluidly [57]. Although the exact distances that have been used as a proxy of the interactional spaces vary across cultures, most interpersonal interactions with acquaintances tend to occur under 1.5m [86]. Another key construct that is related to the body orientation of people is the notion of *f-formations* (facing-formations). These refer to the ways people cluster so that they can have direct and equal access to each another [39]. An f-formation can be identified by analysing people's proximity and bodies orientations when they establish conversation groups (e.g., side-by-side, face-to-face/vis-a-vis, circular or L-shapes) while standing close to each other [82]. The analysis of these f-formations has been key in the study of collaboration in contexts such as decision making [49] and healthcare [54]. In sum, proxemics has been used as a lens to analyse spatial behaviours in several areas of study. In this paper, we build on the proxemics constructs described above to report and give meaning to teachers' perceptions of visual representations of *x-y* positions and body orientation of teachers and students in the classroom.

2.2 Classroom Analytics

The term *classroom analytics* has been proposed as a lens to connect proxemics, pedagogy, data and educational space design [52]. Under this umbrella, indoor positioning and computer vision have been proposed as promising technologies that can enable new ways to study educational processes in physical learning spaces.

Several attempts to scale up direct classroom observations have been developed using video analysis. For example, Raca [68] applied tracking algorithms to investigate the impact of the teacher's position on the level of attention of a large audience. A similar goal was set by Watanabe et al. [91] by tracking lecturers' and students' faces from video data, while Bosch et al. [11] tracked teachers, gestures and slide transitions by analysing subtle changes between video frames in lecture presentations. Ahuja et al. [2] applied similar tracking algorithms using a multi-camera setup to detect teachers' and students' head and body orientations and gestures. The assumption in all cases is that teachers deliver a class from the 'front' of the classroom (hence, the tracking is restricted to a section of the room) while students remain seated. Yet, from K-12 to higher education, novel classroom design approaches (such as open learning spaces [70], flexible classrooms [87]) are challenging lecture-style practices. As a result, new analytics approaches are needed to generate a deeper understanding of the spatial behaviours in such dynamic classroom spaces. To summarise, firstly, none of these previous works provided accurate positioning traces and distances among people and classroom resources. Secondly, while video permits rich activity capture, it provides no support for quickly seeing *activity patterns* that need to be understood by learners (whether students, or teachers in a professional development context).

It is in this respect that there has been growing interest in using micro-location "wearables" in education. For example, beacon-enabled proximity sensors (i.e., triangulating the position of people's mobile devices or electronic tags) have been used for students to register class attendance [36] or to receive contextualised information while navigating a university campus [30]. Chng et al. [16] used a number of depth cameras to track inter-personal distances and characterise the types of social interactions occurring among students in a maker-space. Riquelme et al. [72] used beacons to automatically identify how students interacted with others and with bookshelves in a library. Echeverria et al. [23] used wearable location sensors to visually analyse teamwork strategies of students in healthcare. Yan et al. [94] scaled up the analysis of social networks formed by students at a school level through a longitudinal positioning study. Finally, Fernandez-Nieto et al. [26] proposed three techniques to model indoor positioning data captured from team training contexts using social network analysis and detectors of f-formations. This is notably the only work to include f-formations, but in common with the other approaches cited, did not evaluate the visualisations with stakeholders.

Besides the work by Shapiro and Garner [83] who proposed minimalistic visualisations of unidimensional positioning of teachers in a classroom over time (i.e., considering only the 'y' coordinate), only heatmaps have been used by other researchers as the main visualisation technique to explore how teachers can make sense of x-y positioning data. For example, Saquib et al. [76] presented a system that enabled school teachers to interact with heatmaps to observe what parts of the classroom they visited more and which students they interacted longer with. To achieve this, small trackers were embedded into furniture and students' shoes. An et al. [5] presented a set of tangible lamps that can be located on students' desks that would change their colour to reflect the amount of time a teacher has spent in close proximity to some groups. Similar work was presented by Martinez-Maldonado [50] who provided a hand-held device showing a heatmap of the locations of groups of students in the classroom.

2.3 Movement Visual Analytics

As a related realm, movement visual analytics [6, 7] has been concerned with questions related to the representation of movement, and more broadly of spatial and temporal data. A series of studies have explored aggregating different types of data or representations as additions to location data (e.g. GPS or in-door positioning data). For example, Flower Diagrams [6] have been used to represent spatiotemporal events at the scale of a city. Hyougo et al. [37] presented the Amoeba visualisation to portray people's movement between metro stations. Many more spatial-temporal analyses of geographic scaled data have been presented [8, 88]. The sport visualisation literature also tackled the question of representing movement, orientations, and spatial relationships between people [64]. For example, Vleugels et al. [90] used trajectories to assess team strategies in ice hockey. SoccerStories [63] supported analysts to better understand soccer data, e.g., player's position, passes and goal attempts. Other tools, such EagleView [13] have been used to tack people's interactions in video using proxemic dimensions, such as distance and orientation.

At the scale of indoor spaces, positioning data are most often used in analysing people's spatial patterns (e.g. [24, 41]). Meanwhile, trajectories have also been frequently studied to understand crowd behaviors in shopping centres [93] and museums [44]. However, people's body orientation is rarely separated from their moving directions in indoor movement analytics, since existing research mostly concerns people's location, movement, or trajectory patterns rather than their attention patterns [21] (i.e., which directions they attend to). All previous work on proxemics is a motivation to explore their application and usefulness in educational. In terms of classroom proxemics, teachers' rotation data is as important as their location and movement data [5]: without rotation data, it is unclear which adjacent students the teacher is facing, and whether a teacher seems to under- or over-attend to certain directions. In the case of nursing students, rotation is important to validate aspects such interpersonal interactions, where the majority of intensive and delicate interpersonal transactions occurs [17], or to identify facing-formations (f-formations), which indicate the ways people cluster so that they can have direct and equal access to one another (for example in side-by-side, face-to-face, in a circle or L-shapes). F-formation analysis has enabled HCI and CSCW research to understand how teams coordinate and communicate to achieve tasks including collaborative information-seeking [49], healthcare [54], and even cooking [61].

2.4 Information Visualisation and Sensemaking

Sensemaking is a term used in several literatures, providing complementary perspectives on how people grapple with information overload, ambiguity and the need to make high stakes decisions under pressure. For instance, Weick [92] draws attention to the ways in which professional teams (e.g. in emergency response) construct "plausible narratives" given dynamic environments; Dervin [19] studied information seekers' responses when their goals are obstructed in some way; within the CHI and InfoVis communities, Russell et al. [74] studied intelligence and business analysts, highlighting the central role of evolving representations to organise data to augment the limitations of human reasoning. Emerging from the latter work, a key HCI vision was summarised by Card [15] in a 2004 keynote address:

"[...]the purpose of information visualization is insight, or more particularly, a larger process that might be called sensemaking. [...] sensemaking systems combining visualization (the mind's eye) with semantic content analysis and sensemaking operations (the mind's muscle)."

Our work addresses this challenge, seeking to demonstrate how visualisations summarising complex, multimodal activity data can be better designed to give educators and students insights.

2.5 Research Questions

To summarise, thus far, significant advances have been made in the design of (proxemics) theory-based infrastructure for classroom analytics, but a key feature of human spatial behaviour has been missing to date — *location integrated with body orientation* — and the very limited analytics work on this has not been empirically evaluated with teachers. Furthermore, in the absence of sound visualisation design that can be shown to aid *sensemaking*, enriching activity data with such attributes adds no value to stakeholders seeking insights. We therefore pose the following two applied research questions, concerning the potential for sensemaking that dandelion diagrams offer by adding body orientation cues to spatial visualisations:

- ***RQ1:*** *To what extent do dandelion diagrams enable teachers' sensemaking of classroom spatial behaviours?*
- ***RQ2:*** *To what extent might dandelion diagrams help improve teaching practice?*

3 EDUCATIONAL CONTEXTS

This section describes the two learning contexts (A and B) this paper focuses on and the tracking system used. Campos et al. [14] suggest that it is critical to understand the variations in interpretations of learning analytics visualisations depending on the different roles an educator plays. In Context A, the teachers play the role of reflective practitioners [77] regarding their own practice and that of other teachers, while in Context B, teachers reflect on their students' performance and spatial behaviours. The contexts are in widespread use internationally, and as such, provided representative test-beds to evaluate the classroom analytics. Context A focuses on co-teaching in a laboratory classroom and Context B focuses on student teamwork in healthcare simulation. This illustrates the technical feasibility of visualising the spatial behaviours of the two main active educational stakeholders in most regular classrooms: teachers and students [20]. Moreover, in both educational contexts the development of spatial competencies is especially crucial for professional development (e.g., refer to [47] and [89] for contexts A and B, respectively).

3.1 Learning Context A: Co-teaching in the Science Lab

The first learning context involves weekly 2½ hour laboratory classes (labs) of a first-year undergraduate Science unit at University of Technology Sydney, in which students run physics experiments. The lead teacher and a teaching assistant co-teach each lab with typically 30-40 students working in 10-13 teams of 2-3 students each. Positioning data of both teachers was captured from eighteen labs randomly chosen (1-18). All labs were conducted in the same 16.8m x 10m classroom (see Figure 2, top) equipped with workbenches, a lectern, a whiteboard, and multiple laboratory tools. A limited number of photos were shot during the classroom sessions.

3.2 Learning Context B: Teamwork in Nursing Simulation

The second learning context involves 11 classes taught in an undergraduate Nursing unit at University of Technology Sydney. Approximately 25 students typically attended, organised in teams of 4-6 students, each performing a simulation (average duration 1.09 hours, std=14.35) around a patient bed in a training ward (see Figure 2, bottom). One team of the five in each class volunteered to be video-recorded and have their positioning data recorded. Students are expected to learn how to work effectively as a team when a

Figure 2: Learning contexts from which positioning data was captured. Top: A Science Lab. Bottom: A Nursing Simulation Classroom.

patient is experiencing an allergic reaction. Students are asked to play different roles, namely: a) the team leader, b) registered nurses (Nurses 1 and 2), c) a scribe nurse (Nurse 3, who documents all the procedures performed), and d) the patient (enacting the voice of the patient manikin). In addition, one teacher in each class played the role of the main doctor in the ward, moving around to observe the nursing teams.

3.3 Positioning Tracking System

The *x-y* coordinates and body orientation data of the two teachers in each Science Lab (Context A) and the Nursing teacher and five students of the tracked team (Context B) were automatically recorded through wearable sensors located inside a waist pack worn on the front of their bodies. The sensors were part of the Pozyx ultra-wideband (UWB) system. The cost of this tracking system was 1,500 EUR. The system can be installed and calibrated by educational stakeholders with basic technology literacy (i.e., capable of following technical instructions). The system captures positioning data at a 2Hz average sampling rate (with an error rate of 10 cm as reported by the vendor). Eight anchors were temporarily affixed to the classroom walls to estimate the positions of the sensors. Each data point included the x-y positioning coordinates (in millimeters), and the body orientation (measured as an angle) with respect to an arbitrary point in the room. For Learning Context A, given the large number of teams in each lab (10-12), the positions of students' experiments were captured by an observer using a tablet-based observation tool.

4 DESIGN AND ANALYSIS

This section presents: 1) the design of the dandelion visualisation diagrams, 2) details about the participants involved in the evaluation study, 3) the study protocol, and 4) the analysis process.

4.1 Dandelion Diagrams

The dandelion diagram is a positioning visualisation technique that aggregates positioning and orientation data, and thereby can depict both the whereabouts and heading directions of a person at different points in time. Dandelion diagrams also visualise the trajectory of people across the physical space, which can reveal their mobility patterns. Moreover, it uses color codes to communicate extra information, such as to differentiate the data points representing multiple actors in a collaborative process. The visualisation is agnostic to the underlying positioning tracking system. The input data for dandelion diagrams should be formatted continually in equal timeframes (e.g., 1 data point per second as described below). Each data point should include both *location* (i.e., x-y cartesian coordinates), and *orientation* (in radians or degrees). The dandelion diagrams feature the following four visualisation design components:

(1) *Spotlight metaphor.* The position and orientation of an actor in a given point of time are represented in a triangular shape, following the metaphor of "spotlight" (see Figure 3, 1). The farthest vertex indicates the x-y location of the actor, and its opposite side shows the direction the actor is facing to. This representation is commonly used in video games and navigation systems, and can intuitively depict an entity's location and orientation.
(2) *Trajectory.* The trajectories of an actor are delineated by connecting every two consecutive position coordinates, which shows any change in location and orientation over the visualised period of time (see Figure 3, 2).
(3) *Density stacking.* Based on the metaphor of the heatmap, each spotlight shape is semi-transparent, and multiple shapes can stack on one another to increase the density of the colour, which reflects that the actor was cumulatively staying in a location (see Figure 3, 3).

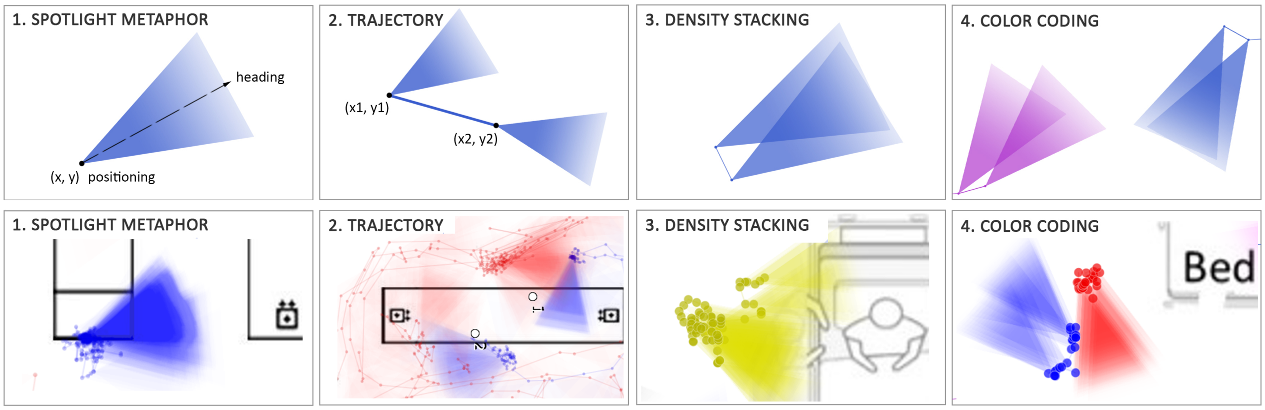

Figure 3: Top: Illustrations of four major design components of the Dandelion Diagram. Bottom: Embodiment of these design components in data visualisations using data from the two learning contexts.

(4) *Colour coding.* The different colours of the spotlight shapes represent different actors in the practice context, to help the audience differentiate multiple roles in a collaborative process (Figure 3, 4). Alternatively, this colour coding feature can also be used to represent other types of information (e.g., in a prior iteration [4], it was used to differentiate data points from different activities or periods of time).

4.2 Participants

The study presented in this paper focuses on the perspectives of teachers involved in the design, delivery or evaluation of the two units of study described in section 3. For Context A, the unit coordinator (physics teacher 1 - PT1 - who designed the learning tasks and did not teach any class); a main teacher and a secondary teacher (PT2 and PT3, respectively, who taught a total of 14 classes in pairs) participated in the study. All of the participants were experienced teachers in each of their roles (males: 3, average years teaching: 11.3). For Context B, 5 nursing teachers (NT1-5) inspected students' positioning data (females: 4, average years teaching: 12.6). NT1-4 delivered the 11 simulation classes and NT5 is a nursing researcher who assesses nursing education programs at the hosting university.

4.3 Study Design

Inspired by theoretical foundations of information visualisation design [55, 78], and sensemaking with data visualisations [14, 15, 66], we used a set of dandelion diagrams as *evolving prototypes* to investigate the relationship between teachers and the positioning data, beyond learning about the specific visualisation technique. For this, the eight teachers in both learning contexts were interviewed with the purpose of documenting their perceptions of the dandelion diagrams about themselves (in Context A) and their students (in Context B). Each interview was recorded using an online video conferencing platform (i.e., Zoom) and had an approximate duration of 60 minutes. Before each interview, the four major design components of the dandelion diagrams were explained to the teachers using examples such as the ones depicted in Figure 3. They were also invited to ask clarification questions regarding the design of the visualisations during the rest of the interview. Following a semi-structured format, the interview had two parts:

Part 1. A think-aloud protocol was followed to document how teachers explored the positioning data in order to address RQ1 (sensemaking of spatial behaviours). These data were presented to teachers as digital indoor maps corresponding to *critical classroom events* of the classes relevant to them in two ways: i) by visualising x-y coordinates only, and ii) using dandelion diagrams. The x-y coordinates were presented in the form of regular heatmaps as in previous classroom studies reported in Section 2.2 [50, 76]. The same data was made available through the dandelion diagrams. The maps were generated by normalising the positioning data to 1Hz to make them comparable.

The *critical classroom events* presented to teachers were selected based on previous work. For Context A, results from a previous qualitative study [51] emphasised the importance of understanding how teachers interact with (i) classroom resources, (ii) students and (iii) each other in co-teaching scenarios, which is aligned to contemporary literature on the materiality of the classroom environment [96]. Each class was segmented into three phases by the unit coordinator. Phase 1 includes the main teacher of the class giving instructions (average duration 13 ±8 minutes). Phase 2 corresponds to the period in which all students start working on the experiment(s) in small teams (1.5 hours ±18 min). Phase 3 corresponds to the time when some teams complete their experiments and start leaving the class (33 ±22 min). The analysis of this paper focuses on Phase 2, which enables comparison across the classes considered. Phase 2 was further segmented into quartiles of the same duration. A total of five critical events were selected by the research team from the resulting quartiles, displaying events identified by the teachers who participated in the previous study as examples of potential interactions of teachers *with classroom resources* (2 instances), *with students* (one instance) and *between themselves* (2 instances). Details of these five critical events, and the extent to which each is representative of the dataset, are provided in the next section.

For Context B, the critical events were closely related to the learning design of the team activity created by the unit coordinator. High effective teams should go thrugh the following events: (i) perform an initial set of vital signs measurements; (ii) prepare/administer the intravenous fluid-IV antibiotics; (iii) perform another set of vital signs measurements after the patient complains of chest tightness; (iv) stop the IV antibiotic; (v) perform an ECG; and (vi) call the doctor after stopping the IV antibiotic. In this case, the research team randomly selected instances from this critical moments, focusing on events iv and v, which are the most critical events identified by the unit coordinator. All the teachers within each context inspected the same set of visualisations.

Part 2. Then, teachers were asked to respond to two main questions (and trigger sub-questions) to elicit their perceptions of the dandelion diagrams in terms of sensemaking (RQ1) and potential to support teaching practice (RQ2).

(1) Does the information displayed in the dandelion diagrams enable the *sensemaking* of classroom spatial behaviours? If so, How? Trigger questions:
  - What differences does it make to add rotation/trajectory information to the positioning data maps, if any?
  - Could you name some examples from your experiences in which the heading information can help us identify what was happening in the classroom from the positioning data?
  - Can you envisage any risk in showing the diagrams with or without body orientation information?

(2) To what extent can the information in the dandelion diagrams can contribute to improve *teaching practice*?
  - Do you think such visualisations can support or hinder teachers' reflections upon their practice? Why?
  - Do you think such dandelion diagrams could also support professionalisation of researchers/experts in doing their research or training teachers? Why and How?
  - How do you envisage teachers can use the diagrams to support reflection and teaching over time?

4.4 Analysis

The interviews were fully transcribed using a professional service. In qualitative studies, notions of generalisability and reliability are usually replaced by validity, rigour and attention to the quality in the research process [18]. To achieve this, we used data triangulation (various sessions with teachers in two contexts), triangulation of sources of evidence (think-aloud recordings, video data, and interview responses), and analysis triangulation (three researchers in the analysis process). Informed by best practices of qualitative research in HCI [53], we analysed the interviews as follows.

Analysis of Part 1: Vignette analysis. This involved three researchers independently screening the video recordings of the interviews looking for how teachers talked about spatial behaviours based on the visualisations of x-y coordinates and the dandelion diagrams. Then the researchers discussed each particular moment, selecting vignettes that could potentially point to insights and contradictions across teachers inspecting the same visualisations. The researchers discussed their independent analyses to reach an agreement. Results from this analysis are reported in Section 5.1 by describing the critical classroom event, and a summary of teachers' perceptions on them. Footage from the classroom sessions was additionally used to confirm teachers' interpretations of the diagrams they explored.

Analysis of Part 2: Interview analysis. Given the direct alignment between the interview protocol and the research questions, statements of interest were jointly identified by three researchers. These were thematically coded [12] by one researcher. Resulting coded statements were double-coded by other two researchers until full agreement was reached. Next, researchers had several discussions to identify and group emerging themes in alignment to the interview questions, which are reported in Section 5.3.

5 RESULTS

5.1 Vignettes from the co-teaching context (A)

5.1.1 *Vignette A1: Proximity to Classroom Resources.*

This vignette focuses on two *critical classroom events* in which teachers were in close proximity to key classroom resources. Previous studies looking at classroom proximity traces have assumed that the teacher may be interacting with classroom resources if they are within arm's reach [51] (e.g., while giving an explanation to students). The two classroom maps on the left of Figure 4, illustrate two instances where the secondary teacher (red data points) is very close to the classroom whiteboard (see Points A and B) and the main teacher (in blue) is at a bench where there are no students (Point C) for an approximate period of 22.5 minutes.

When teachers explored the visualisations of *only x-y coordinates* (Figure 4, left), they confirmed the assumption is that close proximity to a classroom resource most commonly means that teachers may be using it. The unit coordinator (PT1) explained this as follows *"It is unusual to stand at the whiteboard not using the whiteboard unless there are students standing in front of him or her"*. The main teacher who was in the room in both sessions (PT2) also assumed that the auxiliary teacher in red (PT3) was *"probably explaining some theoretical points, using the whiteboard"*. Yet, PT3 confirmed that he *was scanning all the tables to see if all students were maintaining self regulation"* in session 1 (top), and *"just standing there and seeing if anyone needed help"* in session 4 (bottom). This teacher also explained that for Point C, that teacher was *"most likely using the bench to write on the lab sheet, indicating who did which experiment, and who attended"*.

However, when the same teachers looked at the dandelion diagrams (Figure 4, centre), all of them changed their minds about the spatial behaviours in both situations. For example, PT1 indicated that PT3 spent most of the time supervising and did not consider this behaviour adequate if extended for a long period of time (see Point A): *"the [red] teacher seems to be just watching the crowd. This should not really happen unless you use a whiteboard, which obviously is not the case"*. This was confirmed through a snapshot of the classroom footage (see Figure 4, top-right). Regarding the blue dandelion at Point C (Figure 4, bottom- centre), he suggested a particular behaviour where the 'spotlight' remains at a specific angle as follows: *"it's not like a swiveling over like watching people. So I suspect that teacher in blue is either idle or explaining something to students"*. PT2, after looking at his own data, explained: *"It seems I was just deeply looking to the class, because there are dense dots. It is near the bench, so I was probably explaining something to some group of students there gathered around me"*. PT3 confirmed that in Session 1 (Point A) he was *"facing the students, changing [his] orientation from left to right, trying to scan the whole classroom to see if there*

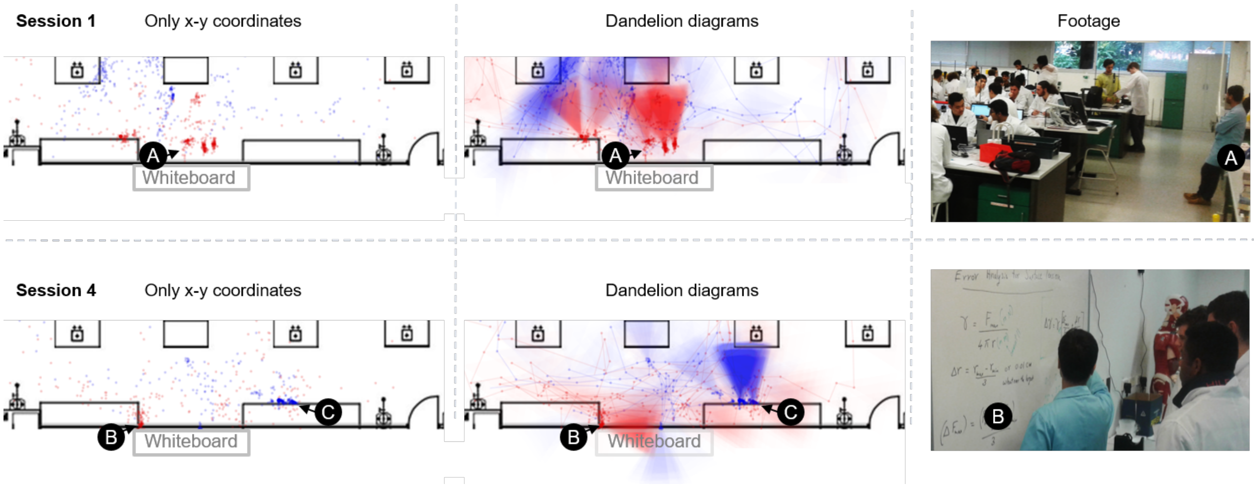

Figure 4: Visualisations over 22.5mins approximately, of the main teacher (blue) and the secondary teacher (red) in close proximity to the classroom whiteboard (see points A and B) and an auxiliary bench (C). Left: *x-y coordinates only.* Centre: *dandelion diagrams.* Right: *video footage* of the critical events.

were any problems or safety regulations that needed attention". Yet, he corrected himself as he could see through the dandelion diagram that his body orientation in Point B was towards the whiteboard, explaining this as follows: *"I was writing on the whiteboard or explaining a formula written on the whiteboard to some student"* (see Figure 4, bottom-right).

In sum, the added information contained in the dandelion diagrams enabled teachers to understand the situation more in detail. This also demonstrates that it is not sufficient to simply use the proximity distance as a proxy to identify if certain classroom resources are being used by the teachers. Importantly, teachers could differentiate important spatial behaviours, such as scanning the classroom when the spotlight is *swiveling* versus the dense stacking indicating that the body was oriented towards a fixed point for longer periods of time; these look identical in an x-y heatmap. The next vignette focuses on spatial behaviours when teachers are close to students.

5.1.2 Vignette A2: Proximity to Students. This vignette is focused on a *critical classroom event* that is representative of 20-40 instances that occurred in each class (avg=30; std= 10.3): teachers standing in close proximity (within 1 metre) to teams of students working on their experiments. An instance was selected based on a previous study [51] in which 3 clusters of teachers' positioning data points are surrounded by 4 students' experimental setups. Figure 5 depicts the selected instance visualised by plotting x-y coordinates (left) and dandelion diagrams (right). Teachers were asked to comment on what they thought PT3 (in red) was doing in close proximity to team 4 (Point X) and what PT2 (in blue) was doing near team 7 (clusters in Points Y and Z) for a period of 23 minutes approximately. This instance was selected because the body orientation data in Figure 5 (right) appears to help disambiguate which team of students is being attended to (i.e.„ although the teacher at Point Y is closer to team 7, his attention was in fact on team 6 working further away on the lab bench).

Similar to the vignette A1, when teachers explored the x-y data plot (Figure 5, left), they confirmed that the assumption is that being in close proximity to students means that they may be interacting with that team. PT1 explicitly explained this, by considering the details of the learning design (i.e., *"Because this is a very concentrated experiment, you have to be in close proximity to the students to talk to them"*), as follows: *"Just looking at the obvious proximity, we have teams 4 and 6 for Point X. For Point Y, we have team 7, and 5 possibly. This is the principal teacher so for Point Z may also be close to the PC checking information."*. The other two teachers (whose data was represented in the diagrams) followed the same rationale (e.g., PT2 stated: *"At Point X I was attending team 4 because I was closer to them, and so on."*.

Yet, when teachers explored the dandelion diagrams (Figure 5, right), they had to revisit how they initially interpreted the data. For example, PT3 (in red) explained how the information about his body orientation and that of the other teacher, could help him confirm how they used the space to support students, as follows; *"From position X I was facing team 4 so I was like helping them. From Y, maybe [the other teacher] was [walking] from [position Z] and maybe was monitoring team 6 from afar"*. PT2 (in blue) also corrected himself and could describe the situation by looking at the dandelion diagrams representing his own data: *"So I said in X I was attending number 7. But my conclusion was wrong because I was oriented towards group 6. But it is too far away from this group unless there is some student from this team maybe asking some question. Looks like definitely from point Z I was explaining something to team 7. Awesome!"*

In sum, the added body orientation information enabled teachers to get a richer picture of the classroom situation they experienced. The next vignette explores two cases in which both teachers were providing close attention to only one team at a time, which we refer to as instances of co-teaching.

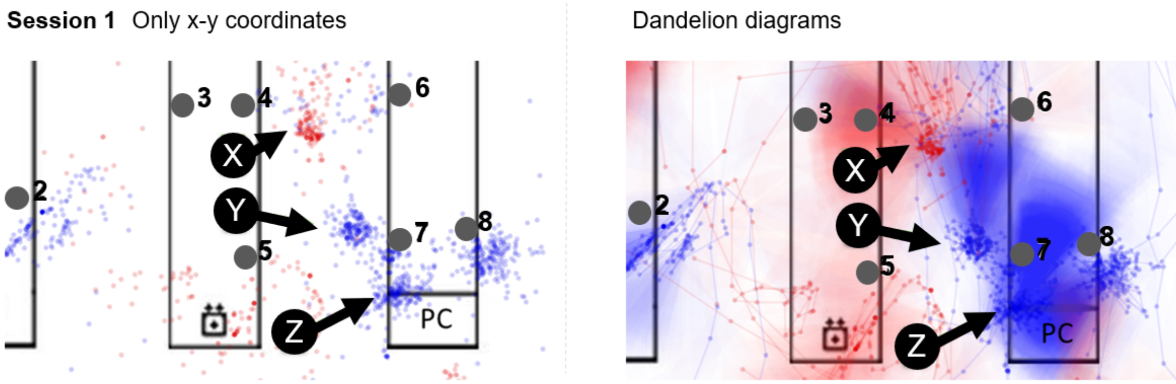

Figure 5: Visualisations over approximately 23 mins. of the main teacher (blue) and the secondary teacher (red) in close proximity to students' lab experiments (see points X, Y and Z). Left: *x-y coordinates only.* Right: *dandelion diagrams.*

5.1.3 Vignette A3: Instances of Co-teaching and F-formations. This vignette is focused on two *critical classroom events* that are representative of the 3-10 instances that occurred in each class (avg=5.6; std= 4): both teachers standing in close proximity (within 1 metre) to the same team partially at the same time. Two instances were selected to illustrate two different f-formations displayed by the spatial behaviours of the teachers approximately 22.5 minutes apart. The classroom maps at the top of Figure 6 illustrate an instance of a face-to-face f-formation of both teachers near team 1, and the maps at the bottom illustrate a side-by-side formation [39], where both teachers faced team 2. Both moments were extracted from the same class session to enable comparison.

When teachers inspected the maps showing only x-y coordinates, the teachers did not have much evidence to reflect on. Both maps in Figure 6 (left) look similar. PT1 wondered if *"maybe the (red) teacher sort of sought some extra help from the (blue) teacher to support team 1"*. The other two teachers explained that having two teachers in close proximity to the same team may be a sign of students needing to *"solve a problem"* (PT2) or to *"debug the experiment or explaining to students what they needed to do"* (PT3). Yet, teachers did not explain much about their own team dynamics as a teaching team when attending the same group of students.

When looking at the dandelion diagrams (Figure 6, right), for both cases, they all reflected about the strategies that could potentially be illustrated through these examples in terms of socio-spatial behaviours. For example, PT1 explained that, in the case of the *face-to-face* f-formation (Figure 6, top-right), *"even though they may have attended the same team a few minutes apart, what it actually shows is that team 1 requires quite some attention because there's a fair concentration of both teachers, the red and the blue."* PT1 also explained that the body orientation gave him clues about the kinds of interactions that may have occurred: *"If the blue is talking to you, or the other way around, they would be facing each other. The main teacher might as well talk to one of the students who is engaged in that experiment because is facing to the other direction. The red one is engaged with these students at the bench. You see? The red is much, much more concentrated"*.

In the case of the *side-by-side* f-formation (Figure 6, bottom-right), the dandelion diagrams helped PT3 to recall exactly what happened, and he reflected on his collaboration strategies as follows: *"So, the clear difference is that in the [face-to-face formation] the main teacher commonly talks to the [secondary] teacher; and in the [side-by-side formation] we usually are giving instructions to students"*. PT3 also explained in more detail how the information about their body orientation helped him reflect on their social dynamics. He explained: *"face-to-face situations would be when we are both having a discussion so that we can both work on the same project. But the side-by-side was the situation when one tutor was actually explaining to the group and the other is standing there. So, you see? like the fans [spotlights] actually intersect"*.

The next set of vignettes illustrate new aspects yet to be discussed related to social dynamics, since it focuses on the Nursing teams of 5 students engaging with their teacher.

5.2 Vignettes from the teamwork contect (B)

5.2.1 Vignette B1: Teacher Monitoring or Intervening. This vignette is focused on a *critical event* when one of the teams of nurses is attaching the 3-lead electrocardiogram device (ECG) to the simulated patient. During this procedure, nurses around the bed attach the ECG directly to the patient's chest. This vignette illustrates nurses' embodiment of this task in the classroom space for a period of one minute (one point per second). This instance was selected because the teacher was in close proximity to the team (see grey data points in Figure 7).

When nursing teachers (NT1-5) where asked to explain the situation using Figure 7 (left), four out of five interpreted that the role of the teacher was actively involved in helping and guiding nurses through the process (performing an *intervention*, for example, to provide feedback to the students) by focusing on Point A in the figure. For instance, NT3 mentioned that *"in this situation [nurses] commonly don't realise what is going to happen so they may need a little bit of guidance and reassurance from the teacher"*. NT5 more strongly assumed that *"the teacher must have been explaining something specific or nurses asked for some kind of clarification"*. NT2 (whose data was being inspected) admitted that he could not remember what may have been happening without having further information.

However, when presented with Figure 7 (right), all the teachers changed their initial interpretations. Three out of five teachers

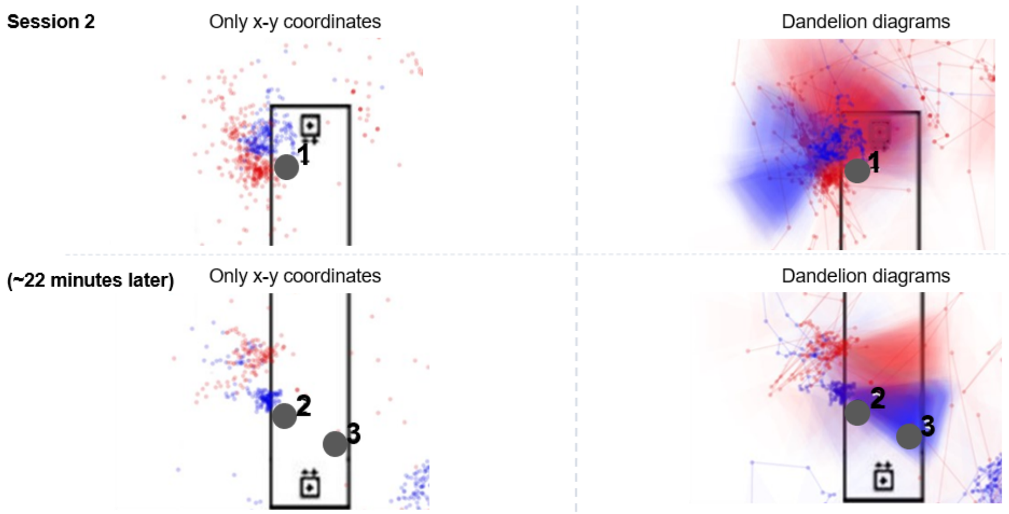

Figure 6: Visualisations approximately 22.5 mins. apart, of the main teacher (blue) and the secondary teacher (red) while both attending to the same team of students. Left: *x-y coordinates only*. Right: *dandelion diagrams face-to-face* (above) and *side-by-side* (bottom).

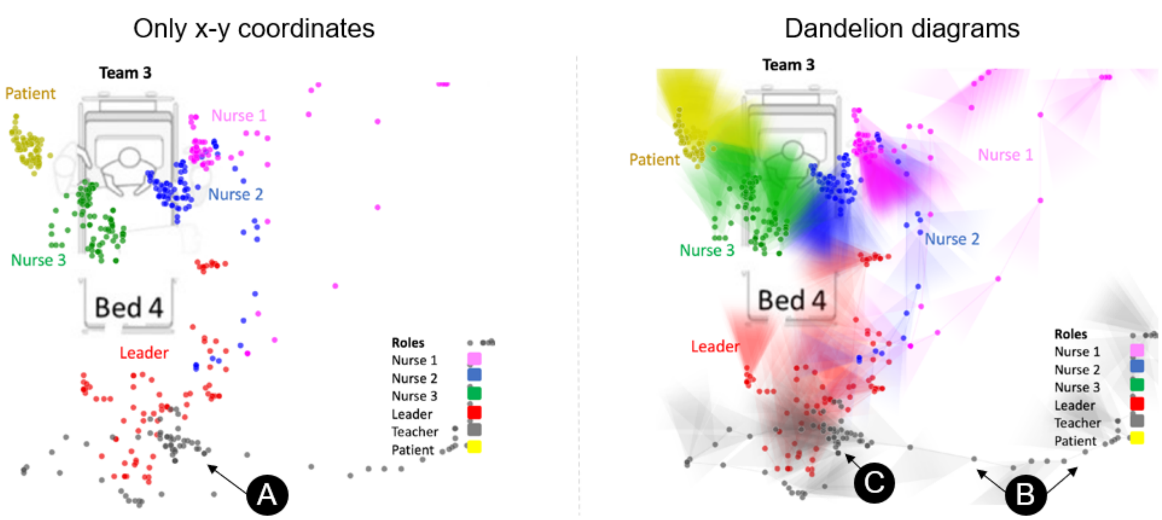

Figure 7: Visualisations over one minute of a teacher, and four student nurses playing different roles in a team simulation during a critical event: attaching an ECG device. Left: *x-y coordinates only*. Right: *dandelion diagrams*.

pointed at the teacher's trajectory (Point B), which was interpreted as the teacher just *monitoring* the team and then moving away to the next bed. NT1 indicated *"I can see the teacher was moving away to the next bed [pointing at the trajectory]"*. NT2 this time commented *"So you can see that I was standing off to the side just looking, and I might have come over to briefly say something to the team leader [referring to Point C]. I didn't invade their space for some particular reason"*. This monitoring behaviour was confirmed through the video footage.

This vignette illustrates that visualising the trajectories and the body orientation of the teacher and students contributed to characterising how the teacher's classroom tasks (e.g., monitoring versus intervening students) were enacted. This may be helpful to train novice teachers for them to learn how to work in the classroom space.

5.2.2 Vignette B2: Spatial Team Dynamics. This vignette focuses on the spatial behaviours of two teams (3 and 5) during the most critical event of their team simulation: noticing the patient's adverse reaction to an antibiotic and stopping its intravenous (IV) administration (located at the top right hand side of the bed in all diagrams in Figure 8). In the simulation illustrated in this vignette, there is commonly one student (Nurse 3 in Team 3 and the team leader in Team 5) asking questions to the student enacting the voice of the patient (student sitting next to the bed whose data is depicted in yellow). According to the teachers, the spatial behaviours of Team 3 were more effective compared to Team 5.

Based on the x-y coordinates (Figure 8, left), teachers did not perceive major differences between both teams. NT1, NT2, NT4 and NT5 explained, using similar words, that in both teams Nurses 1 and 2 performed the critical actions. Regarding Team 3, NT2 explained: *"...so, nurse 1 and nurse 2 have identified the incident. They realised that the adverse event probably is related to the antibiotic being delivered and therefore they are around the IV fluids"* (Point A in Figure 8, top-left). Similarly, NT5 explained the following for Team 5: *"I think that nurses 1 and 2 took a very active approach. And probably nurse 1 was who was stopping the IV fluid (signalling Point B)"*. The teachers also inferred some differences between the behaviours of students across both teams (e.g. asking questions to the patient or checking the IV machine) by noticing which students were close to each other or to the patient. For example, the team leaders in both groups behaved differently during the critical event. The team leader in Team 3 was effectively positioned according to her role. This was confirmed by NT4 as follows: *"It looks like the team leader of team 3 is at the base of the bed (Point C) from where she can notice if something is wrong with the patient"*. In contrast, in Team 5 the team leader was standing at an unexpected position during the adverse event: *"Oh look! [signalling Point D], it looks like the team leader is in a different position here, because usually they are at the end of the bed. So it looks like she/he is actually asking the patient"* - NT1.

In contrast, when teachers inspected the dandelion diagrams (Figure 8, centre), they identified certain spatial behaviours according to nurses' roles. For the case of Team 3 (top-centre), teachers used the body orientation of the students as a potential marker of interaction with the patient or with other team members. For example, NT4 said: *"everybody was facing the patient"*. NT1 further interpreted the information about body orientation in terms of team dynamics, as follows: *"You can see nurse 3 is focused on the patient (see Point E) and you can see nurses 1 and 2 have gone and stopped the IV antibiotic (Point F)"*. NT5 added: *"it is clearer here that the leader had a kind of communication with nurse 1" (signalling Point G)*. However, for the case of Team 5 (bottom-centre), teachers highlighted some potential areas for improvement. For example, although NT1 effectively recognised team leader's behaviour from his spatial traces (i.e., *"I can see here that the team leader may be doing the patient's assessment (signalling Point H")*, NT2 explained this may be related to some problems faced by this team as follows: *"I'm not happy with the team, I think the team leader should not be doing the procedure. It should be [nurse 1] or another nurse allocated to this task"*. Similarly, NT4 explained this in terms of a leadership problem, as follows: *"...the team leader is doing everything and not delegating. Nurse 3 has done nothing (see Point I). Nurses 2 and 3 seem to be waiting for direction and taking no initiative"*.

In sum, with the x-y heatmaps, teachers could not differentiate the two teams, but with the dandelion diagrams, they were able to identify key behaviours related to the *effective* execution of the team task (by Team 3), in comparison to a team showing potential *leadership and communication* issues (Team 5). The next section presents additional insights from the rest of the teacher interviews.

5.3 Thematic results

This subsection presents reflections externalised by teachers during the interviews. Questions asked were organised according to our two research questions under the themes: added value of the dandelion diagrams (RQ1) and envisaged integration into teaching practice (RQ2). A third theme emerged concerning potential challenges, risks and limitations.

5.3.1 Added Value of the Dandelion Diagrams. We identified two sub-themes in this regard:

Advantages over representations of x-y coordinates. The first subtheme that emerged addresses the benefits of incorporating the representation of body orientation in the visualisation, in comparison to existing tools that only depict coordinates, e.g., a heatmap, or point cloud visualisation. As NT2 experienced, when there were only dots (x-y data) on the visualisation, the audience would not have complete insights into the situation: *"you're only going to see part of the information, you might not see everything."* In contrast, with the dandelion diagrams, *"when you see more of that directional information you can then put together what is actually happening"*. As stated by PT2, *"if only the dots [are shown], it just says that you spent more time in a certain location. But when you add a cone (body orientation) you will see exactly where the teacher was facing to and you could attach some explanation to those dots"*. Correspondingly, the teachers provided examples about how the dots-only visualisation can lead to more misinterpretations of the situation. For instance, PT3 explained: *"Teachers may not be facing the group at all. They may be facing the other way. So it may be easy to interpret that they were actually helping the group because they were somewhat close to them, but it was something else in reality"*. More examples could also be found in the vignette review sections (i.e., subsection 5.1.2). Hence, as NT4 explained, *"the points [alone] can be misleading when you try to read them"*. A similar perception was shared by other teachers. This recurrent opinion confirmed that one major added value of the dandelion diagram is the aggregation of x-y position and body orientation, which help teachers to better interpret the classroom situations at critical moments.

Potential complement to video analysis. Another emerging subtheme concerns how the dandelion diagrams can serve as a complement or alternative to video analysis, to save teachers' time and efforts in professional training. In current contexts, video has been widely adopted as a learning tool to promote practitioners' reflection on their performance. For example, in a training session, teachers might need to watch and analyse classroom recordings of peers or their own, and discuss different aspects of practice. A similar approach has also been followed in the training of nurses. Despite being effective, this video analysis approach can be time-consuming for practitioners who already have busy routines. As experienced by our teachers, they suggested that the dandelion diagrams may serve as objective summaries or episodic indexes to help professionals intuitively analyse the depicted incidents, or quickly retrieve a relevant video clip. As NT5 explained, *"for me as a teacher, it will save a lot of time, because I won't need to go to the video as a source of information. I can just use this visualisation to explain what is going on, and I know that it will be accurate."* Correspondingly, another similar explanation was offered by PT2: *"it can work as a kind of summary for reflection because I don't think*

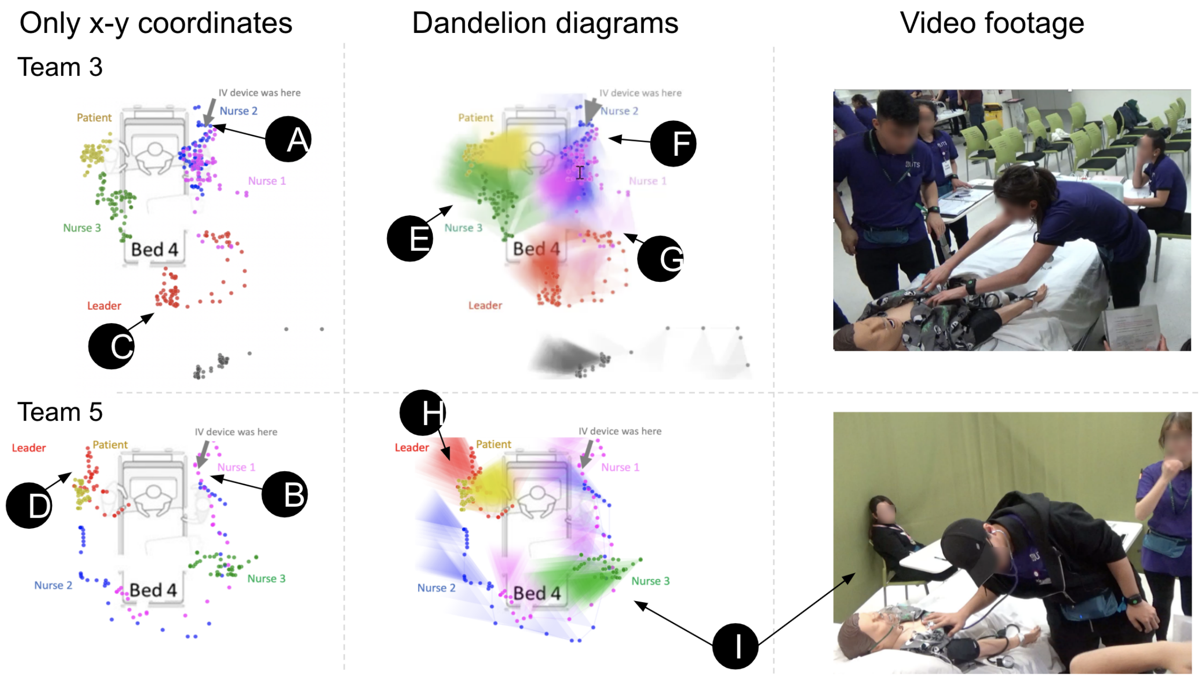

Figure 8: Visualisations over one minute of teams 3 (top) and 5 (bottom). Left: x-y coordinates only. Centre: dandelion diagrams. Right: footage of the critical event: stopping the IV fluid on time.

any teacher is going to go through the video recording of one hour or two hours to see how to do the teaching." In addition, NT2 pinpointed another potential advantage of dandelion diagram as an alternative to the video approach, *"I think it gets away from the whole issue around privacy."*

5.3.2 Envisaged Integration into Teaching Practice. Under this theme we summarise the teachers' opinions on how the dandelion diagrams could be integrated into existing practice of professional learning and teaching. The first three subthemes address what the dandelion diagram could be potentially used for to facilitate the process of professionalisation, whereas the last subtheme summarises when and where professionals might use the visualisation as a tool.

Enabling evidence-based reflection. All teachers in both contexts believed that dandelion diagrams can support practitioners' reflection both individually and collectively, by summarising evidence from their own practice. For example, in the context of the physics labs, PT2 believed that the dandelion diagrams could serve as a reflection of how teachers have helped their students and motivate them to *"think about what needs to be changed before the next class"*. PT3 said that this visualisation tool, as a more objective data portrayal, could help them identify *"unconscious bias"* in their spatial performance and thereby *"promote learning better"*. In the nurse training context, NT2 believed that the visualisations could be used not only for *"self-reflection"*, but also for *"group reflection"*, in which a team of nursing students could reflect on *"what worked well and what didn't work well and what was going on here and what would they should do differently the next time"*. Similarly, NT5 envisaged that the dandelion diagrams could offer students clues to help them identify surprising or unwanted patterns, which provoked reflective questions such as *"what happened to me in this situation? Why? How can I improve it? What can I do to avoid it in the next simulation?"*.

Facilitating example-based learning. The teachers also highlighted the promises of dandelion diagrams in helping professionals learn from others' (good or bad) practices. For instance, NT2 considered them potentially beneficial in professional learning, if the visualisation technique is used to curate and compare examples of *'good'* and *'bad performance'*: *"here's some examples about [. . .] really good interaction using this visualisation, compared to another example where someone was facing in the opposite direction or away from the patient most of the time"*. NT3 proposed using anonymised visualisations for peer case analyses, e.g., to help nurse trainees to discuss opportunities for improvement from others' cases. Moreover, NT4 believed that the dandelion diagram visualisations could serve as concrete demonstrations for novice professionals to understand ideal practice patterns in certain situations: *"that is a good way to sort of introduce new teachers [. . .] what pattern we think is probably more suitable or the best to use in those various circumstances"*. She gave an example about how this would work better than only providing abstract instructions to novice professionals: *"the visualisation helps, certainly, because just talking about roaming around [is not enough]. What does roaming around mean? And, you know, the dandelion diagram can be used to illustrate that"*.

Augmenting feedback provided to students. Several teachers also pinpointed the potential of the dandelion diagram in terms of supporting instructors to generate more personalised, concrete feedback for learners. For example, as NT1 explained: *"I think it would definitely give more support in regards to teachers giving student feedback."* She first argued that the visualisation tool could help teachers assess the performances of students in detail: *"you see the visualisation and you say, well, sometimes the students do what they're expected to do, and sometimes they don't, or sometimes they might be slow to react to what's happening"*. She also explained how such insights could help the teacher to give more pertinent feedback to the students: *"then you could base your feedback on that as well. You would actually say to them: I can see that you were in this direction, in this particular position, could you tell me a little bit more about what you were doing during that time?"* Moreover, NT2 pointed out that the dandelion diagrams could help teachers to generate relevant feedback in their own professional development: *"very useful information that could come of that [the dandelion diagram] for the teachers in terms of the feedback in debriefing in professional situations"*.

When to use the Dandelion Diagram. In terms of supporting learners' reflection and instructors' feedback, the teachers recognised that the debriefing session (or a quick feedback session) after an episode of practice (i.e., a class), would be a good occasion to integrate the visualisation tool: e.g., *"when we're debriefing with the students. We could show them this visualisation" (NT3). NT2 emphasised that it would be particularly beneficial if the debriefing session took place in "relatively real time, after the scenario."* This would make sure that the practitioners still retain fresh memories about the practice session, *"so they would not need to see the video as well"*. In terms of supporting learners' example-based learning, some ad-hoc training sessions were considered suitable occasions to utilise the dandelion diagrams, e.g., to curate examples of good and bad practices (NT2, PT1), and peer case studies (NT3). Moreover, PT2 suggested that the visualisation could also be integrated *"with a journal for teachers to reflect on the decisions they took"*. NT3 suggested using the visualisation as an awareness tool to help teachers *"in trying to maintain professionalism"*. PT1 mentioned the possibility of using the visualisation as a long-term intervention in professionalisation to see how it would promote iteration and evolution in professionals' practice. In addition, PT2 specifically proposed using the dandelion diagram together with video, in which the visuals could be *"useful to give a summary for certain periods"*, and help practitioners *"navigate to a specific video section and then figure out what happened there"*.

5.3.3 Challenges, Risks and Limitations. This theme collates the teachers' opinions about the potential challenges, risks and limitations of using the dandelion diagrams in practice, which has led to some detailed considerations in designing and implementing this new tool. The first challenge refers to how to represent absolute time duration in addition to the relative proportion of time in the visualisation. Each frame of the dandelion diagram depicts spatial data within a certain period of time, thereby, its color density represents the relative proportion of time rather than an absolute duration. Yet, as recognised by PT2, practitioners sometimes may be interested to know *"exactly how much time a blue cone represents"*. To resolve this need, we propose that future diagrams could add extra annotations to indicate the absolute duration of a specific data cluster. These annotations could be either auto-generated or based on manual labels.

PT3 raised another challenge which is about the over-saturation of the color density which might cause certain data points being *"washed out"*. This could be avoided by dynamically configuring the amount of color density based on the time-frame of the whole visualised session: i.e., the longer the session, the weaker each accumulation of color density will be. NT2 noted that the position of the tracking sensor on the body should also be carefully considered, to maximally guarantee the accuracy of the data in terms of body orientation: *"there's probably some [...] considerations about how to best position [...]"*. He envisioned that the sensor unit might be integrated into a smart vest or glasses in the near future.

Apart from these design challenges and considerations, NT3 also pointed out two concerns in implementing this visualisation in practice. The first is the potential *"embarrassment"* it might bring to teams of students who did not perform well, and this implies that extra thought would be needed regarding who to share the diagrams with and when to anonymise them. A second concern was about how effective this tool would be in regard to changing professional behaviours. While agreeing with the opportunities that can be created for professional learning and reflection, she also emphasised that more evidence would be needed to assess *"whether it would actually contribute to changing behaviours"*.

6 DISCUSSION

In this section we summarise the key findings of the study, share our critical reflections, consider the broader literature, and note the limitations of this work.

6.1 Implications for Supporting Sensemaking and Improving Teaching Practice

The key role that data may have on teachers' sensemaking is a rapidly growing topic of interest in the emerging field of learning analytics [14]. However, turning human activity and behaviour into data points does not guarantee that educational stakeholders will be able to do anything practical with it [80]. Spatial data bring additional challenges for sensemaking because the vast amounts of sensor data can be both overwhelming, and stripped of valuable contextual cues. As suggested by Campos et al. [14], there is a timely need for HCI and learning analytics communities to explore a broader range of instructional contexts and jointly enrich the typology of teachers' sensemaking of various learning data. Motivated by this, our study explored teachers' sensemaking of spatial data in a physics lab and a simulated hospital ward: two different educational contexts that both involve dynamic, embodied practice and require educators' reflection and analysis on spatial behaviors.

The responses we have been able to make to the first research question take the form of the vignette analyses presented in section 5.1. These demonstrate how the dandelion diagrams enabled teachers to differentiate classroom interactions whose differences were invisible in x-y heatmaps lacking body orientation cues. For example, the analysis associated with the data vignette related to proximity to classroom resources (section 5.1.1) illustrated how the dandelion diagrams aided teachers' reflection, but could also be used to inform learning spaces research and development. Thus, the dandelion diagram could be a key resource for designers, researchers and developers interested in the assessment of material features of emerging classroom spaces [96]. This suggests that classrooms could also be a meaningful application context for visual analytics of movement [6, 7] which has been predominantly focusing on studying geographic patterns (e.g., [6, 8, 37, 88]) or sports performances [63, 64, 90] from spatiotemporal data.

The dandelion diagram could also be used to characterise effective ways to approach students (see vignettes in sections 5.1.2, 5.1.3 and 5.2.1). This is important since it has been reported that teachers are often encouraged to co-teach in large open learning spaces without having developed the capabilities to collaborate with peers and use the space effectively [48]. The detection of f-formations and visualisation of the spatial data from teams of students looking after a simulated patient were useful to identify effective team workflows. With such analytics in place, it becomes possible to identify the patterns that characterise high effective teams in critical situations, as illustrated in the vignette presented in section 8, and as suggested in emerging literature [65].

The thematic analysis presented in section 5.3 showed how teachers benefited from the additional orientation cues to disambiguate the interpretation of the spatial behaviours. This surfaces a significant value of aggregating orientation data with the x-y positioning data: enabling the understanding of attention patterns. Existing visual analytics of spatiotemporal data have mainly focused on people's location, movement and trajectory patterns [21], for example, how crowds travel between metro stations [37], how players move in a soccer game [63], or how a visitor move across different spots of a museum [44]. Due to their analysis interest, orientation has been rarely represented separately from moving direction. Whereas, in this study, key design features of the dandelion diagrams, namely the spotlight metaphor and the density stacking, enabled teachers to characterise spatial (attentional) behaviours of the teachers such as monitoring or *"scanning"* the classroom versus remaining focused on a classroom resource or small groups of students. Teachers also envisaged how they could appropriate the visualisation tool into their regular teaching practice, mainly as a resource for self-inquiry and to train novice teachers. This is of particular importance in higher education where lecturers and teaching assistants often lack basic pedagogical training [31].

6.2 The Risk of Over-Interpretation

As illustrated in the previous section, teachers generally perceived the exploration of dandelion diagrams as a positive experience. However, we identified several instances of potential over-interpretation of the classroom situations based on the positioning data. Although teachers were often reminded that they were seeing only indoor positioning data, they attributed other meanings to these data in terms of the task or social aspects. This mainly occurred in Context B where teachers expect students to communicate effective in teams. For example, for the cases of the teams presented in Vignette B2 (section 8), teachers often interpreted the angle of spotlight as evidence of *verbal communication* with other people, instead of simple body orientation. For instance, NT1 often verbalised expressions such as: *"You can see nurse 3 is again 'communicating' with nurse 2 here* and *you can see there's a lot of 'collaboration and 'communication' between nurse 1, 2 and 3.* These two statements were refuted after inspecting the video footage. On other occasions teachers' over-interpretations did coincide with what actually happened, based on the video, because students are meant to communicate and collaborate according to the learning task, and it is expected that they do so especially when they stand face-to-face for some time. However, the problem of over-interpretation is not exclusive of the dandelion diagrams as it occurred also while teachers inspected the x-y coordinates and it has been reported as a widespread concern in the sector of learning analytics [3, 80]. It follows that if dandelion diagrams are to be embedded as either a teaching support tool, or for professional development, it is critical (as with all instruments) to clarify their scope: positioning data depicts only spatial behaviours, and verbal or video data are needed to make stronger inferences about collaboration or effective communication. We discuss under future work how such modalities could be added.

6.3 Ethics and the Risk of Harmful Surveillance

Cathy O'Neil [59] has documented the damage to teachers' employment conditions from automated assessments based on both poor data and black-box algorithms. The use of data in education should start from the premise that such data is commonly incomplete [40]. Therefore, we caution in the strongest terms against using visualisations of the sort presented here, with the purpose of summatively assessing the performance of teachers or students. In another study, teachers explicitly stated that positioning data about themselves should be shared with peers for the purpose of helping others' to learn from mistakes or 'good' practice [51], and this coincides with the uses of the dandelion diagrams envisaged by the teachers in our study, presented in section 5.3. Related to the risk of over-interpretation presented above, there are also potential concerns with further and unintended uses of sensor data for making decisions that can affect students, teachers or the broader educational systems. In that same study [51], teachers were against the use of positioning data to measure their performance, because the data can be easily misinterpreted by others who may not be aware of the context and other sources of evidence that are needed to gain a rich understanding of the complexity of classroom practices. In line with this and the present study, we encourage other researchers interested in the dandelion diagrams to use them only for supporting teachers, and for professional development purposes. Similarly, the surveillance of activities and the collection of classroom data must not harm student progress [85]. Our own future work is aimed at generating a deeper understanding regarding to what extent sensor data can complement the sensemaking process of classroom activity, and finding ways in which these data can be effectively used to support teaching and learning with integrity.

6.4 Limitations and Future Work

Our study presents some limitations. First, although the positioning data of teachers and students was captured in-the-wild (from authentic classroom settings), the exploration of the dandelion diagrams by the teachers was conducted under more controlled conditions. Future work should focus on exploring how teachers may use these visualisations as a regular part of their teaching practice either in real-time (in the classroom) or during authentic debrief sessions.

Second, our qualitative study focused on a small sample of authentic classes (i.e., two educational contexts featuring two classroom architectural designs). Future work can explore the capabilities of the dandelion diagrams to support reflection in other educational disciplines (beyond Health and Science education) and educational levels (e.g., primary or secondary schools), and for other classroom architectures.

Third, in our study, the dandelion diagrams were always explored by teachers after exploring the x-y coordinates data plots. The rationale was that given the qualitative nature of the study, we wanted to identify variations in the sensemaking process by disclosing body orientation data after the coordinates). We recognise, however, that the process of comparing the dandelion diagrams with a visualisation of data points, and asking open questions about them, could have reduced the opportunities for design innovation along new trajectories, as argued by Greenberg and Buxton [28]. Moreover, with a larger sample and a different study design, it would be possible to explore variations in the dandelion diagram features or other visualisation techniques representing the body orientation data for the purpose of usability evaluation. This further exploration goes beyond the scope of this paper, but is an avenue for future work to refine the design concepts introduced here.

Fourth, the positioning tracking system we used is just one of several alternative solutions that have been identified in the area of multimodal learning analytics (e.g., using video-based systems or beacons), indoor positioning tracking systems are rapidly evolving and dropping in price [95]. Therefore, further development work can focus on embedding the dandelion diagrams into a visual interface that teachers can directly interact with in real-time or for post-hoc reflection, regardless of the underlying positioning hardware used. Moreover, adding *interactivity* to the visualisations opens up new possibilities for focusing on subsets of data, for instance, how a particular student has interacted with others, while the addition of *animation* could show movement unfolding over time to clarify how f-formations grow and change.

Finally, as argued above, positioning and body orientation are just two features of many other ways in which people interact in physical learning spaces. Although in most teaching it remains impractical to replay the entire video recording of classroom activity, these clearly contain rich information not captured in dandelion diagrams, including the content of verbal interactions, body language, gaze and the actions students and teachers perform. These enable deeper reflection on higher-order competencies that go beyond the analysis of positioning behaviours (e.g., effective teaching, teamwork and leadership). Our future work envisages new ways to make more effective use of video recordings by using summary visual representations of classroom data, such as the dandelion diagrams, to navigate around, and highlight clips within, relevant video episodes to aid reflection.

7 CONCLUDING REMARKS

In this paper, we built on concepts underpinning *classroom proxemics* as the design rationale for a novel visualisation technique, the *Dandelion Diagram*, to visualise digital traces of the *x-y* positions, movement trajectories and body orientations of teachers and students in physical learning spaces. Through our qualitative analysis of teachers' feedback on these representations, drawn from two authentic learning contexts we addressed two research questions concerning the visualisation's support for teachers' sensemaking of their own and students' spatial behaviours, and the potential contribution of the visualisation technique for improving teaching practice. We conclude that teachers envisaged multiple potential uses of such data (i) for them to reflect on their own teaching; (ii) to support the development of teaching skills of novice teachers and teaching assistants without strong pedagogical training; (iii) the provision of feedback to students engaged in developing spatial capabilities in healthcare; and (iv) to support further research assessing the design of learning spaces, and in identifying effective workflows in both teacher and student teamwork.

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