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# EYE TRACKING IN EDUCATION

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## Abstract

*Relevance:* Eye tracking, understood as a method for recording eye movements, gaze fixations, and selected oculomotor parameters, is now widely recognized as an important tool for investigating visual attention and cognitive processing. This article outlines the development of the method from pioneering studies of reading and visual perception to its contemporary interdisciplinary applications. Particular attention is paid to the use of eye tracking in education, especially in research on learning from text, images, and multimedia materials, in studies of expertise, and in the diagnosis of students' cognitive difficulties. A brief section was devoted to presenting selected works by the interdisciplinary Cognitive Didactics Research Group, established by the author at the Pedagogical University of Kraków.

*Purpose:* to analyze the development of eye tracking as a method for studying eye movements and to determine its significance and potential applications in educational research, particularly for investigating the cognitive processes of pupils and students.

*Methods:* theoretical analysis of scientific sources on eye-tracking issues, generalization of contemporary studies in the field of education, and presentation of the results of empirical studies conducted by the Research Group on Cognitive Didactics, which applied oculography, electroencephalography, heart rate variability analysis, and other non-invasive methods.

*Results:* it was found that eye tracking is an effective tool for investigating visual attention, cognitive strategies, and information-processing methods during learning. The method makes it possible to analyze how students read texts, interpret graphs, images, video materials, and solve tasks. Differences between expert and novice strategies were identified, as well as the possibility of diagnosing cognitive difficulties and the перспективність of using eye tracking for designing effective learning materials and supporting the educational process.

*Conclusions:* eye tracking occupies an important place among modern methods for researching educational and cognitive processes, as it allows the study not only of learning outcomes but also of the course of thinking activity. Combining eye tracking with other diagnostic methods contributes to a deeper understanding of learning processes and opens broad prospects for improving pedagogical practice and educational theory.

**Keywords:** eye tracking, education, neurodidactics, oculography.

**Introduction.** Investments in the quality of education are among the most cost-effective public investments, as even a moderate improvement in learning outcomes translates, in the long term, into increased productivity and prosperity (Hanushek & Woessmann, 2015). If we wish to genuinely improve the quality of education, we must ensure the quality

of teacher training. The modern teacher should be familiar with the basic principles governing cognitive processes, attention and memory, and understand the limitations and possibilities arising from the neurobiological determinants of learning.

In this context, increasing attention is being paid to neurodidactics, an interdisciplinary

perspective that brings together didactics, cognitive psychology, and neuroscience. One of the principal popularizers of this approach is widely considered to be the German mathematician Gerhard Preiss, who developed the concept of neurodidactics at the turn of the 1980s and 1990s (Friedrich & Preiss, 2003). In Poland, these issues began to gain clearer visibility toward the end of the twentieth century (Błasiak, 1996).

Recent decades have witnessed the rapid development of non-invasive methods for studying the brain. The most important of these include electroencephalography (EEG), functional magnetic resonance imaging (fMRI), structural magnetic resonance imaging (MRI), magnetoencephalography (MEG), and functional near-infrared spectroscopy (fNIRS). These techniques make it possible to investigate, respectively, electrical activity, hemodynamic processes, and brain structure, and they now constitute the basic toolkit of modern neuroimaging (Yen et al., 2023).

Within this broader context, eye tracking occupies a distinctive position. It is not a technique for measuring brain activity directly, but rather a tool for recording visual behavior, from which one may infer the dynamics of attention, cognitive strategies, and modes of information processing. In research practice, it therefore serves as a particularly valuable complement to neurocognitive studies, especially where perception and problem solving must be examined under relatively natural conditions.

**Purpose:** to analyze the development of eye tracking as a method for studying eye movements and to determine its significance and potential applications in educational research, particularly for investigating the cognitive processes of pupils and students.

**Methods:** theoretical analysis of scientific sources on eye-tracking issues, generalization of contemporary studies in the field of education, and presentation of the results of empirical studies conducted by the Research Group on Cognitive Didactics, which applied oculography, electroencephalography, heart rate variability analysis, and other non-invasive methods.

**Sources.** *A Brief History of Eye Tracking.* Eye tracking, that is, the recording of eye movements and gaze-fixation points, is now one of the key methods for studying visual attention,

perception, and cognition. The origins of this field date back to the nineteenth century, when researchers began to ask whether the eye moves smoothly during observation or instead performs rapid jumps separated by brief stops. Louis Émile Javal is regarded as one of the pioneers of this line of research: as early as 1879, he described the discontinuous character of eye movements during reading. These observations laid the foundations for later studies of vision and text processing (Wade & Tatler, 2011; Tatler et al., 2010).

A major contribution to the development of the field was made by Edmund B. Huey, who constructed one of the first devices capable of tracking eye movements during reading. His studies were groundbreaking because they showed that the analysis of eye movements could provide insight not only into the act of seeing itself, but also into text comprehension and the unfolding of cognitive processes (Huey, 1908; Hessels et al., 2025).

Another important stage is associated with the work of Guy T. Buswell, who analyzed the ways in which people inspect pictures and demonstrated that observers do not distribute their attention evenly across the visual field, but instead concentrate on selected elements. Equally influential were the studies of Alfred L. Yarbus, who showed that eye movements depend not only on the properties of the stimulus itself, but also on the observer's goal and the task being performed. The same image may therefore be viewed in strikingly different ways depending on the cognitive intention guiding observation (Tatler et al., 2010).

In the second half of the twentieth century, eye tracking became an important method within cognitive psychology. A particularly significant role was played by Keith Rayner's studies of reading, which demonstrated that eye movements make it possible to trace information processing almost in real time (Rayner, 1998, 2009). As the technology advanced, invasive techniques were gradually replaced by modern remote systems that are more accurate and much easier to use.

Today, eye tracking is an interdisciplinary method used in psychology, neuroscience, linguistics, human-computer interaction, marketing, medicine, and education. Researchers no longer examine only fixations and saccades, but also time to first fixation, scanpaths, regressions, and changes

in pupil diameter. As a result, eye tracking has become an important instrument for investigating

attentional mechanisms and cognitive strategies (Hessels et al., 2025).



**Fig. 1.** Heat map of the author's gaze fixations in Kraków's Main Market Square.

*Eye Tracking in Education.* In recent years, eye tracking has assumed particular importance in educational research. Learning very often involves selecting and organizing visual information: a student reads a text, interprets a graph, analyzes an illustration, watches a video, or integrates information from several sources. Recording eye movements therefore makes it possible to investigate not only the outcome of learning, but also the course of the cognitive process itself what the student looks at, how long attention is sustained, and how gaze shifts between different elements of the material (Jarodzka et al., 2017).

One of the main areas of application of eye tracking in education concerns research on learning from text, images, and multimedia materials. Eye-tracking data make it possible to determine whether students attend to relevant elements, overlook important information, or successfully integrate text with an illustration, diagram, or graph. For this reason, the method is particularly well suited to studies of cognitive load and multimedia learning (Alemdag & Cagiltay, 2018; Scheiter & Eitel, 2016). Eye tracking is equally useful in analyses of learning from video materials, where it enables researchers to

examine the dynamics of visual attention during viewing (Deng & Gao, 2022).

Second important area concerns research on expertise. Comparisons between novice learners and more advanced individuals show that experts identify relevant information more quickly, attend less frequently to secondary elements, and employ more economical scanning strategies. This has clear didactic significance, because it helps explain how information processing changes as knowledge and experience develop (Jarodzka et al., 2017).

Eye tracking is also used, at times, as a tool for supporting learning. A good example is provided by eye movement modelling examples, in which students observe the material together with a recording of an expert's gaze path. Such solutions can help direct attention toward the most relevant elements and support the development of more effective cognitive strategies, although their effectiveness depends on both the type of task and the learner's level of preparation (Jarodzka et al., 2013; van Marlen et al., 2021).

Applications of eye tracking in the teaching of mathematics, science, and technical subjects are especially promising. The method makes it possible to investigate how students read tasks, interpret

graphs, diagrams, and equations, and integrate different representations of knowledge. In this way, it becomes possible to identify the points at which cognitive difficulties arise and to design teaching materials more effectively. Recent review studies indicate that eye tracking is becoming an important tool for investigating learning processes in science education and, more broadly, for research on the design of effective instruction (Chytry et al., 2025; Tóthová & Rusek, 2025).

At the same time, eye-tracking data require cautious interpretation. The mere fact that a learner looks at a given element does not in itself imply full understanding. Eye tracking is therefore best treated as a complementary method, to be combined with achievement tests, interviews, analyses of students' verbal statements, or think-aloud protocols. Despite these limitations, it remains one of the most promising tools in contemporary educational research, because it opens access to processes that are usually invisible to both teacher and researcher (Jarodzka et al., 2017; Chytry et al., 2025).

**Results and Discussion.** *From the Experience of the Kraków Research Team.* In 2014, I founded the Cognitive Didactics Research Group

at one of the faculties of the Pedagogical University of Kraków. The group brought together computer scientists, physicists, mathematicians, chemists, biologists, and educators. We conducted research using eye tracking, EEG, HRV, EDA, facial-expression analysis, and other non-invasive measurement techniques. Among these approaches, oculography was used particularly extensively, because it is relatively non-invasive, highly useful in educational research, and well suited to analyzing the work of pupils and students while solving tasks. An example characteristic of this line of inquiry is presented below.

Fig. 2 presents the distribution of a participant's gaze fixations while solving the following problem: "A pond is becoming overgrown with duckweed. Every two days, its surface area doubles. The entire pond was covered within 64 days. After how many days was one quarter of the pond covered?" This is one of many examples among hundreds of recorded eye trajectories registered during task analysis and decision-making. It can be clearly seen which elements of the problem statement required greater attention.

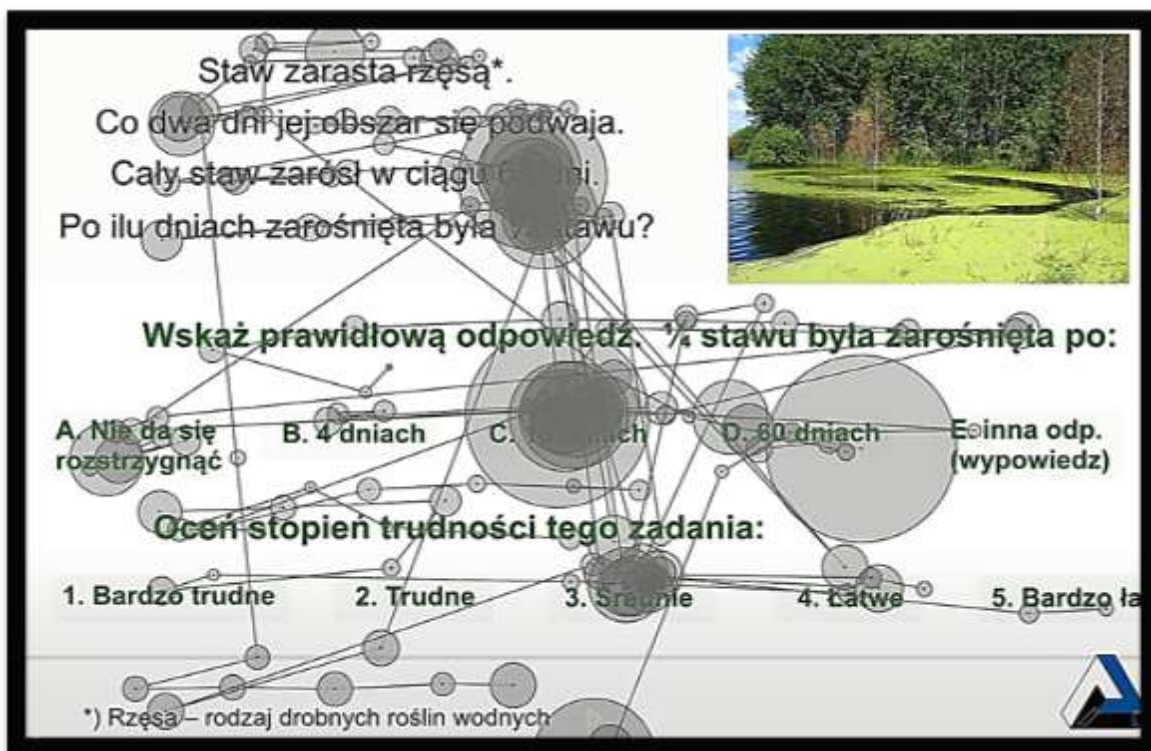


Fig. 2. Gaze fixations and scanpaths recorded while solving the duckweed-overgrowing-the-pond problem.

One of the inspirations for initiating eye-tracking studies was the work of Adrian Madsen and his collaborators on differences between experts and novices in problem solving. The Kraków research team subsequently undertook numerous projects on strategies for solving tasks in mathematics, physics, and computer science, on the analysis of visual representations, and on changes in pupil diameter and other oculomotor parameters during the reading and interpretation of educational materials.

An important feature of this work was the integration of didactic, cognitive, and experimental perspectives, which made it possible to treat eye tracking not merely as a technical instrument, but as a method for investigating the actual thinking strategies of pupils and students (Błasiak et al., 2013, 2015). Traditional methods such as tests, questionnaires, or interviews usually capture only the final outcome of a student’s activity, whereas eye tracking makes it possible to analyze the process of perception and information processing itself.

A particularly important line of research concerned the solution of tasks requiring the analysis of a drawing, diagram, or other graphical representation. The results showed that oculography makes it possible to distinguish between expert and novice strategies and to identify the moments at which cognitive difficulties emerge. Through the analysis of fixations, saccades, and scanpaths, it

becomes possible to determine whether a student is focusing on relevant data or whether attention is being diverted by secondary elements (Rożek et al., 2014).

Another interesting area of research conducted in the Kraków group involved the analysis of how algorithms presented in the form of flowcharts and pseudocode are read. It was shown that the form of representation influences both the course of visual attention and the effectiveness of task solving. The results confirmed that the formal notation typical of programming languages may constitute a practical cognitive barrier even in relatively simple tasks, especially when students have not yet developed appropriate strategies for analyzing the material (Andrzejewska et al., 2016).

A further important line of research concerned the perceived usefulness of physics formulas. In co-authored studies, we analyzed how students assessed the importance of selected formulas and how these declarations related to the actual course of their visual attention. The use of eye tracking made it possible to show that students’ subjective opinions are not always consistent with their actual cognitive processing (Pęczkowski & Błasiak, 2017). Fig. 3 shows the visual eye trajectories of a student answering the following question: “Choose those formulas that, in your opinion, will be useful to you in life.”

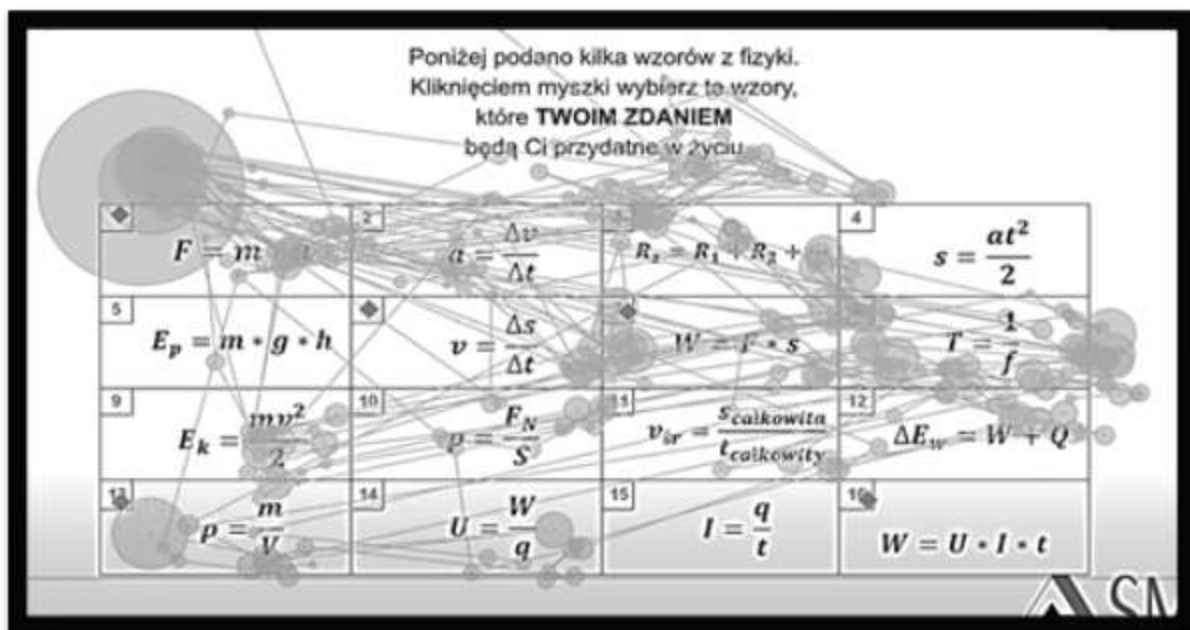


Fig. 3. Gaze fixations and scanpaths recorded while selecting the formulas that the student considered useful

Experiments were also conducted on selected oculomotor parameters and changes in pupil diameter during reading. In a study involving individuals aged 8 to 79 years, fixation times and parameters of saccadic movements were examined, among other variables. These studies broaden the educational applications of eye tracking by adding a developmental and biometric perspective, showing that gaze analysis may be useful not only for investigating problem-solving strategies, but also for diagnosing perceptual conditions associated with age (Kazubowski & Błasiak, 2021).

Members of this research group emphasized the need to integrate eye-tracking data with broader didactic, psychological, and subject-specific reflection. In this way, eye tracking became not only a measurement technique, but also a tool for a deeper understanding of the processes of learning and teaching in mathematics and science education (Stolińska et al., 2014).

**Conclusion.** Eye tracking now holds an established place among the methods used to investigate cognitive and educational processes. Its development from the first observations of eye movements in the nineteenth century to contemporary high-precision eye-tracking systems

clearly shows that gaze analysis can provide valuable information about attention, cognitive strategies, and modes of information processing. In education, this method makes it possible to understand more fully how students read, analyze graphs, interpret illustrations, and solve problem-based tasks.

The particular value of eye tracking lies in the fact that it makes it possible to investigate not only the outcomes of learning, but also the course of the cognitive process itself. In this way, it can support both theoretical research and educational practice, especially in the design of educational materials and in the diagnosis of students' difficulties.

The studies discussed here show that oculography can be effectively applied to the analysis of problem-solving strategies, to the ways in which visual representations are read, and to the cognitive determinants of learning. It may therefore be concluded that eye tracking remains one of the most promising methods in contemporary educational research, and that its further development may significantly enrich both educational theory and teaching practice.

### Conflict of Interest

The author certifies that no conflict of interest (financial, professional, or personal) exists that could have influenced the objectivity of the research results or conclusions. The integrity of the double-blind peer review process was ensured through a mandatory declaration of the absence of conflict of interest submitted via the journal's editorial system. This protocol guaranteed complete author anonymity and the independence of the expert evaluation throughout the entire editorial cycle.

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# ВІДСТЕЖЕННЯ РУХІВ ОЧЕЙ В ОСВІТІ

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## Реферат:

*Актуальність.* Ай-трекінг, що розуміється як метод запису рухів очей, фіксації погляду та вибраних окуломоторних параметрів, нині широко визнається важливим інструментом для дослідження зорової уваги та когнітивних процесів. У статті окреслено розвиток цього методу від піонерських досліджень читання та зорового сприйняття до його сучасних міждисциплінарних застосувань. Особливу увагу приділено використанню ай-трекінгу в освіті, зокрема в дослідженнях навчання за текстами, зображеннями та мультимедійними матеріалами, у вивченні експертності, а також у діагностиці когнітивних труднощів студентів. Окремий розділ присвячено представленню вибраних праць міждисциплінарної Дослідницької групи з когнітивної дидактики, створеної автором у Педагогічному університеті Кракова.

*Мета:* проаналізувати розвиток ай-трекінгу як методу дослідження рухів очей та визначити його значення і можливості застосування в освітніх дослідженнях, зокрема для вивчення когнітивних процесів учнів і студентів.

*Методи:* теоретичний аналіз наукових джерел з проблематики ай-трекінгу, узагальнення сучасних досліджень у сфері освіти, а також представлення результатів емпіричних досліджень Дослідницької групи з когнітивної дидактики, у яких застосовувалися окулографія, електроенцефалографія, аналіз варіабельності серцевого ритму та інші неінвазивні методи.

*Результати:* встановлено, що ай-трекінг є ефективним інструментом для дослідження зорової уваги, когнітивних стратегій і способів обробки інформації під час навчання. Метод дає змогу аналізувати, як студенти читають тексти, інтерпретують графіки, зображення, відеоматеріали та розв'язують задачі. Виявлено відмінності між стратегіями експертів і новачків, можливість діагностики когнітивних труднощів, а також перспективність використання ай-трекінгу для проектування ефективних навчальних матеріалів і підтримки навчального процесу.

*Висновки:* ай-трекінг посідає важливе місце серед сучасних методів дослідження освітніх і когнітивних процесів, оскільки дозволяє вивчати не лише результати навчання, а й перебіг мисленнєвої діяльності. Поєднання ай-трекінгу з іншими методами діагностики сприяє глибшому розумінню процесів навчання та відкриває широкі перспективи для вдосконалення педагогічної практики й освітньої теорії.

**Ключові слова:** ай-трекінг, освіта, нейродидактика, окулографія.

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