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REVIEW ARTICLE

Eye-Tracking in Educational Practice: Investigating Visual Perception Underlying Teaching and Learning in the Classroom

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Abstract
Classrooms full of pupils can be very overwhelming, both for teachers and students, as well as for their joint interactions. It is thus crucial that both can distil the relevant information in this complex scenario and interpret it appropriately. This distilling and interpreting happen to a large extent via visual perception, which is the core focus of the current Special Issue. Six empirical studies present examples of how to capture visual perception in the complexity of a classroom lesson. These examples open up new avenues that go beyond studying perception in restricted and artificial laboratory scenarios: some using video recordings from authentic lessons to others studying actual classrooms. This movement towards more realistic scenarios allows to study the visual perception in classrooms from new perspectives, namely that of the teachers, the learners, and their interactions. This in turn enables to shed novel light onto well-established theoretical concepts, namely students' engagement during actual lessons, teachers' professional vision while teaching, and establishment of joint attention between teachers and students in a lesson. Additionally, one theoretical contribution provides the very first model of teachers' cognitions during teaching in relation to their visual perception, which in turn will allow future research to move beyond explorations towards hypothesis testing. However, to fully thrive, this field of research has to address two crucial challenges: (i) the heterogeneity of its methodological approaches (e.g., varying age groups, subjects taught, lesson formats) and (ii) the recording and processing of personal data of many people (often minors). Hence, these new approaches bear not only new chances for insights but also new responsibilities for the researchers.

Keywords Visual perception · Teacher · Student · Teacher-student interaction · Eye-tracking · Professional vision · Student engagement

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Classrooms full of pupils are dense of competing, transient information meaning that many things happen, they happen at the same time, and they happen fast (Doyle 2006). This is true from the perspective of the teacher, who has to monitor, manage, evaluate, and educate all pupils in a personalized way and at the same time (Berliner 2001, 2004; Livingston and Borko 1989). It is also true for the pupils themselves, who have to extract the relevant information from the teacher and the instructional material in order to learn, neglect irrelevant distracting behavior from their peers, but interact with them whenever necessary for their learning. On top of that, for both perspectives, the situation is not merely a passive one, but highly interactive and depending on their very own behavior. A necessary prerequisite for these complex classroom interactions is what the involved actors *see* and how they *interpret* it (i.e., visual perception, see also Sherin 2014; Van Es and Sherin 2002). The method of choice to study visual perception is eye-tracking (Holmqvist et al. 2011). Eye-tracking is the method to measure and record the movements of the eyes in relation to an external stimulus to learn what a person saw. Such recordings can be subsequently enriched with verbal protocols (Ericsson 2018) to investigate how this person interpreted what she/he saw, and thus, what she/he visually perceived. While eye-tracking is traditionally used in laboratory experiments, the visual perception in classroom scenarios as described earlier can hardly be captured in such controlled settings. The current Special Issue taps exactly into this niche by presenting innovative research approaching this complex, information-rich and dynamic real-life classroom setting with eye-tracking. In total, it comprises cutting-edge research in six empirical, one theoretical paper and two discussions, one from an educational science and one from an eye-tracking perspective.

In the following, we show how the contributions to this Special Issue enrich existing research, in which many ways they take innovative steps, and based on this, what promising avenues they address for future research. In a first step, the empirical contributions can be grouped methodologically allowing insights into new actor perspectives in the classroom. These new actor perspectives in turn shed new light into well-established theoretical concepts in a second step, in which ultimately this Special Issue is sorted. Both groupings, despite some limitations, offer opportunities for future research agendas to improve the understanding of the role visual processes play in educational practice.

Methodological Innovations—Gaining First Insights into New Actor Perspectives

Eye-tracking plays an increasingly vital role in educational science (Jarodzka et al. 2017; Lai et al. 2013) as it enables us to shed light upon the initial steps of human cognitive-information processing (i.e., visually taking in, integrating, and actively searching for information). Figure 1 clusters existing research (*dashed line*) and the articles of the current Special Issue (*continuous line*) into the actor perspective (teacher vs. learner vs. teacher-learner interaction) on a continuum of laboratory and real-life settings.

Starting off in the "learner" *box* is the "classical" eye-tracking research in Educational Sciences. This is where most of the research has been conducted and published thus far. Here, we find a plethora of studies investigating the underlying visual perception of one single learner who processes more or less artificial learning material in an eye-tracking laboratory (Lai et al. 2013). From this research, we can deduce, for instance, how to improve the instructional design of multimedia learning and testing material (Jarodzka et al. 2017).

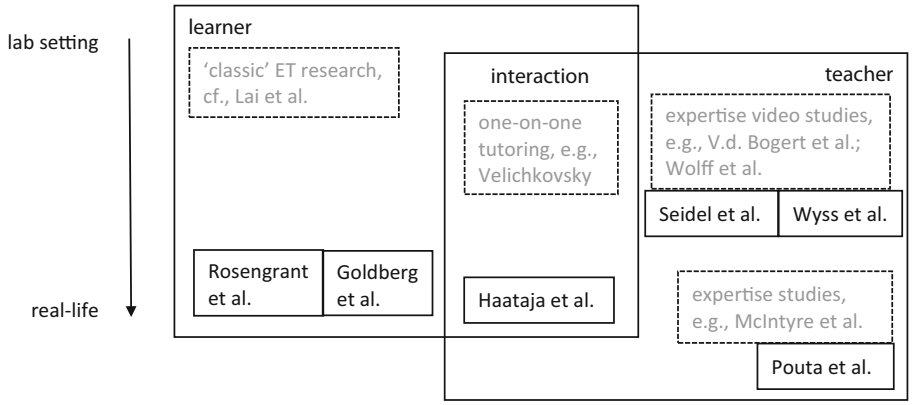

Fig. 1 The role of visual perception in diverse actor perspectives during actual classroom teaching

Previous research, however, indicates that such a learning scenario does not necessarily translate into learning in a classroom, both in terms of learning outcomes (Skuballa et al. 2019; Zambrano et al. 2019) and visual perception (Oliva et al. 2017). Therefore, it is a sensible and critical step to investigate learners' visual perception during learning in an authentic classroom scenario. Two articles within the current Special Issue address this aspect. Rosengrant, Hearrington, and O'Brien used mobile eye-trackers with six to eight university students over a course of several lectures to investigate how the distribution of students' visual perception changes over time. Eye-tracking learners within an authentic educational setting over a longer period of time are truly original and novel. We hope to see more studies of this type in the near future which help us understand to which extent research findings from the laboratory can be transferred into teaching classrooms. At the same time, a closer look at the educational practice in real classrooms will stimulate new research questions arising from these authentic scenarios. Processing datasets from classrooms is time-consuming and can easily overburden researchers. Goldberg, Sümer, Stürmer, Wagner, Göllner, Gerjets, Kasneci, and Trautwein tap into this issue and offer a solution. They studied university students' visual perception within an authentic lecture, albeit with a regular video recording. The innovative aspect of this study is the use of machine learning to automatically analyze these video recordings allowing to draw conclusions on learners' visual perception. The innovative and charming aspect of this approach is its potential to conduct research in educational practice, where video recordings of large numbers of learners are far more feasible than eye-tracking a constant and small number of students.

Moving forward to the "teacher" *box*, we can place video-based eye-tracking research on teachers' professional vision. This research builds upon well-established eye-tracking research into visual expertise from other domains (Gegenfurtner et al. 2011; Sheridan and Reingold 2017). First research into teachers' visual expertise (also called professional vision; Goodwin 1994) shows that with increasing experience, teachers are capable of picking up visual cues from video recordings of authentic classroom lessons (Van den Bogert et al. 2014; Wolff et al. 2016; Yamamoto and Imai-Matsumura 2013) and interpret them appropriately (Wolff et al. 2015, 2017). In the current Special Issue Wyss, Rosenberger, and Bührer enrich the existing literature by comparisons of the eye-tracking and verbal data from teacher trainers to student teachers. This type of research bears two benefits: (a) deeper understanding of teachers' professional vision and how it develops, (b) broader understanding of what and

how teachers are supposed to visually perceive in contrast to what experienced, but not necessarily good teachers perceive. Since years of teaching do not guarantee good teaching practices, understanding what a teacher trainer visually perceives provides an idea of what teachers are supposed to perceive. Similarly, Seidel, Schnitzler, Kosel, Stürmer, and Holzberger show video clips of authentic classroom lessons to more- versus less-experienced teachers. The truly new aspect of their study is the unique combination of eye-tracking with diagnoses of pupils' behavior and elaborations on that. More of such research could strengthen our understanding of the role visual perception plays for teachers in evaluating their own pupils. Moving from the laboratory to the authentic classroom, the so-called mobile eye-tracking is the method of choice (for more information on this methodology, see Wade and Tatler 2005). Mobile eye-tracking allows capturing teachers' visual perception *during* teaching in real and their own classrooms instead of only passively observing video clips of other teachers' teaching. First studies have shown that in this interactive, dynamic environment, teachers' visual perception of the classroom plays a key role in classroom management and teaching (Cortina et al. 2015; McIntyre et al. 2017, 2019). In the current Special Issue, Pouta, Lehtinen, and Palonen captured not only frontal teaching—as the few studies conducted before—but also focused on episodes of pupil-teacher interactions. For these episodes, the authors investigated teachers' visual perception of the situation including what they looked at (via eye-tracking) and how they interpreted it (via retrospective verbal protocols). More mobile eye-tracking research would allow us to understand how teachers' visual perception comes to play in the very act of teaching (for methods to capture teachers' in-action cognitions, see Crasborn et al. 2010).

The "interaction" *box* is thus far the most understudied aspect. The only laboratory studies on interactive gazes have studied a one-on-one situation that were not necessarily in educational contexts, but showed the key role of visual perception in gaze interaction (Nüssli and Jermann 2012; Shvarts and Abrahamson 2019; Velichkovsky 1995). In the current Special Issue, Haataja, Salonen, Laine, Toivanen, and Hannula present the—to our knowledge—the first publication on joint eye-tracking of pupils and teachers within authentic lessons in a classroom. With the help of multiple mobile eye-tracking glasses, a specifically developed analysis software, and the coding of classroom videos, the authors were able to describe when which actors look at each other and, thus, seek information from the other. As this was only a very first case study, much more research is needed to understand when and why pupils and teachers look at each other in the course of teaching and learning. This could reveal the role of gaze in non-verbal communication.

The new wave of research is marked by new technologies allowing us to leave the laboratory behind us and step into real-life teaching classrooms. In sum, we can observe a tendency to move from a strong focus on a mere student-on-material-perspective towards authentic classroom situations. There are no conventions related to methods, reporting, data analyses, and study design, etc., because these studies are breaking new ground in the area of educational sciences. Finally, newest developments include teacher-student interactions by successfully combining synchronizing both perspectives. These new methodological approaches do not only open the possibilities to study new actor perspectives within the classroom but also to shed light on new theoretical concepts as discussed in the following section. It is important to note, though, that apart from the upper part of the left box ("learner": classic ET research) existing research is extremely scarce. Hence, all research in the remaining boxes (parts) are very much needed to reach an understanding of the role of visual perception in classrooms.

Conceptual Innovations—Gaining Novel Insights into Established Theoretical Concepts

The above-described methodological novelties that enabled new perspectives on the events occurring in a classroom also rendered it possible to shed light on theoretical concepts that were thus far hardly accessible to studies in educational practice.

Learner Perspective A substantial amount of research has already been conducted on the role visual perception plays when learners interact with their instructional material in a laboratory setting (Jarodzka et al. 2017; Lai et al. 2013). However, little is known about the role of learners' visual perception in the educational practice. To our knowledge, the current Special Issue for the first time emphasizes this aspect. Seidel at al. studied to which extend it is possible to deduce students' engagement and their underlying characteristic profiles (e.g., strong, struggling, underestimating) from mere visual observation. The authors showed that experienced teachers can do so quite proficiently thereby also contributing to our knowledge on teachers' professional vision (see next section), while beginning teachers struggle with it. The study of Goldberg et al. adds to this picture. Based on their findings, we can assume that beginning teachers could be supported by machine learning algorithms when trying to detect student engagement from video recordings. Such a tool could be used in teacher training to support beginning teachers in their development of professional vision and help them improve detecting students' engagement. Rosengrant et al. have studied students' engagement directly by eye-tracking them in real lectures for a longer period of time. These authors showed that—at least on a university level—students' engagement in the lecture is higher than often expected by practitioners (De Bruyckere et al. 2015) and that, despite fluctuations, students' visual attention can remain high in long-lasting lectures. Of course, more research is needed to study students' engagement in educational practice, but these three studies indicate already that this seems to become a fruitful avenue.

Teacher Perspective The role of teachers' visual perception has already been the subject of research under the term "professional vision" (Goodwin 1994; Sherin 2014). Thereby the emphasis is put on the difference between seeing/noticing events in the classroom and interpreting/reasoning about them appropriately (Feldon 2007; Van Es and Sherin 2002). While we know from large amounts of research that the role teachers play for students' learning is key, we also know that not only beginning teachers suffer from underdeveloped professional vision (Sabers et al. 1991) but also experienced teachers do not see everything that is happening in the classroom (Nuthall 2005). Still, the field of research on measuring teachers' professional vision directly with eye-tracking is relatively new as was shown by a recent review referencing no more than ten thus far published studies (Beach and McConnel 2019). Wyss et al. investigated how teacher educators detected (measured via eye-tracking) and interpreted (measured via verbal reports) critical incidents happening in a classroom as seen on a video recording. In line with the little prior research in this specific area (e.g., Van den Bogert et al. 2014), they found evidence that the combination of eye-tracking and verbal reports has the potential to capture differences between more- and less-experienced teachers, in particular for those who have detected the critical incident. Only this combination of methods truly allows not only to understand what and where a teacher looked at but also why. However, as most of this research only used a very limited number of video examples, far more research is needed to describe in depth this observatory aspect of professional vision in teachers and

how it develops. In the future, such research might even result in enriching the assessment of student teachers based on video recordings of classrooms (Seidel et al. 2010) by taking into account in even more detail what these teachers see. Wolff, Jarodzka, and Boshuizen provide for the first time a detailed theoretical framework for this emerging research field (for a more global model, see Lachner et al. 2016). This model describes teachers' classroom management scripts incorporating organized knowledge and perception with their effects on situational awareness and representations of classroom events. The authors do this by contrasting novice and expert teachers. This model can not only help to synergize existing research into a broader picture but also clearly point towards new research avenues that need to be taken up. It is important to note the lack of specific theoretical models in the field of cognitive and perceptual processes underlying teachers' classroom behavior, which thus had to borrow from adjacent fields, which did not allow for specific predictions. The model by Wolff et al. can be indeed the breaking point as it will allow future research for the first time to go beyond mere explorations towards hypothesis-driven research to improve and expand the model presented by the authors.

Learner-Teacher Interaction Already from a very young age on, humans are able to infer where other persons are looking, simply by looking at their eyes (Antsis et al. 1969; Farroni et al. 2002). We can also use our gazes to direct another person's eyes towards something or someone (Brooks and Meltzoff 2002; Corkum and Moore 1995). This phenomenon is crucial to learning; it is called "joint attention" (Baldwin 1995; Bloom 2002; Brooks and Meltzoff 2005). Even though such form of non-verbal communication plays a pivotal role in learner-teacher interaction (called "overlapping' in teaching": Banbury and Hebert 1992), it is surprising, how little research has been done on this topic thus far (for exceptions, see McIntyre et al. 2019). In the current Special Issue, two articles tackled this topic. First, Pouta et al. investigated how and when experienced and student teachers establish joint attention with their pupils during lessons. Interestingly, the authors showed that apart from other differences in their professional vision, both groups used different moments during their instruction of fractions in mathematics to establish joint attention with their pupils. That indicates that knowing when and how to establish joint attention with your pupils might also be a part of teachers' professional vision. It would be very interesting to study in the future, whether this also holds true for teaching other subjects. Second, Haataja et al. went one step further in studying the role of joint attention during actual teaching in a classroom by combining both the teacher's and the learners' visual perception (as measured by eye-tracking). The authors found that the joint attention between teachers and their pupils depends on situational differences, as well as on teachers' agency and communion (cf. Gurtman 2009). Obviously, far more research in real classroom during actual teaching is needed to truly understand the role of joint attention during teaching and learning. These two studies, however, have shown us the potential eye-tracking has to bring us one step closer to this understanding.

Open Questions

Above, we outlined which actor perspectives are thus far understudied and stress the need to move towards ecologically valid real-life classrooms. Additionally, we describe which theoretical concepts surrounding the role of visual perception during teaching and learning in the

classroom still need to be explored by future research. However, two issues need to be addressed before this research can thrive.

First, as can be seen in the existing studies, but also in the novel studies presented in the current Special Issue, this type of research attempts the balancing act between experimental and methodological rigorousness on the one hand, and the complexity and uncontrollable nature of an authentic classroom full of pupils. As much as it is tried to "squeeze" participants' data into (quasi)experimental conditions (e.g., experienced vs. novice teachers), it is important to keep in mind that each participant is an individual interacting without restrictions with other individuals. Also, even if it is considered to re-record the same classes with the same teachers, each lesson will somehow differ from the one before. Hence, this type of research will always retain a lot of confounding factors by its very nature. Another result of this balancing act between experimental research and classroom practice is that most studies are conducted under very different circumstances in terms of the subject taught, the age group of the learners, their gender, the teaching form, etc. It is very likely that all of these factors influence the visual perception of the involved actors which make a generalization of findings difficult. For instance, reading a text in a language lesson will require different viewing patterns than a hands-on biology class where pupils experiment themselves. It is difficult thus, to draw conclusions from one study to another, albeit not impossible as has been recently pointed out for expertise research by Boshuizen et al. (2020) through knowledge restructuring by processing cases.

Second, since the EU General Data Protection Regulation came in place in March 2018, this sort of already very effortful and difficult data collection came almost to a hold due to new legal regulations. Eye-tracking data recordings in a classroom intrinsically include plenty personal data not only from the participants under investigation (e.g., the teacher wearing the eye-tracking glasses) but also from everyone else who is in the visual field of the eye-tracked participant (i.e., all pupils and other colleagues in the classroom). As explained above, it is highly essential to conduct this sort of research with school children. In such cases, however, not only the children themselves need to give permission to be recorded through the glasses of the teacher but also their parents. It is easy to recognize that this is a cumbersome procedure (in a class with 25 pupils, 51 signed consents have to be collected, 25 by the pupils, 25 by their parents, 1 by the teacher) in order to record one participant. Innovative approaches are needed to prevent that researchers will withdraw themselves from these complications and move back to artificial laboratory scenarios with adult university students as participants. Among those approaches, it seems particularly promising that researchers in educational science join their forces to collaborate (a) with important stakeholders in educational practice (e.g., teachers, school boards, parents) and involve them stronger into the research, and (b) with ethicist and lawyers to work on solutions that enable research while protecting personal data from recorded persons. We have to keep in mind that with new technologies come new possibilities, but also new responsibilities.

The current Special Issue has shown the necessity to study the visual perception of both teachers and learners within authentic instructional settings to truly understand its role in educational practice. Eye-tracking has shown to be a powerful tool, thus far mainly known for its application in laboratory research, to capture the processes of visual perception even in the field. Given that researchers manage to overcome the here identified challenges, this line of research has the potential to bridge the gap between educational research and practice and shed light upon key processes underlying learning and teaching that were in the shadows thus far.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

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