Supporting Attentional Control in XR Learning under Real-World Distraction and Interruption

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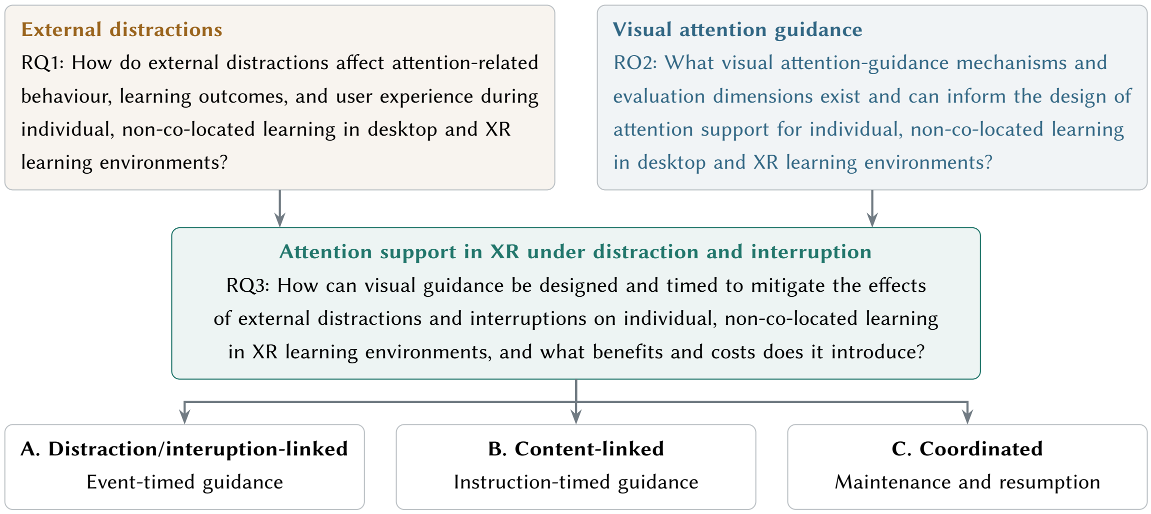

Fig. 1. Two foundations converge on attention support in XR learning. The order is conceptual, not the chronology of data collection. Arrows indicate how evidence informs design; the three lower branches are alternatives for discussion, not promised implementations.

Individual, non-co-located e-learning requires learners to attend to digital learning content while remaining situated in and responsive to their physical environment. External events may act as irrelevant distractions that should ideally be ignored, or may require learners to interrupt learning and attend elsewhere. This doctoral research investigates how attention can be supported in these situations across desktop and extended-reality (XR) settings. RQ1 examines how distractions affect attention-related behaviour, learning outcomes, and user experience. Two studies investigate such effects across desktop and immersive VR, and across different presentation settings; data collection is complete and analysis is ongoing. RQ2 investigates approaches that could inform attention support. A systematic review organizes 107 attention-guidance technique entries from 40 studies, while an exploratory comparison study examines selected techniques through subjective judgments and visual-search performance. RQ3 integrates these foundations by developing and evaluating visual guidance intended to mitigate the effects of distraction and interruption during individual XR e-learning. Candidate directions include guidance linked to distraction events, guidance linked to instructional content, and support for maintaining attention and resuming learning after interruption. Evaluation will distinguish learning outcomes, attention-related

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behaviour, and the additional demands introduced by assistance. I seek symposium feedback on the scope and design of this final integration and on the evidence needed to demonstrate meaningful attention support beyond visual redirection.

CCS Concepts: • **Human-centered computing → Mixed / augmented reality**; **Virtual reality**; **Empirical studies in HCI**.

Additional Key Words and Phrases: Extended reality, learning, attentional control, external distraction, interruption, visual attention guidance, immersion and presence

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1 Introduction

Individual, non-co-located e-learning allows learners to engage with digital learning content while remaining situated in and responsive to their physical environment. Events in that environment may compete with the learning task for attention. Some are irrelevant distractions that should ideally be ignored so that learning can continue, whereas others may require the learner to suspend learning and attend elsewhere. How can digital learning systems, and particularly XR systems, support learners in maintaining attention when irrelevant events should be ignored, while still allowing them to respond appropriately when external events require attention?

Presenting learning content in AR does not necessarily protect learning from distraction. In one vocabulary-learning study, AR users reported less frequent distraction than tablet users but showed a greater distraction-related decline in immediate oral recall [6]. This finding highlights a distinction between feeling less distracted and maintaining learning performance.

Visual guidance is one possible form of support, but maintaining attention in the presence of irrelevant distraction and supporting resumption after an interruption are different tasks. A controlled VR study found that cues performed differently when guiding users to new targets and back to previously viewed targets [9]. Attention can also shift without eye movement [4], so gaze toward learning content does not, by itself, establish cognitive engagement or comprehension. My research investigates how attention can be supported during individual, non-co-located e-learning when events in the learner's physical environment compete with or interrupt the learning task. RQ1 examines how external distractions affect learning across desktop and XR settings. RQ2 investigates visual attention-guidance approaches that can inform the design of support. RQ3 integrates these foundations by examining how visual guidance can mitigate the effects of distraction and interruption in XR-based e-learning. Figure 1 and Table 1 summarize this progression.

I distinguish *external distraction*, where an irrelevant event outside the learning application competes for attention but should not require suspension of the learning task, from *interruption*, where an external event or demand requires the learner to suspend learning and attend elsewhere [5]. I use *system intervention* to refer to assistance provided by the learning system, such as visual guidance, pausing, or a reminder. Such interventions may help the learner, but may also introduce additional interruption and therefore require evaluation. Throughout, *XR* refers to augmented, mixed, and virtual reality, while desktop serves as a non-XR comparison.

2 External Distractions

RQ1: *How do external distractions affect attention-related behaviour, learning outcomes, and user experience during individual, non-co-located learning in desktop and XR learning environments?*

Table 1. Research questions, supporting work, and current progress.

	Research focus and work	Progress
RQ1	**How do external distractions affect learning?** Two studies: one compares desktop with VR, and the other compares within three immersion settings on Apple Vision Pro, measuring learning, behavior, and experience under distractions.	Data collection complete; analysis ongoing.
RQ2	**How can visual cues guide attention?** A review of 40 studies organizes 107 attention guidance techniques and their evaluation methods. An exploratory study recreates and compares selected techniques with 12 participants.	Review and study completed; analyses and manuscript under revision.
RQ3	**How should XR support focus and return to learning?** Use findings from RQ1 and RQ2 to develop and test a selected form of support, assessing its benefits and any disruption it causes.	Planned; type of support and platform undecided.

A formative survey conducted among students informed four auditory scenarios – notification sounds, keyboard typing, phone conversations, and construction noise – that may distract them during learning. These survey-informed scenarios were simulated in two studies (Figure 2).

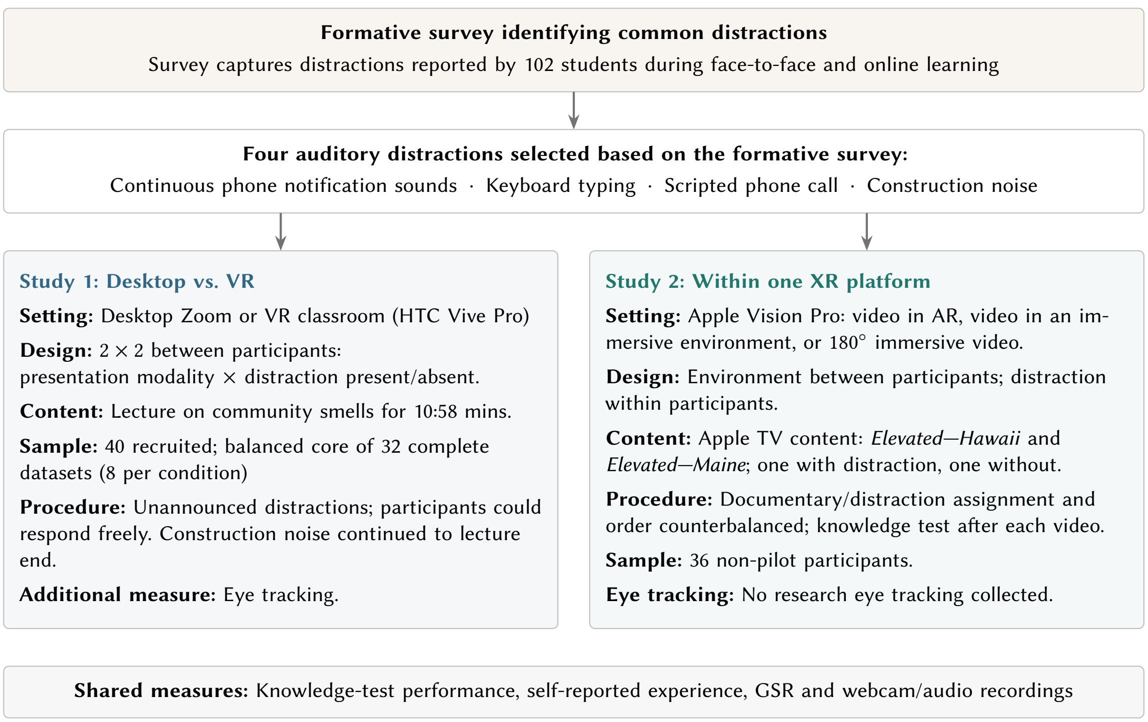

Fig. 2. Formative survey and two distraction studies addressing RQ1. Survey findings informed the selection of distractors used in both experiments. Study 1 varies presentation setting and distraction between participants; Study 2 varies presentation setting between participants and distraction within participants.

Figure 2 summarizes the two designs. In Study 1, the balanced core comprises 32 participants, with additional usable records varying by outcome. Tobii Pro Glasses 2 recorded gaze in both settings, including inside the HTC Vive Pro visor. Perceived-distraction questions were administered only to the distracted groups. Study 2 collected no research eye tracking. Data collection is complete; analysis is ongoing.

3 Visual attention guidance

RQ2: *What visual attention-guidance mechanisms and evaluation dimensions exist and can inform the design of attention support for individual, non-co-located learning in desktop and XR learning environments?*

3.1 Reviewing and Organizing Existing Techniques

As systematic literature review was conducted covering 40 studies identified through database searches and citation tracking. It organized 107 technique entries from AR, VR, and traditional displays into a taxonomy describing how perceptible the guidance is, how it directs attention, where it is used, and which visual variables and gestalt principles it employs. This brings explicit cues, such as arrows and highlights, and subtle cues, such as blur and high frequency flicker into a shared framework.

I also examined how the studies evaluated guidance. Differences in tasks, scenes, cue settings, and measures make their results difficult to compare directly. This motivated a common-task comparison of selected techniques. Figure 3 shows the pipeline involving the systematic review & the development of the common task.

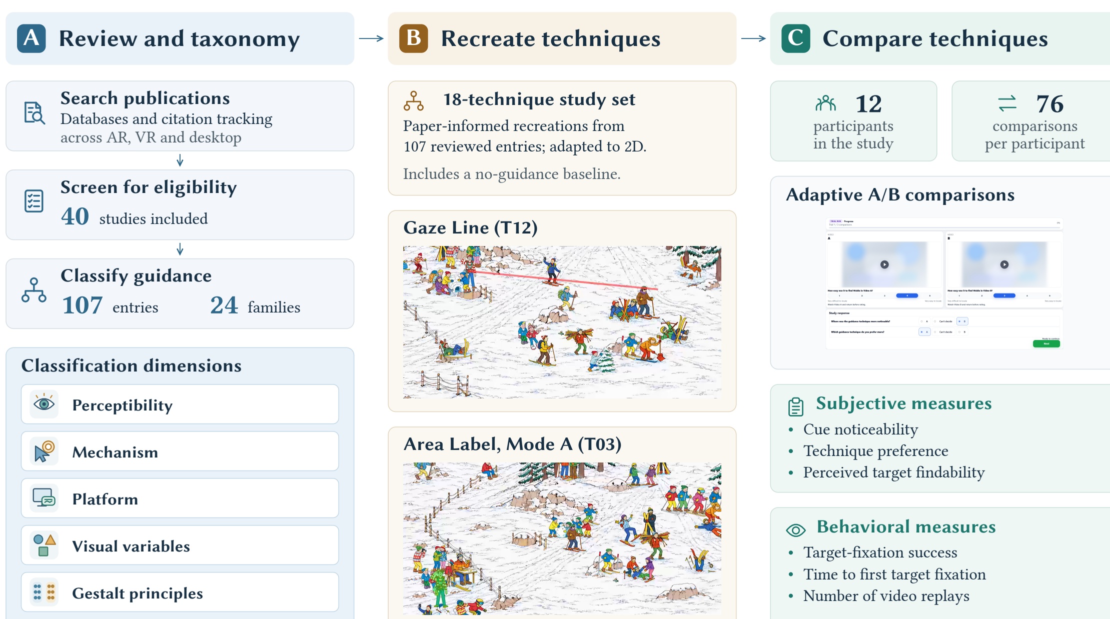

Fig. 3. RQ2 workflow: (A) review and classification, (B) recreation and adaptation of selected techniques to a common visual-search task, and (C) exploratory comparison using subjective and behavioral measures.

3.2 Comparing Techniques in a Common Visual Search Task

To examine techniques under consistent conditions, an exploratory desktop study was conducted with 12 participants and 18 conditions, including a no-guidance baseline. Each participant completed 76 adaptive pairwise comparisons using short visual-search videos. They judged which guidance was more noticeable, which they preferred, and how easy it was to find the target. Tobii Pro Spectrum eye tracking and interaction logs recorded whether and how quickly they fixated the target, and how often they replayed the videos. Analyses and the manuscript are under revision.

Candidate cues for RQ3 will be selected for their fit with the lesson and XR setting, informed by the taxonomy and benchmark findings once analyses are complete.

4 RQ3: Attention support under distraction and interruption

RQ3: *RQ3: How can visual guidance be designed and timed to mitigate the effects of external distractions and interruptions on individual, non-co-located learning in XR learning environments, and what benefits and costs does it introduce?*

Prior VR research has examined gaze-triggered restoration and compared guidance with restoration after distraction [9, 10]. Han et al. reported greater fixation on learning content and higher immediate knowledge-test scores when gaze-contingent rendering reduced the visibility of irrelevant virtual objects [7]. Content-linked signaling also improved recall in a desktop 360-degree lesson [1]. These findings motivate guidance, but do not establish protection from external auditory distraction or effective support after a required task switch.

The intended contribution is evidence about when visual guidance supports learning under external competition, and when its additional demands outweigh its benefits.

4.1 Candidate Directions

Table 2 presents alternatives; one will be selected and developed. A *mechanism* determines what guidance changes or communicates, while a *delivery policy* determines when or whether it appears. Comparing the same cue under different policies could help isolate the value of timing.

Table 2. Alternative directions for RQ3; the mechanism, policy, and platform remain open.

Direction	Support	Candidate comparison
A. Distraction-linked	Emphasize relevant content around a known competing event.	No guidance or matched scheduled cues, testing the value of event timing.
B. Content-linked	Emphasize relevant content when instruction refers to it.	Guidance present/absent, with and without distraction.
C. Maintenance and resumption	Support focus, yield during a required task switch, and assist return.	A fixed policy or ordinary pause/resume, testing whether coordination adds value.

Both the timing and content of assistance need evaluation. Desktop research found that secondary tasks were less disruptive at task boundaries than during ongoing tasks [3], motivating careful timing of system interventions. After an interruption, learners may need help recalling their task context [2]. However, perceived helpfulness does not establish effectiveness: mobile learners valued resumption cues without significant improvements in completion time or error rate [8]. RQ3 will therefore test whether the selected support improves learning or task continuation, alongside how helpful learners find it.

4.2 Benefits and Costs

Evaluation will assess whether support improves *learning or task continuation*, how it changes *attention-related behavior*, and what *additional demands* it creates, including workload, annoyance, obstruction, and interference with required external activity. Gaze return and perceived helpfulness will be assessed separately from learning outcomes.

Comparisons intended to isolate visual guidance should match instructional information and viewing time. Recaps and replay change the information or exposure provided, and therefore require a different comparison; visual emphasis alone cannot recover inaudible narration. Synchronized event logs will connect assistance to learner behavior, while dismissal or deferral will allow learners to prioritize a required task switch.

5 Contribution, Next Steps, and Symposium Questions

This thesis aims to explain how external distraction affects XR learning, provide a basis for choosing visual guidance, and evaluate one form of attention support, including its benefits and costs.

Having completed my second PhD year, I will finish the distraction analyses, then select, pilot, and evaluate one guidance approach. The findings and symposium feedback will determine whether a further study of timing or resumption is warranted.

At the Doctoral Symposium, I seek feedback on:

(1) **Thesis coherence:** Do the distraction studies and guidance work form a coherent contribution to attentional control in XR learning?

(2) **Research direction:** Which offers the strongest next step: distraction-linked guidance, content-linked guidance, or coordinated maintenance and resumption?

(3) **Evaluation:** What evidence would demonstrate meaningful learning benefits, and which assistance costs matter most?

(4) **Scope:** What can one focused intervention study establish, and what would justify an additional study?

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