Context-Aware Classrooms as Places for an Automated Analysis of Instructional Events

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Abstract. Context-Aware Classrooms (CACs), or ambient classrooms, are places in which instructional events can be captured and analyzed, thanks to advanced signal processing techniques. For CACs to be used for a better understanding of the educational events (teaching or learning), theoretically grounded approaches have to be reviewed and their main variables of interest presented. In this paper, three types of approaches to study the use of CACs (behavioral, ecological, and enactivist) are discussed, first theoretically, then about what each approach brings to the research on educational research. Some implications to build more ecologically-sound in presence or hybrid instructional sessions after the COVID-19 are drawn.

Keywords: Context-Aware Classrooms, Observation systems, Behaviorism, Ecology, Enactivism.

The COVID-19 pandemic has challenged education systems because remote instruction was to be quickly implemented at a large scale, often without specific guidance [1]. This sudden change did not allow stakeholders to properly take care about attendees' privacy, their disengagement [2] or negative emotional mood [3], and to get information to analyze and reflect about the situation [4]. Two years after this shift, it is time to take a step aside to try to build a novel ecosystem into which build both in-presence and hybrid instruction with would meet the following requirements: – accounting for more ecologically-sound places that allow various hybrid instructional situations; – using artificial intelligence-based tools to analyze behavioral, cognitive and emotional features more cautiously, notably in respecting attendees' privacy; – allowing in-depth teachers' reflection on their practice. A promising path is to consider the use of context-aware classrooms as containers to capture, observe and transmit instructional events.

Capturing and observing instructional events occurring in classrooms, for teachers and researchers, is a fruitful approach to help progresses, reflection and comprehension about these events. The first observation systems were human-based, then were assisted by a large range of tools or instruments, like audio recorders, video cameras, or mobile eye-trackers. More recently, ambient classrooms have become a sort of "meta-device" embarking these tools [5] either to make rooms more reactive to instructional events, or to engage deeper studies about the instructional and learning processes.

A Context-Aware Classroom (henceforth, CAC), also known as an ambient, ubiquitous, adaptive, intelligent, responsive, smart, or pervasive classroom, represents any physical environment in which instructional and learning events occur, and in which specific ways to capture and analyze these events are enabled. The data capture and analysis is supported by several digital devices using a very disparate bulk of models, techniques and tools: signal analysis and processing techniques, robotics, artificial intelligence, sensors, controllers, and effectors [6], or, simpler, many kinds of media [7]. In that way, they can help overcome human observers' attentional limits and some biases in the observation of instructional situations [8].

However, the very role of CACs is seldom elicited: ambient classrooms are built and tested for very different purposes, from triggering a specific device to measure classroom's climate. So far and broadly, the educational use of CACs is mainly behavior-centered, where the latter respond to some very shallow events (e.g., attendees are entering a room), akin to demoing materials, and solutionism [9] appears to be one of the main drivers. At second sight, CACs are rooms with ears and eyes and can either be seen as intensive surveillance tools [10], or tools to better understand instructional or learning events.

The question we will answer in this paper is how CACs can be used to have a better understanding of the educational events (teaching or learning), using theoretically grounded approaches, that would help build new ecosystems for a "post-pandemic new normality". The remainder of this paper is as follows. Section 2 gives an overview of the various variables to be observed in classroom events, either by humans or automated methods, embedded in CACs. Section 3 will introduce to three main theoretical approaches of classroom observation that can be implemented in CACs, and Section 4 will develop in more depth how these three types of CACs work.

1 Educational Variables Subject to Observation

What are the raw variables that can be observed in classrooms? Four main types of variables can structure the observational process [11]:

- *presage variables*, are about the teachers' characteristics that can have an effect in the instructional process, like their experience, their beliefs and knowledge. These variables can be investigated by questionnaire before or after observation sessions;
- *contextual variables*, are related to the classroom size, the material—they are often named "structural quality" [12]. These variables are easier to measure and to quantify than the other ones [13];
- *process variables*, are behaviors and events that take place in the teaching–learning context (often named "process quality"). Even though these variables are more difficult to perceive and analyze either by humans or machines, because they are mostly hidden and transient [14], they play a crucial role in students' achievement [15];
- *product variables*, or outcomes, are measurable consequences of the teaching–learning processes, such as students' achievement, attitudes, beliefs. These variables, often evaluative, are rather easy to collect and analyze digitally [16].

It is noteworthy that process variables can roughly pertain to three different categories [17]. *Socio-emotional support*, which encompasses the ways teachers promote a positive climate supporting students' autonomy and well-being. *Classroom and resource management*, which relates to the ways teachers manage students' behaviors and propose high-quality learning resources. *Cognitive and content-related*, which relates on the ways teachers support students' learning, creativity, and understanding of the taught content. We will focus on process variables, whose both the variability during instruction and their impact on learning are crucial. Some questions arise: Which theoretical perspective to adopt in studying them? Which are their pros and cons?

2 Classrooms as Context-aware: Three Theoretical Accounts

Technology-enhanced learning research is an under-theorized field [18]: roughly a third of the investigated research papers mention a theory explicitly. The lack of theories underlying the development of techniques or devices is harmful for the validity of the research done. Using a device or a computer-based system without being aware on the underlying theory can lead to solutionism: the implementation does not address any specific problems and can be seen as purposeless. Before detailing the different types of CACs it is worth discussing the most influential educational theories which can be invoked in the functioning of a CAC.

To make these theories more understandable and real-life related, let us take a real-life example. Sarah, a middle school mathematics teacher, teaches every Monday morning in a context-aware classroom. We will follow her to see how the theoretical perspectives would change the analysis of her classroom management and her students' activities.

2.1 Behavioral Approach

The most known approach is to consider that teachers and students are reacting to different stimuli in the classroom, these stimuli being triggered by humans or purely mechanical, as *external* forces. For instance, a ringing bell gives an information about the end of a lesson, and calls for getting out of a classroom; a teacher manages her classroom through various cues (facial expressions, comments, feedback), hereby preventing her students from engaging themselves in misbehaviors. Teachers use these methods very commonly. Four basic behavioral operations are promoted in classrooms [19]:

- *positive vs. negative reinforcement*, when a positive vs. negative stimulus is added contingently to a desired behavior vs. a misbehavior. For instance, badges or incentives are such positive reinforcers;
- *extinction*, when a behavior comes to decrease because its reinforcement decreases. For instance, students become less and less misbehaved because they do not get any advantage in their misbehavior, which is not recognized by the teacher over time;

- *response cost punishment*, when positive stimulus is removed upon undesirable behaviors. For instance, students who misbehave cannot be praised by their teacher any more;
- *punishment with aversives*, when a negative stimulus is added upon undesirable behaviors. For instance, a scholarship can be withdrawn to students who do not show up to exams.

The information flow of the behavioral approach, as typically implemented in CACs, is depicted in Figure 1. First, sensors get information (visual and auditory features, etc.) from the instructional scene, then its main features are processed to further infer the likely behaviors. The status—a psychological construct using behaviors as proxies—can then be determined, and effectors can trigger an action or assign tags to people or objects. This loop is enacted continuously and helps teachers and students do, for example, clerical tasks. Some process variables can still be captured with this approach, even though they are fully behavioral, like resource and classroom management-oriented. In Simondon [20] words, behavior-oriented CACs behave mostly as *tools*, which help action.

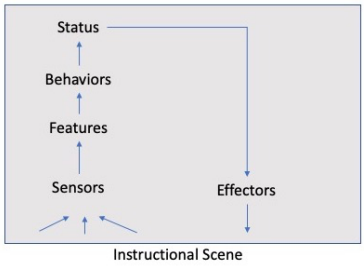

Fig. 1. CACs information flow in behavioral approaches.

Sarah's classroom: In this approach, Sarah and her students enter in the CAC and automatically trigger the lights on, the students' faces are automatically recognized, and an attendance report is sent to the school administration. When Sarah praises a student, the student's name is retrieved and she is given a credit in a specific badge (like in ClassDojo, https://www.classdojo.com).

This purely behavioral approach cannot be used neither to analyze cognitive processes, nor to account for the environment. The two following approaches are more devoted to these points.

2.2 Ecological Approach

In this second approach, stemming from ecological psychology, behavior is determined by the interaction of the individuals and the environment:

> "ecological psychology theories […] strive to explain the natural patterns of stimuli, both social and physical, which exist in the individual's immediate environment and subsequently impact the individual's behavior and experience." [21, p. 4]

People and other objects are considered as part in an environment, inserted into multiple perception–action loops mediated by devices. An individual perceives an element of the environment (e.g., an object, another individual) and exerts an action consequently, to continue to be well-balanced within the environment. In this approach, both internal and external forces are considered in interaction [22] and there is an interdependence between the people and the room's devices. This case entails that the *situated* perspective is crucial: the actual place where we are living plays an important role on the individuals' experience. For instance, a research showed that the likelihood that a group of students in a STEM (Science, technology, engineering, and mathematics) course are engaged in an activity is related to both the teachers' close presence and the frequency of her interaction with the group [23].

Information is gathered from the environment to take decisions. The "thinking body" is taken as point of departure, whereby teaching and learning are natural events occurring in a natural world [24]. Compared to the previous approach, both the classroom and the individuals' cognitions are relevant entities. Observational units are about social events that emerge from the analysis, and are not pre-established from the individuals point of view [25]. The behaviors are not purely disconnected, but connected to practice [24].

The main information–action flow in CACs within an ecological approach is depicted in Figure 2. Individuals trigger various perception–action loops in relation with the objects and other individuals with which and whom they interact, the greyed loops showing previously triggered loops. After Simondon [20], ecologically-oriented CACs behave mostly as *instruments*, which help perception.

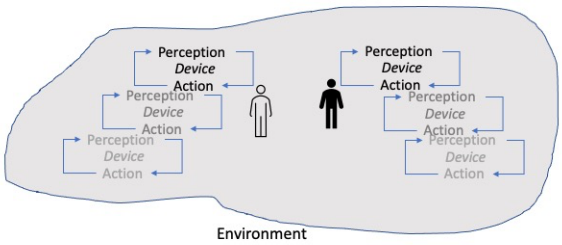

Fig. 2. CACs information-action flow in ecological approaches.

Sarah's classroom: In this approach, Sarah's and her students' behaviors are implicitly linked to each other because they are all immersed in the same environment. For instance, when Sarah leads a discussion about a given topic, participants' utterances obey to some implicit rules, like the following: 1. When an individual finishes her turn, she can select the next speaker, by a specific gaze or body orientation; 2. If no speaker is selected an individual can choose to speak (auto-selection) [26]. The environment's features are guides that ecologically constrain individuals' behaviors, even without explicit rules. In that case, a CAC can help observe and measure this turn taking in capturing and analyzing individuals' face orientation and body pose to predict turn taking [27].

2.3 Enactivist Approach

An enactivist approach considers that the changes in an individual do not lie in the individual or the changes by themselves, like in the previous approach, but by the interaction between the individual and the environment at *a personal and first-person level* [28]. Perception, cognition, and emotion are fully integrated with sensorimotor action [29], and knowledge emerges from this action. The immersed individuals perceive the other attendees and objects, and the observation units are not pre-established but are found through inquiry [24], through concrete experience and activity, being *coupled* to each others'. In that way, the individuals' practice emerges from the situation: they are led by the situation, they do not possess it [30]. Fundamentally, answering the question of how to teach in an enactivist way is trying to answer the question: "How is like to be a teacher or students in a classroom?"

As the previous, this approach is fully compatible with the multimodal analysis of the classroom environment [31], but needs a step further: the account of first-person perception within its environment. To data about attendees' location, speech, gesture, and posture, one has to add information about gaze, emotion or other physical-based measures (e.g., electrodermal) [30].

Figure 3 below depicts the main situation of individuals in CACs in an enactivist approach. Attendees' actions, equipped by devices that extend their capabilities, are coupled in the environment [32].

Sarah's classroom: In this approach, Sarah's and her students' perceptions, sensorimotor actions, emotions, are all involved and updated all along their action to build knowledge of the situation. Their posture, gestures, and speech, form traces of their practice as, respectively, teacher and students, and the artefact they use extend their mind. This approach is closer to the enactment of authentic activities and their capture and analysis is fully multimodal.

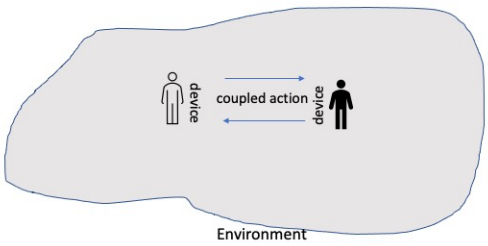

Fig. 3. CACs in enactivist approaches

3 What CACs can do?

In this section, we dive deeper on how a CAC can capture and analyze instructional events, and the limitations of each approach, notably in terms of privacy. Table I below summarizes the main characteristics of each approach: their behavioral account, the main scrutinized classroom variables, and their privacy compliance.

Table 1. Main characteristics of the observational approaches.

Approach	Behavioral account	Classroom variables	Privacy compliance
Behavioral	Isolated	Classroom & resource management	High
Ecological	External, 2nd person	Socio-emotional	Mid
Enactivist	Internal, 1st person	Socio-emotional & cognitive	Low

3.1 Behavior-centered CACs

From a purely behavioral standpoint, the role of a CAC is to capture elementary simple human behaviors and to trigger some events in turn. The application range of this view is already large: for instance, a CAC can react when a teacher enters and put lights and some devices on. It also can have some action recognition processes to assist attendees' actions [33], e.g., recognize teacher's gestures to adjust camera's focus.

Most of behavior-centered CACs gather some raw features of the situation to trigger a low-level information action or a label attribution, like students' attendance, students' badges, powering a device on or off, etc. Their goal is simply derived from computer-based learning analytics systems that gather and compute students logs to deliver raw feedback. These classrooms are based upon the idea that a large number of students can be scrutinized by the CAC (a teacher cannot pay attention to all the students' problems at the same time), and that the teacher can derive an overall management strategy from this log data [8].

The limitations encountered in the implementation of such CACs are as follows. First, they focus on the behaviors of some students (e.g., with special needs) because they occur more than others'. Second, the context in which behaviors are undertaken is often opaque and not captured, as behaviors are captured as isolated. Third, privacy concerns arise, since the attendees can be object to identification, but the intrusiveness of the approach is less important than this of the following approaches because fewer personal data is processed, from fewer people.

3.2 Ecological CACs

Ecological CACs are centered on the multiple social events occurring within them. For instance, video footages can be analyzed to provide information about some attendees' performance or status. In that vein, a recent study [34] investigated the teacher–students engagement behavior in classroom, double-coded by humans. A set of teachers' and students' behaviors was determined (e.g., writing, asking, pointing to the presentation) and their congruency over time was human-coded **(**e.g., a student who is writing when the teacher is pointing something on the board is likely to be disengaged), then a classifier automatically attributed a students' engagement score depending on the previous teachers' behavior. The results show that the classifier more accurately predicts engagement when previous teachers' behavior is accounted in the model and bound to students' own behavior. In that way, ecological CACs can be the place to implement a more thorough and direct behavior rating [8], and also be the place for testing more elaborated pedagogical practices, like active learning [35].

The problems encountered in the implementation of ecological CACs are the following. First, even if some contextual elements can be captured, the way they are actually perceived by the CAC's attendees is not accounted. Second, and compared to behavioral CACs, more data is gathered from the environment (e.g., video, location, posture) and explanatory models of activity relying on this data are needed to explain or predict attendees' behavior. Third, since more personal data is processed in this approach, attendees' privacy is hindered.

3.3 Enactivist CACs

Up to now, enactivist CACs *per se* do not exist yet, even though recent apparatus like mobile eye trackers [36, 37], electrodermal response trackers [31] or other types of sensors capturing various individual data, like pulsimeters, body temperature [38], as well as multimodal learning analytics capturing emotion and gaze recognition systems [39], can help gather and analyze instructional situations in an enactivist way: first-person-based and accounting for context more fully.

As a promising example of what an enactivist CAC could be, researchers [40] developed ACORN, a multimodal machine learning system that analyzes audio and video features of instructional events footages to infer classroom climate, as modeled in the Classroom Assessment Scoring System (CLASS) [41], a reliable and well-studied classroom observation system. The results showed medium correlations between human and machine coding on two CLASS dimensions (positive and negative climate). The intensive computer processing time needed in this approach prevents to deliver real-time information, which is a benefit since many of the information is very intrusive. This point is the most concerning about enactivist CACs, because the first-person data will allow to gather and infer privacy-related information about attendees.

4 Discussion

In this paper, we presented three theoretically grounded approaches to automatically capture and analyze instructional events in Context-Aware Classrooms. Since a large extent of research has been devoted so far to behavioral approaches, designing ecological or enactivist classrooms is a path towards a better understanding of classroom environments and of the many activities teachers and students undertake. More complex variables like socio-emotional and cognitive can be observed and analyzed. However, this benefit comes with a price, which is a huge processing of personal data hindering attendees' privacy. CACs as an instructional technology allows to shed light on some new research concerns: CACs as components of smart universities, CACs as distance learning places.

With the spreading of the Internet of things, an often-encountered story is to consider smart spaces as Russian dolls: several CACs compose a smart university, which in turn can be part of a smart city, etc. We consider CACs as first bricks of smart universities very cautiously: the intention to improve students' experience and learning comes can-

not be fulfilled by the massive capture of personal data, which can entail massive surveillance [42]. Our point is that the intensive processing power available could either be employed to obfuscate personal data at a group-level [43].

Even though classrooms are either places for direct instruction or more distant forms thereof, CACs are not a neutral media that simply deliver learning or teaching experience in distant places, and these two forms of instruction differ in many aspects (e.g., students characteristics, pedagogical strategies). Our point is that e-learning or hybrid situations need to be carefully designed for a sound integration in CACs and that our categorization may help, depending if the emphasis is on behaviors, ecology, or enaction.

Another crucial and final point is not to put teachers and students in the sideline by devising automated decision-making tools that replace teachers' care and empathy by sharper and colder CACs "decisions" [44]. Our point is to delivering CACs' analysis after lesson, to prevent from surveillance and cognitive load overwhelming. In this ways, the post-pandemic teachers and researchers would benefit from a novel place to capture, observe, and analyze instructional events more comprehensively.

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