# Mobile Eye-tracking for Research in Diverse Educational Settings

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Mobile eye-tracking is a technology that captures visual information, such as gaze, eye-movements, and pupil dilations, when learners are mobile. Traditional eye-tracking helps researchers to obtain precise, moment-by-moment information about learners’ engagement, interactions, and learning processes, but it has some weaknesses due to its structural and stationary nature. Mobile eye-tracking can complement such weaknesses by allowing researchers to collect eye-tracking data when learners move around and interact with multiple targets. This chapter demonstrates how mobile eye-tracking can add more authenticity and nuanced information into Learning Design and Technology research, and then introduces potential research themes that can use mobile eye-tracking. This chapter also overviews the overall processes of applying mobile eye-tracking in a research study and provides an example analysis.

# Mobile Eye-tracking for Research in Diverse Educational Settings

Mobile eye-tracking (MET) is a technology that captures visual information (e.g., gaze, eye-movements, pupil dilations) in the moment as people move through different settings. Traditional eye-tracking has contributed to educational research by allowing researchers to analyze learning activities conveyed through one's eyes, such as focused attention, engagement, and emotional reactions (Lai et al., 2013; Rayner, 1998). However, traditional eye-tracking can only be used in limited settings since it requires learners to be stationary. MET can overcome such limitations—allowing for eye-tracking to be utilized as a research tool in diverse, innovative, and authentic educational settings by Learning Design and Technology (LDT) researchers and practitioners. This chapter aims to highlight the potential of MET as a research method and discuss how it can be incorporated into impactful, rigorous LDT research in diverse settings.

## What Can Mobile Eye-tracking Data Contribute to LDT Research?

### Eye-tracking's contributions to educational research

To understand MET's contributions to LDT, educational researchers need to understand how eye-tracking information, in general, can contribute to what we know about human learning. Eye-tracking has been widely used in psychological research since the 1970s (Rayner, 1998), but its application to educational research has rapidly increased since the late 2000s (Lai et al., 2013). Eye-tracking data's primary contributions include: (1) precise information related to learners' cognitive and emotional engagement; (2) the production of moment-by-moment information throughout a person's learning processes; (3) the capture of learners' interactions with learning resources and technologies.

- **Precise measures of cognitive and emotional engagement**

Eye-tracking technology enables researchers to track people's fixations (gaze) and saccades (eye movements between fixations) that can evidence perception and attention, especially when people are performing specific tasks (Rayner, 1998, 2009). Eye-tracking collects multiple measures simultaneously: temporal measures (time and duration of gaze), spatial measures (locations, distances, and directions of gaze and eye movement), and count measures (frequency of gaze and eye movement) (Lai et al., 2013). Also, some eye-trackers capture pupil dilation. Pupils constantly change in size as individuals interact with stimuli. Changes in pupil size are systematically triggered when people are confronted with emotional stimuli (e.g., surprising events) or cognitively-challenging problems (Pomplun & Sunkara, 2003; J. T. Wang, 2011). These measures can be interpreted as either cognitive or emotional indicators of learning and engagement (see *Table 1* for more examples). In sum, via diverse measures, eye-tracking provides psychological and physiological information about learners' cognitive and emotional engagement, which can be understood as an important learning outcome that cannot be fully obtained through surveys, interviews, or video recordings (Lai et al., 2013).

| **Eye-tracking measures** | **Educational interpretation with example studies** |
|---|---|
| Fixation time (duration) and/or count (frequency) | • Cognitive loads or complexity of cognitive processing when learners are asked to solve a problem (e.g., T.K. Wang et al., 2018; Romero-Hall et al., 2013)<br>• Learners' choice of attention and duration of engagement with specific learning resources when multiple resources and stimuli are provided (e.g., Jung et al., 2018; Renshaw et al., 2009)<br>• Attention distribution (e.g., Kiili & Ketamo, 2010) |
| Fixation paths | • Attention paths when scanning different resources before making a choice (e.g., Mayr et al., 2009; Jung et al., 2018)<br>• Order of information processing when dealing with a problem (e.g., Duchowski et al., 2000) |
| Gaze transition | • Sense-making by integrating information from different resources (e.g., Harley et al., 2016; Meißner, Pfeiffer, Pfeiffer, & Oppewal, 2019)<br>• Reaction (e.g., faster gaze shift) to curiosity-based activities (Gottlieb et al., 2013) |
| Pupil diameter dilation | • Cognitive loads when dealing with different tasks (e.g., J. Wang, 2011)<br>• Emotional reaction to interesting stimuli (e.g., J. Wang, 2011) |

*Table 1.* Examples of using eye-tracking measures (using either stationary or mobile eye-tracking) in LDT-related research

- **Moment-by-moment learning processes**

Another benefit of eye-tracking is the real-time continuity of eye-related data (Rayner, 1998, 2009). Rather than measuring learners' engagement across several time-points or their learning outcomes at the end of an experience, eye-tracking can provide precise, moment-by-moment information about learning processes (Hyönä, 2010; Lai et al., 2013). For example, Jamet (2014) used eye-tracking to look for differences in attention paths among undergraduate students with, and without, provided cues as they engaged with a computer-based presentation. By analyzing the moment-by-moment gaze information, he found that students with the cueing presentation paid more attention to important/relevant content throughout the course. Likewise, eye-tracking can help researchers obtain precise insights about paths of engagement and transitions of attention throughout learning processes.

- **Interactions with learning tools**

Since the 2010s, eye-tracking has increasingly been used to investigate learners' interactions with new learning tools and elucidate the effects of specific instructional strategies (Hyönä, 2010; Lai et al., 2013). Because eye-tracking can provide rich information about which representations or features of the environment or stimuli attracted learners' visual attention, it has particularly contributed to research examining computer-based multimedia or game learning (Hyönä, 2010; Romero-Hall, Watson, Adcock, Bliss, & Adams Tufts, 2016; van Gog & Scheiter, 2010). In a game-based learning environment with a video game (*Tomb Raider*), Renshaw, Stevens, and Denton (2009) collected eye-tracking data during undergraduate students' game activities and revealed that, contrary to what students expressed during their post-interviews, the students actually did not necessarily follow the verbal probes. Kiili and Ketamo (2010) adapted eye-tracking to observe how students (ages 10-11) distributed their attention across several areas of interest (AOI; e.g., a virtual character's eyes, classroom binder feature) while they engaged with problem-based game learning about mathematics and geography. The researchers also used eye-tracking to assess whether and how long students took to react to critical feedback for the game. They found that some students failed to notice the feedback. Such information about the real-time visual interactions can help researchers to test their interventions and further develop certain educational resources.

**Limitations of traditional eye-tracking**

Despite these benefits listed above, traditional eye-tracking has some weaknesses due to its structural nature. First, traditional eye-tracking is stationary, so learners need to be geographically fixed in a single location, and they typically cannot move their heads and bodies beyond a limited range of motion or change positions. Doing so will cause the equipment to lose track of the eyes. Having learners stay still may not be possible in many educational settings. In particular, in informal environments, where learning happens as learners are mobile (Sharples, Taylor, & Vavoula, 2005) or on-the-move (Headrick Taylor, 2017), the best opportunities for learning may require movement. Second, traditional eye-tracking is often set up on a computer screen, so it cannot capture learners' visual interactions with targets outside of the screen. Learning can happen beyond the square screen, even with stationary computers. Third, traditional eye-tracking captures no or limited information about contexts surrounding learners, despite the importance of considering contextual and situated information in learning (e.g., Brown, Collins, & Duguid, 1989; Greeno, 1998, 2006).

***Mobile* eye-tracking: Adding more authenticity and investigating learning *in situ***

The development of *mobile* eye-tracking (MET) complements the limitations of traditional eye-tracking by expanding the reach of eye tracking into authentic learning settings. MET allows researchers to collect not only precise but also nuanced and authentic information related to learners' gaze, eye-movements, and pupil dilations *in situ* (Pérez-Edgar, Fu, & MacNeill, in press). This mobility allows for dynamic data to be collected by (a) using eye-tracking even when learners move around, (b) identifying less-limited, more diverse areas of interest (AOI) beyond a predetermined scene, and (c) collecting contextual information along with eye-tracking data.

- **Learning while moving within or across space(s)**

MET's most prominent feature is adding mobility to eye-tracking, so that dynamic data can be captured within one or across multiple settings. Prior to the introduction of MET, most eye-tracking research in LDT took place in computer-based or game-based settings that required learners to stay seated as they watched the same screen the whole time (e.g., Renshaw et al., 2009; Romero-Hall et al., 2016; Kiili & Kemato, 2010). However, MET allows researchers to follow learners outside of lab-based (or stationary) environments and move into the diverse types of educational environments people really inhabit. For example, Foulsham, Walker, and Kingstone (2011) used MET to compare different scanning strategies and gaze distributions between walking on campus and watching a first-person view video of someone walking. *Figure*

*1* also demonstrates another case of MET used to collet moment-by-moment information related to a child’s attention and engagement at a museum.

In addition, MET technology is continuously developing and moving toward wireless collection systems. Early MET versions were wired (e.g., MET glasses had to be physically connected to a portable computer for data transmission). Such wires may cause data loss because they can be accidentally unplugged as learners move about (Jung, Zimmerman, & Pérez-Edgar, 2018). They can also be bulky for young children. However, more recent MET tools enable the use of wireless data transmission through WiFi or Bluetooth (e.g., Franchak, Kretch, Soska, & Adolph, 2011). In other words, MET is getting more feasible for *mobile* learners.


*Figure 1.* A child wearing a mobile eye-tracker and carrying the tablet PC (in the backpack) while exploring hands-on exhibits in a museum.

- **Diverse targets of attention and engagement**

While traditional eye-tracking limited the targets of learners’ attention to specific locations (e.g., within the computer screen), MET allows learners to look at targets beyond a screen—not only objects but also other people surrounding them. MET can capture more diversified AOIs than traditional eye-tracking, which allows learners to move their eyes as they would do in real life. For example, with a virtual simulation environment for nursing education, Romero-Hall et al. (2016) used stationary eye-tracking and predetermined learners’ AOIs (e.g., three virtual patients’ heads, their bodies, pop-up questions) that were presented only in the simulation. MET, however, is not restricted to a specific screen, so it can capture the diverse targets with which learners visually interact. If the researchers had MET in this simulation environment, they could have also measured visual information about how multiple students interacted with each other while sharing the same computer and solving the same simulated problems—as they would really do in a real emergency with colleagues. MET can also be utilized in settings with more varied physical and social subjects to interact with. In our study at a museum (Jung et al., 2018), various types of AOIs were identified—museum exhibits, other visitors, family, guide map—to understand a child's sociotechnical interactions.

- **Contextual and nuanced information derived from MET**

Many MET devices are head-mounted equipment comprised of two eye-cameras: one or two cameras looking back to track a person's pupil(s) and another camera looking forward to record person-centered point-of-view scenes (e.g., Kassner, Patera, & Bulling, 2014). These front-and-back recordings can be integrated into a video data stream that provides eye-tracking indicators (e.g., dots for fixations and lines for gaze paths) on the person-centered video recordings. As such, MET data show eye-tracking information incorporated with contextual information (Eghbal-Azar & Widlock, 2012; Fu, Nelson, Borge, Buss, & Pérez-Edgar, 2019). The person-centered video recordings of MET not only contain detailed information about the learning contexts but also indicate the potential targets of the person's eye-movements, which can give more nuanced data associated with learners' choices of AOI. As shown in *Figure 2*, MET data layers the person's view (right-side), which would help researchers to understand more situated information regarding where the child was gazing and pointing to. The scenes collected from MET provide a different viewpoint from the information captured when using solely a traditional third-person-view camera configuration (e.g., camcorders) (left-side).

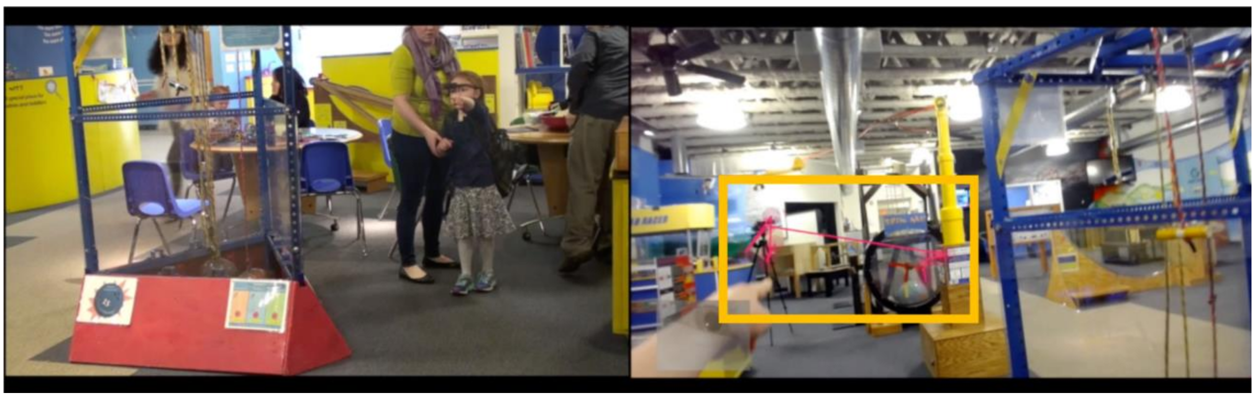

*Figure 2.* A screenshot from the merged video recordings of MET data (right-side) and third-person-view camera recording (left-side) of Celine's (pseudonym) museum exploration with her family. This child was wearing eye-tracking equipment while pointing to the areas she would explore and scanning exhibits (red dots and lines indicate the fixation and eye-movements of the child in the yellow box).

## For which LDT Research Themes can Mobile Eye-tracking be Used?

### Designing diversified learning technologies and environments

MET can benefit researchers in understanding how people learn in diverse types of educational settings and designing better affordances of educational materials in LDT, above and beyond stationary computer-based settings. We suggest using MET for research in diverse technologically enhanced environments, including hybrid computer-supported settings, augmented reality (AR) and virtual reality (VR), museums, and makerspaces.

- **Hybrid computer-supported settings**

MET can advance research in hybrid settings where learners are engaged with both virtual (digital) and physical worlds at the same time. For example, MET was used in an afterschool club where elementary school students learned collaborative design thinking by utilizing papers and pencils, LEGO blocks, and a video game installed in laptop computers (see Jung, Yan, & Borge, 2016 more about the club). Their interactions occurred through both the virtual and real worlds. Children verbally talked to each other or moved around to see what their peers were doing as they virtually built artifacts in Minecraft. MET can help to investigate such multiple layers of learners' interactions including on and off screens.

- **AR and VR**

MET can be used to advance immersive learning environments using VR and AR. Some VR (3D) glasses can incorporate MET, as Duchowski et al. (2000) used eye-tracking to investigate how learners located their gaze to detect problems during virtual training in a simulated aircraft. Such research illustrate the potential for MET to explore visual patterns of problem-solving and engagement in diverse forms of VR educational settings. With AR technology, Harley, Poitras, Jarrell, Duffy, and Lajoie (2016) used MET to examine how learners visually interacted with the Google Earth Display (showing present scenes of historic places) and their mobile AR app (showing historical figures from historic places) for an indoor experiment. By measuring gaze transition between the two devices, the researchers explored how learners compared information from each device and engaged in sense-making about historical differences across locations.

- **Object-based Museums**

Because of its mobile nature, studies situated in museums have used MET to capture engagement as people move around and explore different exhibits. For instance, MET was used to explore visitors' gaze patterns across exhibits (e.g., Mayr, Knipfer, and Wessel, 2009) or behavioral ways of scanning exhibits (e.g., Eghbal-Azar & Widlock, 2012). We also used MET with a 10-year-old child and examined the patterns of his choices over multiple museum exhibits and the pathways of his engagement with each exhibit (Jung et al., 2018). In museum studies, data about gaze allocation and paths from MET are particularly helpful in understanding visitors' choices and behaviors (e.g., how learners scanned and selected specific exhibits, how they engaged with exhibits, or how they read and used information from text instruction). Such information can improve the design and presentation of exhibits.

- **Makerspaces**

In a makerspace, learners may search for information, explore different resources and ingredients they can use, and discuss with other people about what artifacts to make and how to make them. As learners utilize multiple tools and elements (e.g., *Figure 3*) throughout sketching, designing, and/or creating their own artifacts, MET can help explore when and how they utilize specific materials and how their visual interactions with and across diverse tools are connected to their final products.

*Figure 3.* Celine and her mother were wearing MET devices and exploring different materials and resources (e.g., iPad and clays) to initiate their making project.

**Social and sociotechnical interactions**

MET provides detailed and nuanced data about the social and physical targets a learner interacts with. This feature can help support researchers exploring social and technical interactions of learners. We suggest using MET to investigate learners' interactions across multiple technical resources and/or teachers' interactions with students and teaching tools in a classroom.

- **Interactions across multiple resources**

Traditional eye-tracking technology has revealed patterns of online learners' social interactions, such as learners' collaboration and discussion with their peers in Massive Open Online Course (MOOC) environments (Sharma et al., 2015). MET can expand researchers' focus on online collaboration by incorporating more diverse forms of collaboration, including hybrid and face-to-face interactions beyond the computer screen. In particular, it can detect eye-movements across various educational materials (e.g., learners can read paper articles, use mobile devices, or talk to other people in person during a computer-based online activity). In addition, MET can capture learners' in-person social interactions; for example, MET was used to explore child-parent interactions as well as child-exhibit interactions in a museum (Jung et al., 2018). MET can show how learners interact across diverse materials and with other people as they would do in the real world.

- **Teacher interaction in classrooms**

MET can be used in school-based classroom settings. It can help to investigate teachers' cognitive and emotional activities in classrooms or their ways of interacting with students. For example, MET can assess and compare expert and novice teachers' gaze patterns and distributions on their students during their classes (Cortina, Miller, McKenzie, & Epstein, 2015).

Also, MET can measure variations in teachers' degree of cognitive load as they facilitate innovative activities (e.g., computer-supported collaborative activities) in a classroom (Prieto, Sharma, Wen, & Dillenbourg, 2015). These real-time eye-tracking measures of teachers in their classrooms can benefit understanding teachers' authentic interactions with students and instructional tools and provide more precise feedback for teacher education.

**Personalized learning materials and learning analytics**

Eye-tracking itself can be an instructional material that teaches self-awareness because reflecting on one's own MET data can provide a learner with insights into personalized learning processes (van Gog & Scheiter, 2010). Sommer, Hinojosa, and Polman (2016) used stationary eye-trackers to collect youths' eye-tracking footage, showed the footage back to the students to promote their data literacy, and found increases in youths' metacognitive awareness. Likewise, MET can serve as an instructional tool with which people can learn about their visual attention patterns in mobile or place-based educational settings. Furthermore, recent studies have also attempted to develop adaptive multimedia environments that can prompt different materials based on eye-movements (indicating information processing) in real-time (e.g., Scheiter et al., 2019). Therefore, promising advances may help researchers embrace learning analytics to collect and analyze MET data in real-time to develop personalized, adaptive learning materials for more diverse activities.

## Overall Processes of MET Application

In this section, we overview the steps and elements that researchers need to consider throughout the processes of preparing, collecting, and analyzing MET data. Because this chapter does not aim to provide a meticulous guide, and specific how-to varies across different MET technologies, we do not offer precise details for each step.

- **Preparing devices**

Different mobile eye-trackers have been developed for research or marketing purposes (e.g., PUPIL Core®, iMotions®, Tobii Pro®). Each eye-tracker brand needs software to sync and merge eye-tracking footage and point-of-view recordings. As an example, PUPIL labs (Kassner et al., 2014) provide free software (i.e., PUPIL Capture and PUPIL Player) to collect and process MET data through their devices. Depending on the brand, researchers may need to prepare a tablet, portable computer, or PDA to be connected to the eyeglasses with or without a wire; appropriate software should be installed on the computer. In addition, batteries need to be fully charged, and the memory capacity needs to be sufficient for the rich data, especially since MET data often requires a substantial storage capacity and processing speed.

- **Considering data triangulation**

For eye-tracking data, researchers commonly incorporate supplemental data sources (such as stationary camera video recordings) that capture an overall view of the environment (e.g., Jung et al., 2018; Fu et al., 2019). Because MET does not record a person's facial expressions and gestures unless within the participant's visual field, having another video camera can complement the MET data. Also, researchers can prepare a separate audio recorder and attach it to the computer or eyeglasses, so they can add verbal interactions to MET data.

- **Collecting data**

It takes additional time to use MET equipment because researchers must assist participants in wearing the MET devices and then performing calibration. If using a wired version of MET technology, researchers should check to see if the eyeglasses and the tablet are well connected and working. If it is a wireless version, researchers must check their Internet connections. Audio recorders need to be attached. Appropriate software (e.g., PUPIL Capture®) and the recording function on the tablet computer need to be engaged before participants start their activity.

Researchers need to be trained on how to calibrate the eye-tracker. Calibration is used for matching the positions of the person's pupil with the eye-tracking system's standard scale. When calibration is not accurate, collected eye-tracking footage does not indicate actual fixation and saccades, which would harm the validity of the data. Kassner et al. (2014) specified four methods of calibrating: Screen marker calibration (using 9 point animation), manual marker calibration (using a concentric, moving marker), natural feature calibration (using natural features within the scene), and camera intrinsic calibration (calculating camera intrinsics). The methods, however, can vary across different devices and software. Calibration takes 5 to 15 minutes, depending on the expertise of the MET practitioner and the research subject.

- **Processing data**

Processing and preparing MET data is more complex than other forms of video-based data because the collected raw data must be processed through appropriate software (e.g., PUPIL Player) to sync and merge two data streams. Special software aligns the back-facing eye-tracking footage from the eye camera with the front-facing point-of-view scenes. Audio data should also be merged with eye-tracking data. The resultant MET data are formatted as video recordings of point-of-view scenes that are overlaid with circles and lines of different colors, which indicate the targets of the participant's gaze (see *Figure 2*).

Researchers may consider collecting supplemental video data and merge it with MET data, so that they have one video record displaying both scenes (as *Figure 2* shows). Video editing software (e.g., Final Cut Pro X®, iMovie®) can be used to merge these data (e.g., Fu et al., 2019; MacNeill, 2019).

- **Analyzing data**

MET data can be analyzed in diverse ways based on research questions and purposes. Most eye-tracking studies (both stationary and mobile) used quantitative approaches—by coding AOIs, counting gaze duration or frequency, and conducting statistical analyses (e.g., ANOVA). Such approaches allowed LDT researchers to find statistical evidence for spontaneous participant behavior or intervention effects (e.g., Ponce et al., 2018; Romero-Hall et al., 2016). However, because MET data contain rich information regarding the participant's social and environmental contexts, it can also be analyzed in interpretivist, qualitative ways by adapting microethnography, interaction analysis, or multimodal analysis techniques (e.g., Jung et al., 2018).

For analysis, studies have used software including, but not limited to, Datavyu (e.g., Fu et al., 2019), OpenSHAPA (e.g., Franchak et al., 2011), Tobii Pro Glasses Analyzer (e.g., Rainoldi, Neuhofer, & Jooss, 2018) and V-note (e.g., Jung et al., 2018). Many studies use manual coding to identify AOIs. However, some researchers have developed advanced technology to reduce the time and effort of coding. For example, 3D marker tracking was used to sync the locations in a virtual world with the objects in the real-world (Pfeiffer & Renner, 2014). Machine learning techniques have also been used to automatically code MET data (Zemblys, Niehorster, Komogortsev, & Holmqvist, 2018).

## Example Analysis: Case Study of Celine's Situational Interest in a Museum

This section demonstrates an example analysis from a case study of Celine's situational interest during her museum exploration with her mother and younger sister. Celine's family was invited to an hour-long family STEM learning session at a science museum where they explored museum exhibits and then engaged with making activities. During the session, Celine wore the wired version of the PUPIL mobile eye-trackers.

We used MET data to identify evidence of Celine's situational interest during her museum exploration. Situational interest is a relatively short-term interest that is more contingent on external stimuli in contrast to individual interest, which is more stable (Hidi & Renninger, 2006). The development of situational interest involves two phases: it can first be newly *triggered* by the learner's exposure to novel stimuli, and can then be *maintained* throughout certain experiences (Dohn, 2011, 2013; Hidi & Renninger, 2006). We conducted a qualitative interaction analysis on Celine's visual interactions (from MET data) and verbal discourse (from attached audio recording) by adapting the coding framework developed in our previous study (Jung, Zimmerman, & Land, 2019; *Table 2*). Using this framework, we identified visual and verbal evidence of Celine's triggered situational interest (e.g., surprise after visual interactions) and maintained situational interest (e.g., focused attention after triggered situational interest).

| **Situational interest phases** | **Verbal and visual evidence from Celine's MET data** |
|---|---|
| Triggered situational interest | • When Celine verbally expressed surprise, feeling of enjoyment, and/or curiosity right after visually interacted with certain exhibits |
| Maintained situational interest | • When Celine's attention was focused on certain exhibits for more than a minute after having triggered situational interest<br>• When Celine repeatedly talked about certain exhibits or subjects after having triggered situational interest |

*Table 2.* Coding framework adapted from Jung, Zimmerman, and Land (2019)

For example, our findings with MET data showed that Celine's situational interest was triggered by noticing an exhibit of multiple rocks and then maintained by observation activity, particularly with an assistive tool. Once Celine noticed that there were rocks and expressed curiosity, saying "Hmmm, mm?" she approached the exhibit closer. Our MET data showed that her visual attention was targeted to the rocks from distance (*Figure 4*, left) along with the verbal expression of curiosity, which could indicate triggered situational interest. After Celine got closer to the exhibit, she used a magnifier for closer observation and investigation of the rocks. Our MET data showed that she verbally hummed sweetly while she closely observed the rocks through the magnifier (focused attention on the rocks with positive emotion; *Figure 4*, right), which shows her situational interest was maintained throughout the observation activity.

*Figure 4.* Celine's MET data. Her attention was focused on the rocks from a distance when she first found them (left). Her attention was sustained on the rocks as she observed them through the magnifier (right).

This example analysis shows that MET data can be utilized for research about interest, which was associated with both emotional and cognitive engagement, by allowing researchers to analyze the learner's visual and verbal interactions at the same time. Also, this analysis implies that MET was used to identify AOIs from some distance, which may be powerful in investigating how the learner's attention moves within three-dimensional space (beyond a flat monitor screen).

## Additional Considerations Related to MET

Before making their methodological choices, researchers need to acknowledge the potential challenges of MET and how to minimize or overcome them. One primary challenge is the cost. Currently, most mobile eye-trackers cost more than $1,000 (Farnsworth, 2019). Also, MET software and hardware (e.g., laptop, tablet PC) may add to the overall research budget. However, some companies (e.g., PUPIL Labs) provide open-source MET software and many offer discounts for academic purposes.

Another challenge lies with MET glasses. Participants already wearing their own glasses may not be able to wear additional "glasses." Moreover, wearing MET glasses can be heavy, especially for children (Jung et al., 2018), which may interfere with their learning. Like some regular glasses, some participants may find that their MET glasses slide down the nose, which also influences the data quality. Researchers need to keep these in mind when recruiting participants and minimize any potential discomfort of MET glasses.

Furthermore, researchers need to consider that eye information, especially pupil dilations, can be affected by factors other than cognitive or emotional reactions. Pupil diameters change depending on lighting conditions, so measuring and interpreting pupil dilations in settings having non-consistent lighting (e.g., outdoor) may be challenging. Thus, enough understanding of the setting's physical conditions that may influence eye-information is necessary.

However, with technological development, many of these challenges may be mitigated in the future. In the trend of LDT research from investigating the effect of a specific technology or teaching method in controlled settings to exploring authentic learning processes in diverse contexts (e.g., Winn, 2002), precise, rich, and nuanced information of MET can advance the understanding of cognitive, emotional, and social aspects of learning.

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