



UNCOVERING LOWER SECONDARY SCHOOL STUDENTS' APPROACHES DURING BIOLOGICAL OBSERVATION

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Abstract. *Biological observation requires students to distinguish task-relevant morphological features from irrelevant visual information. However, little is known about how lower-secondary school students allocate attention while solving image-based biological tasks. This study examined observational approaches using eye-tracking. Seventy-five students completed 18 feature-identification tasks across fauna, flora, and microscopic life. Hierarchical cluster analysis of standardised eye-tracking metrics, supplemented by qualitative inspection of scan paths, identified four observational approaches: Quick Targeting (54.1%), Diagnostic Scanning (27.2%), Instruction-Guided Search (10.2%), and A Thorough Wander (8.5%). More than 72% of students showed one dominant approach across most tasks. Observational approach was associated with task performance, although the association was small ($\chi^2 = 29.00$, $df = 18$, $p = .048$, Cramér's $V = .085$). Diagnostic Scanning and Quick Targeting showed the highest mean scores (5.54 and 5.52 out of 6), whereas A Thorough Wander and Instruction-Guided Search showed lower scores (5.28 and 5.21). Longer viewing was not associated with better performance. Higher task performance was instead associated with attention to task-relevant morphological features. These findings support explicit visual guidance and systematic comparison of diagnostic features in image-based biology observation tasks.*

Keywords: *eye-tracking, science process skills, scientific observation, secondary education, visual literacy*

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Introduction

Observation is a fundamental component of school biology, yet it is also potentially problematic. Students are frequently expected to identify organisms, compare specimens, and recognise morphological features from visual material, although merely looking at a biological object does not ensure that diagnostically relevant information will be noticed or correctly interpreted. This distinction is particularly important in biology, where learning often depends on differentiating subtle visual characteristics and relating them to biological concepts. The ability to observe biological organisms is an important component of biological learning because scientific observation requires learners to identify, describe, and interpret relevant characteristics rather than merely register visually salient information (Eberbach & Crowley, 2009; Klemm et al., 2020; Kohlhauf et al., 2011).

Scientific observation requires students to selectively attend to biologically relevant features rather than register what is visually salient (Eberbach & Crowley, 2009; Stoskopf, 2005). In this sense, observation forms part of the procedural dimension of scientific literacy. Students need not only conceptual knowledge, but also the ability to obtain and evaluate information through scientific practices (OECD, 2017, 2023; Zoller, 2012). Developing such skills is therefore an important component of science education yet may still be treated as a relatively self-evident activity rather than a scientific skill requiring systematic development and explicit support (Agustiani et al., 2020; Eberbach & Crowley, 2009; Kohlhauf et al., 2011).

A particular challenge in biology education is that relevant biological features of organisms are not always visually salient. Students may have to distinguish a subtle diagnostic characteristic from other, more conspicuous but task-irrelevant information. Scientific observation consequently requires coordination between what is visually available, what the task requires, and what the observer already knows (Eberbach & Crowley, 2009).



Nevertheless, visual observation is still frequently treated in educational practice as relatively self-evident (Mason et al., 2013). Teachers and instructional materials may implicitly assume that directing students' gaze towards an organism, a microscopic image, or a biological diagram is sufficient for them to identify the feature considered important by an expert (Ainsworth et al., 2011; Schönborn & Anderson, 2006). Research on visual attention has challenged this assumption and has shown that gaze location and information processing are related but not equivalent: fixation indicates where visual attention is directed, but it does not by itself establish how the observed information is interpreted or understood (Hyönä, 2010; van Gog & Scheiter, 2010). Thus, a student may look at a task-relevant region without necessarily identifying the biological feature that makes that region diagnostically important. This issue becomes especially important when learners encounter visually complex material and are uncertain about which features deserve attention (Allen, 2025; Eberbach & Crowley, 2009).

Previous research has examined students' difficulties with observation, visual representations, and attention in science learning (Eberbach & Crowley, 2009; Lai et al., 2013; Mason et al., 2013), but considerably less is known about the recurring observational approaches (in this paper, the term is used for observational approaches that lower-secondary students use when they solve biological feature-identification tasks). In particular, it remains unclear whether students employ distinguishable observational approaches and whether these approaches are associated with task success. Eye-tracking provides a way to examine the distribution and sequence of visual attention during task solving alongside students' final responses. The present study uses eye-tracking to identify observational approaches employed by lower-secondary students during biological feature-identification tasks and to examine their association with task performance.

Theoretical Background: Observation as a Key Scientific Skill

Scientific observation is one of the core process skills through which students engage with empirical phenomena and generate information that can subsequently be interpreted, compared, measured, or used as evidence (Harlen & Qualter, 2018; Padilla, 1986). Within science education, observation therefore contributes to the procedural dimension of scientific literacy and provides an important link between direct engagement with phenomena and the development of scientific explanations (Abrahams & Reiss, 2012; Eberbach & Crowley, 2009). Tasks involving the observation and comparison of biological objects can provide opportunities to develop scientific observation by requiring students to attend to and compare observable characteristics (AAAS, 1993).

Scientific observation is not equivalent to simply looking at an object. It is purposeful and guided by the question being addressed, the characteristics of the observed phenomenon, and the observer's prior knowledge (Chalmers, 2013; Klemm et al., 2020). Compared with unstructured everyday looking, scientific observation requires greater systematicity and selectivity because observers must determine which of the many visually available characteristics are relevant to the purpose of the observation (Eberbach & Crowley, 2009; Yurumezoglu & Oztas Cin, 2019). Observation has consequently been conceptualised as an active and theory-informed process in which perceptual information is selected and interpreted in relation to existing knowledge (Brewer & Lambert, 2001; Hanson, 1981). In biological tasks, this may involve distinguishing a subtle morphological feature from visually salient but diagnostically irrelevant characteristics and relating the observed feature to an appropriate biological category or explanation (Eberbach & Crowley, 2009; Lowe, 1993). Observation thus supports subsequent processes such as measurement, data interpretation, and scientific reasoning rather than functioning as a purely sensory act (Priemer & Hellwig, 2018; Wan, 2023).

Previous research has shown that learners do not always manage this selection and interpretation effectively. Studies of secondary and university students have documented difficulties in dealing with observational uncertainty and visually complex empirical material (Priemer & Hellwig, 2018; Schang et al., 2023; Vignal et al., 2023). Research on the epistemological framing of data has investigated how students understand measurement variability and observational evidence (Kanari & Millar, 2004; Rosenberg et al., 2022), while analyses of observational errors have shown how incorrect interpretations can reveal features of students' reasoning (Allchin, 2012; Priemer & Hellwig, 2018). Research on visual attention has further demonstrated that learners may attend to perceptually salient characteristics, such as colour or size, while overlooking less conspicuous but diagnostically relevant features (Harsh et al., 2019; Mukherjee et al., 2020). This difficulty is particularly relevant for novice observers, who have less developed domain knowledge with which to organise and prioritise visual information. Allen (2025) has described the resulting challenge in terms of "perceptual uncertainty". Previous research has shown that, in the absence of sufficient domain knowledge or instructional support, students' visual search may become broadly distributed, inefficient, or strongly dependent on textual guidance (Hannus & Hyönä, 1999; Lowe, 1999; Mason et al., 2013).

The interpretation of gaze patterns is commonly informed by the eye–mind hypothesis, which links fixation with ongoing information processing (Just & Carpenter, 1980). However, eye movements indicate the spatial and temporal allocation of overt visual attention rather than a specific cognitive process. Their interpretation therefore depends on the task and domain and should, where possible, be considered alongside performance or other complementary data (Hyönä, 2010; Schindler & Lilienthal, 2019).

This distinction is also relevant to the educational assumption of “visual transparency”. Biological images, specimens, and diagrams may appear self-explanatory to experts because experience enables them to recognise diagnostically important structures rapidly, whereas the same features may not be immediately meaningful to students (Ainsworth et al., 2011; Schönborn & Anderson, 2006). Consequently, fixation on a relevant region does not necessarily imply that the learner has recognised its diagnostic significance. Similarly, failure to solve a task correctly does not reveal where in the observational process the difficulty occurred. Conventional outcome measures provide information about the final response but only limited information about how visual attention was distributed during the solution process (Jarodzka et al., 2021).

Less is known about recurring patterns of visual search among lower-secondary students when they distinguish biological features. Examining these patterns requires information about how students distribute attention across task instructions, organisms, and diagnostically relevant regions. Such information can help determine whether differences in performance are associated with selective inspection of relevant features, broadly distributed visual search, repeated attention to instructions, or other observable patterns of task engagement. It can also contribute to understanding how visually complex biological material imposes demands on learners’ limited cognitive resources (Sweller et al., 2019).

The Use of Eye-Tracking to Understand Students’ Skills

Traditional assessments of observational skills primarily evaluate the outcome of observation through students’ written, verbal, or practical responses. Eye-tracking complements these measures by recording the spatial and temporal distribution of visual attention during task solving (Hyönä, 2010; Strohmaier et al., 2020). Based on the eye–mind hypothesis, fixation location and duration are commonly treated as indicators of where visual attention is allocated during information processing (Carpenter & Just, 2017). Measures such as fixation counts, fixation durations, and saccadic transitions can therefore be used to characterise how learners visually explore a task and how their attention moves between different sources of information (Holmqvist et al., 2011; Lai et al., 2013; Schindler & Lilienthal, 2019). Accordingly, this study uses eye-tracking to characterise visual-search behaviour and relate it to independently measured task performance.

Educational eye-tracking research has been used to investigate visual expertise and problem solving in a range of domains, including medical image interpretation (Gegenfurtner et al., 2011; Kundel, 2007), science graph and diagram comprehension (Harsh et al., 2019; Mason et al., 2013), and natural science problem solving (Jarodzka et al., 2010; Lai et al., 2013). Across these contexts, previous studies have generally found that greater expertise is associated with more selective allocation of attention to task-relevant information, whereas novices are more susceptible to perceptually salient but less relevant features (Lowe, 1999; Ozcelik et al., 2010). These findings suggest that the organisation of visual search can provide meaningful information about how learners approach visually demanding scientific tasks. Nevertheless, younger learners, including lower-secondary students, remain considerably less represented in educational eye-tracking research than university students, and eye-tracking has been used comparatively less often in biology education (Tóthová & Rusek, 2025).

The present study addresses this problem by using eye-tracking to examine students’ visual behaviour during controlled biological feature-identification tasks. Rather than treating individual fixation measures as direct indicators of conceptual understanding, the study focuses on recurring patterns in the distribution and sequence of visual attention. It relates these patterns to independently measured task performance.

Research Aim and Research Questions

This study examines which recurring observational approaches lower-secondary students employ when identifying biological features and how these approaches are associated with task performance. Eye-tracking data were collected while students solved tasks adapted from the feature-recognition subscale of the Observational Skills Test (OST) (Hašpl & Vojříř, 2024, 2025a). The tasks included examples from fauna, flora, and microscopic life.

Specifically, this study addresses the following research questions:

RQ1: What observational approaches do lower-secondary school students employ when identifying morphological features of organisms?

RQ2: What is the relation of the employed observational approaches and secondary school students' task performance in identifying morphological features of organisms?

By recording the distribution and sequence of visual attention during task solving, this research aims to address a gap in current knowledge regarding how lower-secondary students navigate visual biological stimuli. Identifying these observational approaches provides empirical insights relevant to biology education, including the design of instructional support for observational skills and visually balanced biological assessment tasks.

Research Methodology

Design

This quantitative study uses eye-tracking to examine observational approaches during biological task solving and their association with task performance. Data were collected in July and August 2025 using a controlled, screen-based task environment. The analysis was conducted at the level of individual task solutions. For each task solution, the task score was matched with eye-movement measures describing the distribution of visual attention. These indicators covered the task instruction, organism images, morphologically relevant regions, and diagnostic features.

The analysis proceeded in three stages. First, eye-tracking metrics were extracted and standardised separately for each task. Second, these metrics were used to identify recurring observational approaches through cluster analysis. Third, the identified approaches were compared in terms of their eye-movement characteristics, their consistency within individual participants, and their association with task performance.

Sample

The study included 75 lower-secondary school students (ISCED level 2) from schools in different regions of the Czech Republic. The analyses were conducted on their individual task solutions. Participants were drawn from metropolitan centres, regional towns, and smaller municipalities to increase the sample's geographical and socio-demographic heterogeneity. All participants agreed to study participation. The participant sample size was comparable in scale to those used in educational eye-tracking research (Gegenfurtner et al., 2011; Lai et al., 2013). In addition, data saturation is proposed as a useful basis for evaluating participant sample size in scene-viewing eye-tracking. Hoogerbrugge et al. (2025) showed that the additional information provided by each new participant decreases progressively and becomes limited once gaze-distribution and AOI estimates have stabilised. The present sample was above the sample sizes at which this diminishing-return pattern became pronounced in their empirical analyses.

Data collection was carried out in a quiet, secluded place to minimise external distractions. Each student was seated individually in an adjustable chair at a viewing distance of approximately 65 cm from a high-resolution display monitor (1920 x 1200 pixels). Eye movements were recorded using a professional screen-based eye-tracker, the Tobii Pro Fusion, operating at a sampling rate of 250 Hz and mounted unobtrusively directly below the PC display.

Instrument

The study used an eye-tracking adaptation of the feature-recognition subscale of the Observational Skills Test. The instrument underwent pilot testing and expert validation in previous research (Hašpl & Vojříř, 2024, 2025b). The selected tasks were modified for use with eye-tracking technology. To ensure optimal discriminative power and avoid ceiling or floor effects, tasks selected for the eye-tracking adaptation met a medium-difficulty criterion: tasks with prior student task performance ranging from 30% to 70%. The final eye-tracking instrument consisted of 18 tasks preceded by one practice task designed to familiarise participants with the visual environment and procedure.

Each task was presented on a single screen using the same visual structure. A written instruction specifying the morphological feature to be identified appeared across the upper part of the screen. Below the instruction, six high-resolution colour photographs were presented simultaneously in a 2 × 3 grid. The photographs were numbered 1–6 to allow participants to report their selections unambiguously.

The required feature occurred only in a subset of the six photographs. Participants therefore had to inspect all relevant specimens and independently determine whether each image did or did not contain the specified feature.

A task consequently required not only the detection of a salient visual element but also the discrimination between diagnostically relevant morphological information and other visually available characteristics.

Biological Categories & Selection Principles

The 18 tasks represented a broad range of biological material and were distributed across three major domains: fauna, flora, and microscopic organisms or tissues. The fauna tasks included vertebrate and invertebrate groups; the flora tasks included gymnosperm and angiosperm taxa, and the microscopic category included microorganisms and histological material. The specific taxonomic groups were selected to expose participants to different types of morphological structures and visual-search demands.

Four principles guided stimulus construction. First, the tasks were designed to minimise reliance on memorised taxonomic knowledge. For this reason, European species that were non-native to the Czech Republic and absent from the lower-secondary curriculum were selected. Second, organisms shown within a task belonged to the same taxonomic order but different genera, thereby increasing overall visual similarity and requiring relatively fine morphological discrimination. Third, photographs of living organisms in natural settings were used wherever applicable to preserve realistic biological variability; taxidermy specimens, herbarium material, and artificial models were avoided. Fourth, the instructions used accessible descriptive language rather than specialised biological terminology so that performance depended primarily on observation rather than prior vocabulary knowledge.

Experimental Procedure

Before data collection began, the eye-tracker was calibrated individually using a nine-point calibration procedure. Participants for whom satisfactory calibration could not be achieved were excluded from the study. Participants then completed one practice task to become familiar with the screen layout, the type of task instruction, and the verbal response procedure. They subsequently completed the 18 experimental tasks in the same predetermined order.

For each task, the researcher displayed it after receiving a verbal indication from the participant that they were ready to proceed. They were required to identify all photographs containing the specified morphological feature. Task-solving time was unlimited, and participants received no feedback on the correctness of their responses during the experiment.

No manual response using a mouse or keyboard was required. Once a participant had reached a decision, the selected image numbers were reported verbally. A second researcher positioned outside the participant's direct field of view recorded the response. This procedure was used to minimise additional eye and hand movements associated with operating an input device and to preserve continuity of visual processing during task solving (Holmqvist et al., 2011; van Gog & Scheiter, 2010). On average, participants spent 5 min 10 s completing the experimental tasks.

Task Scoring

Each of the six photographs presented in a task was treated as an independent decision point. Students earned one point for each correct decision, defined as either accurately identifying and selecting a target image displaying the required feature, or correctly leaving a non-target image unselected (yielding 0–6 points per task).

This element-level scoring procedure enabled partial task success to be represented rather than classifying the entire task as simply correct or incorrect. For example, a participant who correctly classified five of the six photographs received five points even if one target feature was overlooked. This provided a more differentiated measure of task performance for subsequent analysis of its relationship with visual-search behaviour.

Eye-Tracking Data and Metrics Preparation:

Areas of Interest

AOIs were defined separately for each task prior to statistical analysis. The AOI structure reflected different levels of visual information available during task solving:

- the Instruction Area, containing the written task instruction;

- the Image Area, comprising the six organism photographs;
- six Individual Image Areas, one for each photograph;
- Relevant Areas (RA), representing broader morphological regions within which the task-relevant feature could occur;
- Relevant Features (RF), representing the precise diagnostic feature needed to classify an image correctly.

The distinction between RA and RF enabled differentiation between viewing a generally relevant anatomical region and directly inspecting the diagnostic characteristic itself. When corresponding relevant areas or features occurred multiple times within a task, aggregated AOIs were created using categorical tags (Holmqvist et al., 2011; Jarodzka et al., 2010; van Gog & Scheiter, 2010).

Eye-Tracking Metrics

Eye-movement measures were extracted at both global and local levels. Fixation measures included total fixation duration and fixation count, along with the corresponding mean, minimum, and maximum values for the relevant AOIs. Saccadic measures included the total number of saccades, saccades within the instruction and image areas, transitions between the instruction and images, and transitions between individual organism photographs.

For task-specific relevant AOIs, summary metrics were calculated only from AOIs actually present in the given task. Non-existent feature AOIs were not coded as zero values, as doing so would artificially reduce the mean values for tasks containing fewer relevant regions or diagnostic features.

Data Analysis: Data Preprocessing and Standardisation

Raw eye-tracking data were exported in TSV (Tab-Separated Values) format and initially processed in Microsoft Excel. The data were transformed from a wide format to a long format, in which each row represented an individual participant–task solution. This allowed gaze measures and task scores to be matched at the level at which observational behaviour occurred. The final analytical dataset comprised 1350 participant–task solutions, with each of the 75 participants completing 18 tasks.

Because the 18 tasks differed in their visual composition, number and size of AOIs, and baseline viewing characteristics, continuous eye-tracking measures were standardised separately within each task. Each value was converted to a z-score relative to all participants who completed that task. Where a metric showed zero variance within a task, a z-score of 0 was assigned. Task-wise standardisation reduced baseline differences among tasks before cluster analysis, so that clustering was based on relative differences in eye-tracking measures rather than raw differences between tasks (see Gegenfurtner et al., 2011; Wickham, 2014). All subsequent statistical analyses were conducted using IBM SPSS Statistics.

Identification and Comparison of Observational Approaches

Distributional properties of the standardised eye-tracking variables were first examined visually and using Shapiro–Wilk and Kolmogorov–Smirnov tests. Because the distributions deviated significantly from normality ($p < .001$), non-parametric methods were used for subsequent comparisons.

Recurring observational approaches were identified by hierarchical cluster analysis using Ward's linkage method and squared Euclidean distance. The solution retained for interpretation was determined by considering cluster size, differentiation of mean standardised eye-tracking profiles, and the interpretability of the resulting behavioural patterns.

After clusters were established, differences in individual eye-tracking variables among the identified approaches were tested using the Kruskal–Wallis test. Significant omnibus effects were followed by Dunn's pairwise post-hoc comparisons with Bonferroni adjustment. Effect sizes were expressed as epsilon-squared and interpreted according to established guidelines (Tomczak & Tomczak, 2014).

Association with Performance and Within-Participant Consistency

Two additional analyses examined how the identified approaches related to individual participants and to task performance. First, the frequencies with which each participant used the different observational approaches



across tasks were tabulated. The association between participant identity and observational approaches was then examined using a chi-square test of independence, with Cramér's V used to quantify the strength of association.

Second, the association between the observational approach and task performance was examined using a chi-square test of independence. Task performance was represented by the obtained task score (0–6 points), and Cramér's V was used as a measure of effect size. This analysis examined whether task success differed depending on the observational approach employed during a given task.

Visual Confirmation of Clusters

To visually validate and ground the empirical cluster profiles, individual gaze trajectories (scan-paths) were generated using Tobii's I-VT (Fixation) filter (see Olsen, 2012). A qualitative analysis of these spatiotemporal scan paths was conducted to evaluate whether the recorded visual search paths directly mapped onto the quantitative cluster profiles. Two independent researchers examined representative gaze trajectories across the task items. This qualitative examination, with inter-rater agreement among the researchers, served as an additional interpretative check on the cluster profiles, illustrating how distinct observational approaches systematically align with the statistical cluster boundaries (see Saldaña, 2016).

Research Results

Observational Approaches

Initial visual inspection of eye-movement trajectories was conducted across all analytical units, comprising $N = 1350$ individual task solutions. Analysing data at the task-solution level rather than at the individual participant level enabled the capture of intra-individual variation in observational approaches across different items. Students began by reading the task instruction before inspecting the organism photographs. After this initial step, visual-search behaviour differed substantially in duration, fixation frequency, and transitions among AOIs. The order in which students inspected the six photographs also varied across task solutions. Hierarchical clustering of the eye-tracking metrics identified four observational approaches: *Quick Targeting*, *Diagnostic Scanning*, *A Thorough Wander*, and *Instruction-Guided Search*. Qualitative inspection of scan paths was consistent with these cluster profiles. Kruskal-Wallis tests showed that the four identified observational approaches differed significantly across all recorded eye-tracking parameters ($p < .005$, with test statistics ranging from $H(3) = 13.02$ to 963.66 and effect sizes $\epsilon^2 = .01$ to $.71$). Finer subdivisions were rejected because they either produced subclusters that differed only in magnitude or resulted in very small clusters ($<0.4\%$). Furthermore, uniformity of task representation across the four clusters was confirmed, with each task accounting for 3–10% of cluster entries ($SD = .01-.02$), ensuring that clusters reflected students' observational approaches rather than task-specific artefacts.

Cross-tabulation of observational approach usage per participant revealed a strong, statistically significant association between individual students and their selected observational approaches ($\chi^2 = 948.30$, $df = 222$, $p < .001$, Cramér's $V = .484$). Over 72% of students relied on a single dominant observational approach for the majority of their assigned tasks, demonstrating high intra-individual solution-approach stability. *Quick Targeting* was the most frequently used approach, chosen by 68% of participants, followed by *Diagnostic Scanning* (19%), whereas *A Thorough Wander* and *Instruction-Guided Search* were utilised primarily as secondary or task-dependent adaptations.

Observational Approach 1: Quick Targeting

Quick Targeting was the dominant observational approach, accounting for 54.1% of all analysed task solutions ($n = 730$). It was characterised by rapid scanning, targeted identification of relevant morphological features, and swift decision-making without detailed verification. Compared with *A Thorough Wander*, *Instruction-Guided Search*, and *Diagnostic Scanning*, this approach showed significantly lower values across all recorded Areas of Interest, including overall task duration, fixation counts, fixation durations, and number of saccades ($p < .001$). Solvers focused almost immediately on the primary visual features, did not return to the task instructions, and rarely verified their decisions by repeatedly scanning or systematically inspecting all six organism photographs.

Example of a Solution: The scan path shows rapid reading of instructions followed by a brief visual sweep across the photographs. The student skipped Photograph 5 and did not return to review all six photographs. Five of the six decisions were correct (see Figure 1).

Figure 1*Examples of Visual Search Trajectories for Quick Targeting and A Thorough Wander*

Note. Quick Targeting (green) – A Thorough Wander (orange).

Observational Approach 2: A Thorough Wander

A *Thorough Wander* accounted for 8.5% of all task solutions ($n = 115$) and was characterised by detailed but non-selective inspection of most or all organism areas. Compared with *Quick Targeting*, it showed significantly higher values across all global metrics ($p < .001$), including longer total viewing and processing times, more viewing locations, longer fixation durations, and more frequent transitions between specimens. Fixation metrics were above average in both relevant and non-relevant organism areas, indicating substantial visual effort without clearly focused observation. Nevertheless, fixation metrics within diagnostic Relevant Features were significantly lower than in *Diagnostic Scanning* ($p < .001$). This pattern reflects an exploratory search trajectory in which fixations were broadly distributed across diagnostic and non-diagnostic anatomical structures rather than selectively directed towards relevant features.

Example of a Solution: The trajectory displays high-density fixation clusters scattered broadly across all plant organs (flowers, stems, leaves). The solver focused heavily on salient non-diagnostic features (purple flower colour) rather than critical leaf traits, resulting in low decision accuracy (1 out of 6 items correct) (see Figure 1).

Observational Approach 3: Instruction-Guided Search

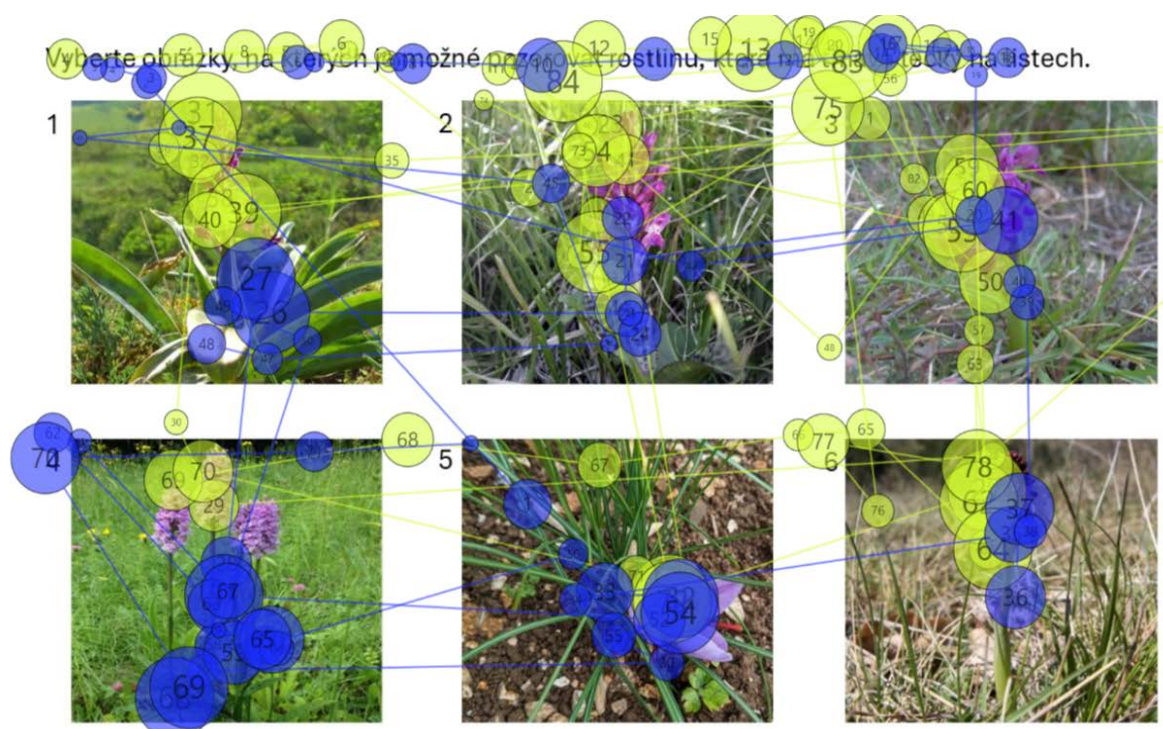
Instruction-Guided Search accounted for 10.2% of all task solutions ($n = 138$). It was characterised by intensive reading and re-reading of the instructions, which directed attention towards broad relevant image areas but did not lead to the identification of specific diagnostic features. Solvers spent an above-average amount of time on the tasks, similarly to those using *A Thorough Wander*, and differed significantly from all other approaches by showing the highest engagement with the task instruction, reflected in greater fixation duration, fixation count, and saccade count ($p < .001$). They repeatedly shifted between the instruction text and broad specimen areas, indicating

difficulty translating verbal descriptions into fine-grained visual feature identification. Although minimum and maximum metrics within individual broad relevant areas were statistically comparable to *Diagnostic Scanning*, fixation counts and durations within specific diagnostic Relevant Features were significantly lower ($p < .001$) and generally below average.

Example of a Solution: The scan path shows repeated re-inspection of key instruction phrases (“dark dots”). Visual processing was successfully directed to vegetative organs, but fixations remained concentrated on dominant stems rather than fine leaf spot patterns, leading to partial accuracy (2 out of 6 items correct) (see Figure 2).

Figure 2

Examples of Visual Search Trajectories for Instruction-Guided Search and Diagnostic Scanning



Note. Instruction-Guided Search (yellow) - Diagnostic Scanning (blue).

Observational Approach 4: Diagnostic Scanning

Diagnostic Scanning was the second most frequent approach, accounting for 27.2% of all task solutions ($n = 367$). It was characterised by selective visual search in which solvers directed greater attention to diagnostic Relevant Features than to general non-diagnostic areas. Their overall visual effort was above average and comparable to *Instruction-Guided Search*, but they spent less time and made fewer fixations on the task instructions, similarly to *Quick Targeting*. Returns to the instructions were infrequent and comparable to observational approaches 1 and 2. Unlike *Instruction-Guided Search*, solvers successfully progressed from broad target areas to specific diagnostic features. Fixation durations, fixation counts, and saccade frequencies within the Relevant Feature AOIs were consistently above average and significantly higher than in the other approaches ($p < .001$), indicating a systematic visual search characterised by greater allocation of attention to task-relevant biological structures and comparatively less attention to non-diagnostic regions.

Example of a Solution: The trajectory reveals focused instruction reading (“dark dots on the leaves”) followed by systematic, detailed inspection restricted specifically to leaf surfaces across photographs. This diagnostic focus yielded perfect correctness (6 out of 6 items correct) (see Figure 2).

Relation of Observational Approach and Task Success

A statistically significant relationship was established between the applied observational approach and task performance ($\chi^2 = 29.00$, $df = 18$, $p = .048$, Cramér's $V = .085$). Although the overall effect size was small, attenuated by high baseline student success and sample size imbalances across clusters, clear performance trends emerged across the 6-point task scale.

Observational approaches focused directly on morphological traits yielded the highest overall performance. Specifically, *Quick Targeting* and *Diagnostic Scanning* achieved similar, superior outcomes:

- *Quick Targeting* showed high task performance (score ≥ 5 out of 6) in 91% of task solutions, a perfect score in 76%, and a mean task score of 5.52.
- *Diagnostic Scanning* showed high task performance in 92% of task solutions, a perfect score in 75%, and a mean task score of 5.54.
- *A Thorough Wander* showed high task performance in 85% of task solutions, a perfect score in 70%, and a mean task score of 5.28.
- *Instruction-Guided Search* showed high task performance in 86% of task solutions, a perfect score in 67%, and a mean task score of 5.21.

These findings highlight that the two approaches associated with the highest mean task scores represented different observational approaches. *Quick Targeting* was characterised by relatively low overall viewing effort, whereas *Diagnostic Scanning* involved greater selective attention to Relevant Feature AOIs. By contrast, *A Thorough Wander* involved greater overall visual effort distributed across relevant and non-relevant regions, while *Instruction-Guided Search* was characterised by comparatively high engagement with the task instructions. These two latter approaches showed somewhat lower mean task scores. Overall, the association between observational approach and task performance was statistically significant but small, indicating that the observed differences in performance across approaches were modest.

Discussion

Students used four recurring observational approaches across the biological feature-identification tasks. *Quick Targeting* was the most frequent approach used and combined rapid visual search with relatively high task accuracy. This finding aligns with dual-process theories of visual reasoning (Evans & Stanovich, 2013), suggesting that students frequently rely on Type 1 cognitive processing, a fast, intuitive, and automatic visual mechanism operating with minimal working memory load, when presented with visual recognition tasks. Although *Quick Targeting* was associated with relatively high performance, rapid search may be less reliable when successful identification depends on subtle diagnostic features. According to Cognitive-Visual Processing Models (Hegarty, 2011; Lowe, 1999), rapid decision-making in visual tasks often relies on *perceptual salience* rather than *conceptual understanding*. Recent eye-tracking research has shown that younger primary pupils display weaker top-down attentional control and greater attention dispersion than older pupils and adults (Jang & Lim, 2026). When task items feature low visual complexity or distinctive, unconfounded traits, Type 1 processing may be sufficient (Evans & Stanovich, 2013). However, in authentic biological observations where diagnostic traits are embedded within confounding visual information, rapid search without systematic verification may increase the risk of overlooking subtle diagnostic features or accepting a visually plausible match too quickly (Kruglanski & Webster, 1996).

Conversely, *Diagnostic Scanning* represented the second most frequent approach. Students employing this observational approach exhibited selective visual behaviour directed towards diagnostic Relevant Features. This behaviour mirrors expert-like observational approach identified in the literature (Gegenfurtner et al., 2011; Jarodzka et al., 2010), where solvers actively suppress non-diagnostic visual noise and direct top-down attention towards task-relevant anatomical structures. Intriguingly, observational approaches characterised by high overall visual effort, *A Thorough Wander* and *Instruction-Guided Search*, accounted for a smaller proportion of solutions. In *A Thorough Wander*, fixations were distributed broadly across diagnostic and non-diagnostic regions. This suggests a lack of domain-specific visual schemas necessary to guide top-down selective attention (see Gegenfurtner et al., 2011). Students using *Instruction-Guided Search* repeatedly returned to the task instruction. This pattern may indicate difficulty linking verbal descriptions with specific visual features.



Crucially, the analysis revealed dominance of individual observational approaches. This pattern indicates within-participant consistency across the present task set. The observed consistency in observational approach selection across diverse taxonomic domains (fauna, flora, microscopic life) is broadly consistent with previous research on visual cognitive styles and perceptual habits (Blazhenkova & Kozhevnikov, 2009), although the present data do not establish that these approaches represent stable cognitive styles. Rather than dynamically re-evaluating their observational approaches based on the specific morphological complexity of the organism presented, lower secondary students tend to apply a default, habitual observation. This may be due to a lack of proficiency in other solving approaches, or they may lack sufficient metacognitive strategies to assess whether the quick approach is appropriate or whether the observation requires more specific attention (see Nicolay et al., 2022).

When evaluating the relationship between observational approaches and task accuracy, clear performance trends emerged. Both *Quick Targeting* and *Diagnostic Scanning* yielded the highest task performance. These findings suggest that greater overall visual effort alone was not associated with higher task performance. Rather, the distribution of visual attention appeared to be more informative than the overall amount of viewing. The success of *Diagnostic Scanning* can be interpreted in terms of its selective focus on relevant morphological features. Deliberate inspection of diagnostic features allows solvers to verify subtle details before making a decision. *Quick Targeting* showed a different pattern. Relatively high performance occurred despite limited verification. Because task stimuli featured prominent visual traits described in plain language, many students were able to recognise target structures rapidly without requiring prolonged verification. However, qualitative scan-path analysis revealed that solvers using *Quick Targeting* frequently skipped entire photographs. Thus, while *Quick Targeting* proved time-efficient in low-to-medium difficulty items, it may be less reliable when successful identification depends on subtle morphological differences. In contrast, *A Thorough Wander* and *Instruction-Guided Search* resulted in lower accuracy. In *A Thorough Wander*, extended viewing was distributed partly across non-diagnostic visual features (e.g., focusing on purple petal colour rather than leaf morphology in plant tasks). In *Instruction-Guided Search*, repeated reading of the task instruction was not accompanied by consistent inspection of the diagnostic features. This pattern is consistent with difficulties in integrating textual and visual information described in cognitive load and multimedia learning research (Mayer, 2005; Sweller, 2011). While the task instructions successfully initiated top-down search towards broad Areas of Interest (Relevant Areas), solvers apparently encountered a cognitive bottleneck when attempting to map abstract verbal descriptors (e.g., “serrated leaf margin”) onto fine-grained visual representations (Relevant Features). As Schnotz (2002) noted, reading comprehension does not automatically yield internal visual schemas.

Limitations

The main limitation concerns the ecological validity of the task design. The observational tasks used static photographs presented on a screen under standardised conditions. This format enabled precise eye-tracking measurement and consistent definition of areas of interest, but it restricted the observer's ability to actively modify the conditions of observation. In authentic biological observation, students may be able to change viewing distance or angle or manipulate a sample. Some authentic forms of observation, such as microscopy or observation at a distance, are also spatially constrained. Nevertheless, the screen-based tasks did not allow students to manipulate specimens or change their viewing position. The screen-based tasks used in the present study therefore reproduce some characteristics of authentic biological observation, particularly the need to identify diagnostically relevant features within a restricted visual field, but they do not capture its full perceptual and interactive complexity. Consequently, the identified observational approaches should primarily be interpreted in relation to controlled, image-based biological observation, and their transfer to other observational contexts should be examined empirically.

Secondly, although the sample was restricted to lower secondary students, this sample size and task volume were relatively large compared with other studies in educational eye-tracking research (e.g., Gegenfurtner et al., 2011; Jarodzka et al., 2010). Although the number of tasks was limited to reduce fatigue during eye-tracking recording, the stimuli covered several taxonomic groups and therefore included variation in biological content. Finally, while screen-based eye-tracking provides an unobtrusive view into real-time visual processing, eye-movement measures cannot determine why a student adopted a particular search pattern, such as distinguishing whether a rapid search termination in *Quick Targeting* stemmed from high perceptual confidence or task disengagement.



The gaze measures nevertheless differentiated the four observational approaches. These differences provide a basis for further research on development of targeted scaffolding, visually balanced assessments, and explicit observational interventions in biology education.

Conclusions and Implications

Four recurring observational approaches were identified in the screen-based biological feature-identification tasks: *Quick Targeting*, *Diagnostic Scanning*, *Instruction-Guided Search*, and *A Thorough Wander*. These approaches differed in how students distributed visual attention across the task instructions, organism images, and task-relevant morphological features.

The observational approach was statistically associated with task performance, although the magnitude of the association was small. *Diagnostic Scanning* and *Quick Targeting* had the highest mean task scores, whereas *Instruction-Guided Search* and *A Thorough Wander* had somewhat lower scores. Overall, successful task solving was associated more with selective attention to task-relevant morphological information than with the overall amount of visual inspection.

For biology education, the findings indicate that students differ in the observational approaches they use when solving biological feature-identification tasks. Therefore, there is a reason to support the development of systematic observation by helping students identify, compare, and verify diagnostically relevant morphological features. Such scaffolding may include targeted visual cues, explicit comparison criteria, and clear links between verbal descriptions and corresponding visual features, while also encouraging students to verify initial conclusions rather than rely solely on rapid visual judgments. Because these implications are derived from controlled, screen-based tasks, they should be examined in more authentic observational settings. Further research should also assess whether targeted instructional support improves students' observational competence.

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Declaration of generative AI use

During the preparation of this manuscript, the authors used ChatGPT-4 and Grammarly for language editing and improving clarity. After using these tools, the authors reviewed, edited, and verified the content as necessary and take full responsibility for the integrity and accuracy of the final published text.

Ethics statement

Ethical standards regarding research with school-aged participants were strictly followed. The study protocol was reviewed and approved by the Research Ethics Committee of the Faculty of Education, Charles University (Approval Code: UKPedF/203185/2025, Date of Approval: April 1, 2025), and informed parental consent was obtained for all participants. Participation was voluntary, and participants could discontinue the session at any time without consequences. The collected eye-tracking and task-performance data were processed in anonymised form.

Declaration of Interests

The authors declared no conflicts of interest.



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