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**Using Sports Interest to Learn Analytics;
The Impact of Contextualization and Familiarity in STEM Learning**

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La présente atteste que le projet de recherche décrit ci-dessous a fait l'objet d'une évaluation en matière d'éthique de la recherche avec des êtres humains et qu'il satisfait aux exigences de notre politique en cette matière.

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This is to confirm that the research project described below has been evaluated in accordance with ethical conduct for research involving human subjects, and that it meets the requirements of our policy on that subject.

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Résumé

Alors que les STEM deviennent centrales dans l'éducation et le développement de la main-d'œuvre, il est essentiel d'apprendre à travailler avec des outils basés sur les données comme les tableaux de bord et les visualisations. Toutefois, les individus ne traitent pas tous l'information de la même manière; une formation efficace doit donc tenir compte des différences cognitives et motivationnelles. Cette thèse examine comment deux facteurs, la propension à la recherche visuelle, soit la capacité à localiser et interpréter efficacement des informations visuelles, et la familiarité contextuelle, ici dans un scénario sportif, influencent l'apprentissage et l'expérience utilisateur dans un environnement d'analyse visuelle ludique. À travers une étude en laboratoire au Canada et une étude en classe en Inde, les résultats montrent que la propension à la recherche visuelle n'améliore pas directement les performances. En revanche, lorsque les individus sont familiers avec le contexte, cette familiarité renforce l'effet de leur propension visuelle : elle réduit la charge cognitive, augmente l'engagement attentionnel et génère des émotions plus positives, menant à des performances plus précises. De plus, la familiarité contextuelle améliore systématiquement le plaisir, la facilité d'utilisation et la satisfaction, peu importe le contexte culturel. Ces résultats montrent que l'apprentissage efficace dans les environnements analytiques découle de l'interaction entre capacités cognitives et résonance contextuelle, soulignant l'importance d'une formation à la fois accessible et significative.

Mots-clés : apprentissage STEM, analyse visuelle, contextualisation, familiarité, propension à la recherche visuelle, émotion, attention, comportement cognitif, performance, expérience d'apprentissage.

Méthodes de recherche: expérience intra-sujets, méthode quantitative, NeuroIS

Abstract

As STEM becomes increasingly central to education and workforce development, learners must be equipped to work with data-driven tools such as dashboards, visualizations, and analytical interfaces. However, individuals do not process information in the same way, and effective STEM training must account for differences in both cognitive abilities and intrinsic motivation.

This thesis examines how visual search propensity, an individual's tendency to efficiently locate, filter, and interpret visual information, and contextual familiarity, particularly with a sports-based scenario, shape learning and user experience in a gamified visual-analytics environment.

Across a controlled laboratory study in Canada and a classroom study in India, findings show that visual search propensity alone does not directly enhance performance. Instead, when individuals' familiarity to the context is high, that influences visual search propensity experiencing lower cognitive load, higher attentional engagement, and more positive emotional states making their performance more accurate and efficient. Additionally, contextual familiarity exerts a consistent and powerful effect on enhancing enjoyment, usability, and satisfaction across cultural groups.

Together, these results demonstrate that effective learning in visual-analytics environments arises from the interaction between cognitive efficiency and contextual resonance. These findings highlight a key implication for STEM education: data-analytics training must be both cognitively accessible and contextually meaningful to support the next generation of learners.

Keywords: STEM learning, visual analytics, contextualization, familiarity, visual search propensity, emotion, attention, cognitive behavior, performance, learning experience.

Research methods: within-subjects experience; NeuroIS; quantitative method;

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List of abbreviations and acronyms

AS - Affective Slider

CLT - Cognitive Load Theory

CSAT - Customer Satisfaction Score

EDA - Electrodermal Activity

ERPsim - Enterprise Resource Planning Simulation

FACS - Facial Action Coding System

H - Hypothesis

IEF - Interest, Enjoyment, and Familiarity (Sports Familiarity Scale)

MLM - Mixed Linear Model / Multilevel Model

NASA-TLX - NASA Task Load Index

PBL - Problem-Based Learning

RQ - Research Question

SAC - SAP Analytics Cloud

SD - Standard Deviation

SDT - Self-Determination Theory

SUS - System Usability Scale

TLX - Task Load Index (NASA-TLX)

UX - User Experience

VSP - Visual Search Propensity

Forward

This thesis consists of 3 chapters, which includes introduction, scientific article, and conclusion. This thesis has been submitted with approval from the Academic Affairs office of the Master of Science program. This scientific article explores the Impact of Contextualization and Familiarity in STEM Learning.

The data collection process for this thesis was conducted in two stages, which has been approved by the Research Ethics Board of HEC Montréal, under the approval certificate number 2025-6355, and 2025-6413. Consent has been obtained from the co-authors for the inclusion of the scientific article.

During the preparation of this thesis, the author used AI to assist with sentence refinement, improvement of writing flow, and correction of grammar and spelling. All content generated with AI assistance was reviewed, edited, and validated by the author, who assumes full responsibility for the final version of this thesis.

The article section has been written in accordance with the formatting and submission guidelines of the journal Trends in Neuroscience and Education. Upon completion, it will be submitted for consideration.

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Introduction

Over the past two decades, the importance of science, technology, engineering, and mathematics (STEM) education has grown substantially across the world, driven by an increasing demand for STEM-skilled professionals and innovation-based economies (World Economic Forum, 2023). Yet, despite this rapid growth, global data indicate a widening skills gap: the World Economic Forum estimates that more than 60% of employers report difficulties finding workers with adequate STEM and digital skills, and by 2030, over 1 billion individuals will require reskilling or upskilling to meet technological labor demands (WEF, Future of Jobs Report, 2023). However, multiple longitudinal studies have revealed a concerning decline in student participation and persistence in STEM pathways. For instance, data from the National Center for Education Statistics (NCES) show that more than half of students who initially declared STEM majors did not complete degrees in those fields (NCES, 2014). Similar findings were reported in recent international research, where first-year dropout rates in higher-education STEM programs were found to be notably high, often linked to perceptions of excessive difficulty and insufficient instructional support (Dauber et al., 2025). Furthermore, longitudinal analyses indicate that students' interest in STEM subjects tends to decline over time, particularly when learning experiences are perceived as overly theoretical or disconnected from real-world contexts (Hu et al., 2022). These findings underscore an urgent need to reimagine how STEM learning is designed and delivered for today's learners, especially Gen Z, by adopting innovative, engaging, and context-rich pedagogical strategies such as gamification, contextualization, and culturally relevant teaching approaches.

To improve STEM learning and re-engage newer generations of learners, educators must focus on the notion of contextualization, a pedagogical method of how scientific and technical knowledge

could be taught. Contextualization involves situating learning within authentic social, cultural, or professional settings so that students can connect abstract concepts to meaningful, real-world experiences (Bouhdana, 2023). When learners perceive that STEM knowledge is relevant to their interests, daily lives, or future careers, they would demonstrate stronger motivation, deeper conceptual understanding, and greater persistence. For example, linking STEM subjects like physics to themes like sports, or entrepreneurship allows students to experience STEM as a living system rather than as disconnected theory. Such context-rich approaches are especially effective for Generation Z learners, who may value applied learning, interactivity, and visible impact. Complementing contextualization with gamified elements, such as progress feedback, challenges, or collaborative goals, can further enhance engagement and sustain attention without overshadowing the underlying learning objectives (Deterding, Dixon, Khaled, & Nacke, 2011). From the perspective of Self-Determination Theory, such design elements nurture the three core psychological needs of autonomy, competence, and relatedness (Deci & Ryan, 2000). When these needs are fulfilled, learners experience greater intrinsic motivation and persistence, making gamified contextualized learning environments both cognitively stimulating and emotionally rewarding. Ultimately, by embedding STEM learning within culturally and socially familiar contexts and leveraging selective gamification to reinforce motivation, educators can redesign learning environments that are both intellectually rigorous and experientially relevant to modern learners.

Within contextualized STEM learning, familiarity functions as an important cognitive mechanism that helps learners anchor new information to what they already know, and their cultural background serves as a complementary influence that enhances emotional resonance and motivation. Familiar contexts, those aligned with a learner's prior experiences, interests, or

everyday environments, reduce extraneous cognitive load, allowing for more efficient information processing and stronger conceptual understanding (Sweller, Ayres, & Kalyuga, 2019). When learners recognize elements of their own world within instructional materials, they can more easily engage in meaning-making and sustain attention. At the same time, cultural relevance deepens this connection by embedding learning within experiences that reflect shared values, identities, and community practices (Ladson-Billings, 1995). Cultural resonance transforms recognition into personal identification, fostering a sense of belonging and purpose in STEM learning. Together, familiarity provides the cognitive foundation for effective contextualization, while culture amplifies its affective and motivational impact, creating inclusive, engaging, and meaningful learning experiences for diverse learners.

In today's digital age, STEM has become the backbone of many modern applied sciences like data science and analytics. Our study focuses on data analytics, a composite concept encompassing data acquisition, data collection, data validation, data processing, data quantification, data visualization, and data interpretation, which represents a key integration of mathematics and technology (ISO/IEC 20546:2019). When applying STEM learning to real-world contexts, disciplines like data science and analytics expand naturally and have become essential for shaping modern technologies and meeting contemporary digital demands. Consequently, it has become increasingly important to make the learning of data science and analytics accessible, intuitive, and user-friendly for diverse learners. Industry reports highlight more than 97 million new data-driven roles are projected to emerge globally by 2025 across AI, machine learning, and data analytics (World Economic Forum, 2023). Yet, the supply of individuals with advanced data skills remains insufficient, with an estimated shortage of 8.5 million data-literate workers worldwide (IBM, 2022). Learning analytics has therefore become a critical component of STEM education and

modern professional training, driven by the rapid expansion of information technology, artificial intelligence, and data-intensive decision environments (Islam et al., 2024; Neri, 2025; Susnjak, 2022). As organizations increasingly rely on data-driven strategies, individuals must learn to interpret large datasets, identify patterns, and generate insights that support complex problem solving. The ability to efficiently locate, process, and understand information in complex data-visualization environments has therefore become a prerequisite for data literacy, which encompasses the critical collection, management, evaluation, and application of data (Ridsdale et al., 2015).

Visual analytics can be defined as the combination of automated computational techniques with interactive visual interfaces that leverage human perceptual and cognitive strengths to support analytical reasoning (Keim et al., 2010). Through visual representations and data-driven interactive functionalities, visual analytics enables users to interpret multidimensional datasets, identify patterns, and make evidence-based decisions (Padilla et al., 2018; Islam et al., 2024). Compared with traditional spreadsheet formats, visual analytics operationalize interactive dashboards, graphs, and charts, allowing users to enhance learning by filtering, sorting, grouping, and exploring data visually. This reduces cognitive load, supports pattern recognition, and improves comprehension (Susnjak, 2022; Neri, 2025).

Given these advantages, a growing pedagogical need is to design contextualized visual analytics learning environments, platforms that contextualize data tasks within meaningful, culturally, or personally relevant scenarios. Contextualizing these visual analytics environments with themes like sports or entrepreneurship helps learners to map complex visual information onto familiar conceptual frameworks, thereby strengthening comprehension, motivation, and cognitive efficiency.

Our study employed “The Agent”, game by Business Builders, a sports-context data-analytics learning game developed by ERPsim Lab (Canada), as the experimental stimulus (*Business Builders Software*, 2024). The game provides a highly relevant, sport-based scenario through which learners engage with data-analytics tasks using interactive dashboards, graphs, charts, and analytic functions built within the SAP Analytics Cloud platform. Empirical evidence supports the educational value of sports-based contextualization. For instance, Metcalf et al. (2008) found that incorporating sports-themed scenarios and featuring well-known athletes can heighten student engagement and stimulate greater interest in science and mathematics disciplines. Sports also function as cultural entities that vary widely across geographical regions, this contextualized environment enables participants to explore real-world data operations while navigating a familiar and engaging domain.

However, an important question emerges: Is contextual familiarity alone sufficient to enhance learners’ performance in a contextualized visual analytics environment? Navigating analytical dashboards requires the ability to search, locate, and prioritize relevant information efficiently, skills that vary widely across individuals. This is where visual search propensity becomes central. Visual search propensity refers to a learner’s characteristic ability to efficiently locate, prioritize, and process relevant information within complex visual displays. Eye-tracking research shows that individuals with stronger visual search skills exhibit more efficient fixation patterns, more directed search sequences, and greater attention to task-relevant regions (Harsh et al., 2019).

In the context of visual analytics learning, visual search propensity may therefore determine how effectively individuals interact with dashboards, process visual information, and solve data problems. Contextual familiarity can complement this by supporting quicker recognition of relevant cues, reducing distraction, and facilitating smoother information processing. Together,

these factors may jointly influence how learners experience the environment cognitively, emotionally, and behaviorally.

According to Cognitive Load Theory (Sweller, Ayres, & Kalyuga, 2019), effective learning occurs when learners can manage intrinsic and extraneous cognitive demands to preserve working memory resources for essential processing. Individuals with higher visual search propensity are better equipped to minimize extraneous cognitive load, as they can rapidly identify relevant cues, disregard irrelevant stimuli, and allocate cognitive resources toward understanding and problem-solving. In contrast, learners with low visual search propensity may experience increased mental effort and slower comprehension when faced with densely structured visual information. Therefore, visual search propensity not only influences task performance but also determines how effectively learners can regulate cognitive load within contextualized learning environments, by shaping engagement, attention, and knowledge acquisition (Wolfe, 2020; Sweller et al., 2019).

While past research has individually explored the roles of motivation, cognitive load, and contextualization in technology-enhanced learning, there remains a significant gap in understanding how these dimensions interact within gamified and contextualized STEM environments. Most gamification research has focused on surface-level engagement outcomes (e.g., enjoyment or participation rates) without deeply examining the underlying cognitive mechanisms, such as how learners allocate attention or manage mental effort. Conversely, studies grounded in Cognitive Load Theory (Feldon et al., 2019) have rarely integrated motivational constructs that explain why learners persist in cognitively demanding settings. Similarly, while contextualization has been shown to enhance relevance and motivation (Metcalf et al., 2008; Bouhdana et al., 2023), little is known about how familiar contexts like sports modulate visual attention, cognitive efficiency, and learning performance.

Another critical gap lies in the limited empirical integration of visual search propensity, a measurable indicator of attentional control and cognitive efficiency, into the study of gamified learning. Although eye-tracking studies (e.g., Tsai & Wu, 2021; Argunsah et al., 2025) have demonstrated that visual search behavior reflects cognitive strategy and emotional regulation, few have linked these metrics with contextualized or gamified instructional designs. Moreover, cross-cultural differences in sports familiarity and motivation have seldom been examined as potential moderators of cognitive load and satisfaction in digital learning environments. Thus, the study seeks to address the following research questions:

RQ1: How does visual search propensity influence learners' performance in a contextualized STEM learning environment?

This question explores the extent to which learners' ability to efficiently search and process visual information predicts their learning performance, cognitive experience, and overall satisfaction.

RQ2: To what extent does contextual familiarity (sports familiarity) enhance learners' performance and satisfaction in a contextualized STEM learning environment?

This question examines whether familiarity with the sports context helps learners' visual search behavior facilitate cognition, attention, and emotion, leading to improved learning outcomes i.e. performance and satisfaction. Specifically, it explores how a familiar context may support more efficient visual information processing and heightened engagement, resulting in enhanced performance and satisfaction.

To investigate these relationships, we conducted two experimental studies. The first was a controlled laboratory experiment in Canada designed to examine how learners' visual search propensity influences their performance when interacting with a contextualized visual analytics

platform, and how this effect is moderated by their familiarity with the contextual domain (sports). The second study, conducted in a classroom setting at a private university in India, served as an observational comparison to explore cultural and contextual differences, particularly whether sports, as a culturally salient domain, shapes learners' perceptions of the environment. Ethical approval was obtained for both studies prior to data collection.

Overall, the findings indicate that visual search propensity contributes more strongly to performance when contextual familiarity (sports familiarity) is high, as learners report lower cognitive effort, higher attentional engagement, and more positive emotional states, factors that collectively enhance task effectiveness, efficiency, and satisfaction. Moreover, participants in India, who demonstrated higher sports familiarity, reported greater enjoyment and higher perceived system usability compared to the Canadian sample, who exhibited moderate familiarity with the sports context. These results highlight the joint influence of individual visual search and contextual relevance in shaping learners' experiences within visual analytics environments.

The structure of the thesis follows an article-style format which begins by introducing the research problem and outlining the central research questions. This is followed by a comprehensive literature review that grounds the study theoretically and leads to the development of the hypotheses. The subsequent section details the methodology, including the data collection procedures and the materials and measures used across both studies. We then present the statistical results, highlighting significant effects, interactions, and unexpected findings. The discussion section interprets these results, addressing their implications for theory, practice, and the broader educational and analytics landscape, while also acknowledging the study's limitations and proposing avenues for future research. The thesis concludes by summarizing how the research questions were addressed and identifying the key contributions and takeaways of the study.

Table 1

Student responsibilities and contribution to the thesis

Stage	Contribution
Research Question	Identifying literature gaps, problematisation, and definition of research questions - 60% - Comments from thesis co-supervisors
Literature Review	Conducting research by reading scientific articles concerning the problem and the constructs, writing of literature review - 100%
Experimental Design	Experimental protocol - 80% - Protocol section on tools set-up provided by Tech3Lab team. Business Builders, “The Agent” stimuli - 100% - Developed by ERPsim Lab team used to fully design the stimuli. Video tutorial - 100% Experimental questionnaire - 100% CER application - 10% - A large part of the application was already done by the Tech3Lab team
Data Collection	Pre-tests - 100% Participant recruitment - 50% - Recruitment done through HEC Panelfox and supplemented by word of mouth. Data collection moderation - 100%
Statistical Analysis	Data analysis - 60% - Extraction of data from tools by Tech3Lab team - Advice sought from Tech3Lab statistician. - Data treated and analysed by the student
Writing	Writing the thesis and its component articles - 100% - Comments from thesis co-supervisors

Article

Using Sports Interest to Learn Analytics; The Impact of Contextualization and Familiarity in STEM Learning

Dhanush Soorya Shankar, Pierre-Majorique Léger, Olivier Caya

1.Introduction

Education has long served as a critical engine of societal and economic development, and its significance has only intensified in today's digital era. In recent decades, the importance of science, technology, engineering, and mathematics (STEM) education has grown substantially worldwide, driven by the rising demand for STEM-skilled professionals and the global shift toward innovation-based economies (World Economic Forum, 2023). By cultivating human capital and expanding intellectual capabilities, STEM education enhances societies' capacity for research, technological advancement, and sustainable growth (Mokhtarzadeh & Mokhtarzadeh, 2025).

Despite this increasing demand, a significant skills gap persists. The World Economic Forum reports that over 60% of employers struggle to find workers with adequate STEM and digital competencies, and more than 1 billion individuals will require reskilling or upskilling by 2030 to meet future labor demands. STEM disciplines play a crucial role in equipping learners, particularly Generation Z, with analytical reasoning, creativity, and complex problem-solving skills essential for navigating the challenges of the 21st century (Coulibaly & Keita, 2024). Beyond supporting technological innovation, STEM education fosters the competencies required for workforce readiness and national competitiveness in a knowledge-based global economy. In an era where artificial intelligence and generative AI systems increasingly shape decision-making, automation,

and everyday digital interactions, it has become essential for learners to understand the scientific principles underlying these technologies. Without a strong STEM foundation, individuals and institutions may struggle to evaluate or anticipate the risks associated with advanced automated systems, including unintended model behaviors and large-scale societal consequences (Amodei et al., 2016). Strengthening STEM competence is therefore critical not only for driving innovation but also for ensuring that emerging technologies are used ethically, responsibly, and safely.

However, despite its importance, evidence shows a troubling decline in young people's engagement with STEM. Research indicates that students' STEM aspirations decrease gradually as they progress through school (Dunn, 2024). The latest PISA results further highlight this concern: in 2022, approximately 30% of students across the EU failed to reach basic proficiency in mathematics, an increase from 23% in 2018, while 24% fell below the proficiency threshold in science, up from 22% in 2018. These patterns signal a steady erosion of foundational STEM competencies. Longitudinal studies similarly show that students' interest in STEM declines over time, particularly when learning is perceived as overly abstract, theoretical, or disconnected from real-world relevance (Hu et al., 2022).

Taken together, these trends highlight a pressing challenge: how can educators maintain learners' motivation, interest, and persistence in STEM? Like how diamonds cut diamonds, STEM can be taught more efficiently and effectively by integrating technology directly into the learning process, as digital tools, simulations, and interactive platforms have been shown to enhance conceptual understanding and engagement (National Academies of Sciences, Engineering, and Medicine, 2018). At the same time, the very technologies that support learning can also distract learners through social media, multitasking, and high-stimulation digital environments that compete for attention. Addressing this tension requires finding a middle ground, leveraging technology to

enrich and modernize STEM learning while designing learning experiences that are focused, motivating, and cognitively supportive. Identifying this balance is increasingly essential for creating effective and enjoyable STEM learning environments for contemporary learners. One promising direction is contextualization, embedding STEM learning within meaningful, familiar, and relatable scenarios. Contextualized approaches strengthen engagement, promote deeper understanding, and help students link abstract concepts to real-world experiences, thereby addressing the motivational and cognitive barriers that often undermine sustained interest in STEM.

Bouhdana (2023) highlights the importance of contextualizing learning activities, for instance, in when reading and solving physics problems is contextualized, individuals tend to perform better. When science is presented in a purely theoretical and decontextualized manner, rather than framed in terms of its relevance to society, students often lose interest. Rayner (2012) argues that contextualization is more effective than traditional, decontextualized teaching because it enhances motivation, problem-solving skills, and overall performance. Similarly, Wilkinson (1999) contends that embedding course material in relevant contexts helps prevent students from perceiving physics as abstract and disconnected from everyday life, thereby increasing motivation. Whitelegg and Edwards (2002) add that integrating real-world contexts fosters problem-solving abilities and demonstrates that physics extends beyond rote memorization and formulas. Since each student has unique interests, it is also important to design problems that reflect the diversity of learners' backgrounds and motivations. In education, contextualization refers to embedding abstract academic problems or concepts into meaningful, real-world scenarios, activities, or cultural settings. This approach helps learners relate more easily to the material, sustain

motivation, and transfer knowledge into practical applications (Bouhdana et al., 2023; Bouhdana et al., 2025).

In our study, we focus on contextualizing data analytics, a composite concept encompassing data acquisition, data collection, data validation, data processing, data quantification, data visualization, and data interpretation, tasks that together represent a key applied STEM discipline (ISO/IEC 20546:2019). The global need for data literacy has intensified: industry estimates project more than 97 million new data-driven roles emerging by 2025 across artificial intelligence, machine learning, and analytics (World Economic Forum, 2023). Yet, the supply of trained professionals remains inadequate, with a shortage of approximately 8.5 million data-literate workers worldwide (IBM, 2022). This widening gap underscores the urgency of making data-analytics learning accessible, intuitive, and user-friendly for diverse learners.

As the digital economy expands, learning analytics has become a critical component of STEM education and modern professional training, driven by rapid advances in information technology, artificial intelligence, and data-intensive decision-making environments (Islam et al., 2024; Neri, 2025; Susnjak, 2022). Within this landscape, visual analytics, defined as the integration of computational data processing with human perceptual and cognitive capabilities, has emerged as an effective pedagogical approach. Through interactive visual structures such as dashboards, graphs, and charts, learners can interpret multidimensional datasets, detect patterns, and make evidence-based decisions (Padilla et al., 2018; Islam et al., 2024). Compared with traditional spreadsheet formats, visual analytics support filtering, sorting, grouping, and exploratory manipulation, thereby reducing cognitive load, enhancing pattern recognition, and improving overall comprehension (Susnjak, 2022; Neri, 2025).

Given these advantages, contextualizing visual analytics within meaningful and familiar scenarios is essential for making data-analytics learning more effective, relevant, and enjoyable. Contextualized learning environments allow students to map abstract data operations onto recognizable real-world frameworks, strengthening both comprehension and motivation.

A key factor in the success of contextualized learning is *context familiarity*, which shapes learners' cognitive, emotional, and behavioural engagement with educational materials. In this study, we adopt a sports-themed contextualized learning environment. Sports represent one of the most dominant and emotionally resonant forms of global entertainment, with viewership and fan engagement increasing substantially in recent years, as documented in global sports industry analyses (Nielsen, 2022). The familiarity and excitement associated with sports make them a compelling contextual vehicle for designing gamified learning environments.

Empirical evidence supports the educational value of sports-based contextualization. For instance, Metcalf et al. (2008) found that incorporating sports-themed scenarios and featuring well-known athletes can heighten student engagement and stimulate greater interest in science and mathematics disciplines. Sports also function as cultural entities that vary widely across geographical regions. Gau et al. (2024) demonstrated that Taiwanese pupils showed significantly higher identification and engagement with baseball, a culturally embedded sport, compared to badminton, illustrating how local spectatorship and cultural familiarity strengthen emotional connection and sustained participation. In this study, we used the [“Business Builders”](#) game that embodies this principle: it leverages the SAP Analytics Cloud platform to facilitate enterprise resource training through scenario-based quizzes and a narrative-driven storyline. In this way, Business Builders provides a contextualized learning environment, which serves as the experimental stimulus that focusses on our investigation into whether contextualization influences the learning experience.

However, an important question emerges: Is contextual familiarity alone sufficient to enhance learners' performance in a contextualized visual analytics environment? Navigating analytical dashboards requires the ability to search, locate, and prioritize relevant information efficiently, skills that vary widely across individuals. This is where visual search propensity becomes central. This study conceptualizes visual search propensity as the learner's ability to efficiently locate, prioritize, and process relevant information within a complex visual display. This interpretation aligns with prior eye-tracking research showing that individuals with greater expertise demonstrate more efficient fixation patterns, more directed search sequences, and increased attention to meaningful visual regions (Harsh et al., 2019). These behavioral differences reflect underlying cognitive mechanisms such as selective attention control, efficient mental effort regulation, and structured perceptual organization, processes extensively described in theories of situation awareness (Endsley, 1995). In visually demanding learning environments, whether in digital dashboards or dynamic display systems, these cognitive efficiencies play a critical role in determining how effectively learners extract relevant insights, integrate information, and make accurate decisions (Endsley, 1995).

Eye-tracking research confirms that fixations, saccades, and blinks are not random but are tightly linked to cognitive load and attentional focus (Kastrati et al., 2021). Learners with higher visual search propensity exhibit longer fixations on relevant regions, more systematic gaze paths, and better task outcomes (Argunsah et al., 2025; Tsai & Wu, 2021). Similarly, expert graph readers demonstrate efficient gaze strategies that correspond to deeper comprehension (Harsh et al., 2019). Within contextualized learning environments, visual search propensity becomes even more critical. A familiar and meaningful context, can direct attention, reduce extraneous search effort,

and facilitate smoother information processing. Thus, familiarity operates as an amplifier of visual search efficiency, linking cognitive and motivational dimensions of learning.

This study therefore investigates how visual search propensity and contextual familiarity jointly influence learners' performance, cognitive load, and satisfaction in a gamified STEM learning environment. By integrating cognitive and contextual perspectives, it aims to advance understanding of how attention and familiarity interact to optimize learning in complex, data-rich tasks.

Despite substantial progress in understanding how motivation, cognitive load, and contextualization influence technology-enhanced learning, important gaps remain in how these dimensions function together within gamified and contextualized STEM environments. Much of the existing gamification literature has concentrated on surface-level engagement outcomes such as participation rates or enjoyment, without examining the deeper cognitive mechanisms that underlie learners' interactions with complex visual information. Conversely, work grounded in Cognitive Load Theory (Feldon et al., 2019) has rarely incorporated motivational constructs that explain why learners persist in cognitively demanding situations. Research on contextualization has shown that familiar scenarios enhance relevance and interest (Metcalf et al., 2008; Bouhdana et al., 2023), yet little is known about how such familiarity influences visual attention, cognitive efficiency, or performance when learners must navigate dense analytical dashboards.

A further gap concerns the limited empirical integration of visual search propensity into studies of gamified or contextualized learning. Visual search propensity, a measurable indicator of attentional control and cognitive efficiency, is central to understanding how learners navigate complex data environments, yet it is seldom examined in conjunction with motivational and contextual factors. Eye-tracking studies have shown that visual search patterns reflect cognitive

strategy and emotional regulation (Tsai & Wu, 2021; Argunşah et al., 2025), but these findings have not been meaningfully linked to contextualized or gamified instructional designs. Moreover, cross-cultural differences in contextual familiarity, such as the prominence of sports within regions, have seldom been explored as moderators of cognitive load, engagement, or satisfaction in digital learning environments.

To address these gaps, the present study integrates Cognitive Load Theory (Sweller, 1988) and Self-Determination Theory (Deci & Ryan, 2000) within a sports-contextualized gamified STEM learning platform. This dual-framework approach enables a more comprehensive understanding of both how learners process visual information and why they remain motivated and engaged while doing so. By examining the relationships among visual search propensity, sports familiarity, cognitive and emotional experiences, performance, and satisfaction, this study seeks to illuminate how motivational and cognitive mechanisms jointly shape learning within complex multimedia environments. Two key research questions guide this investigation:

RQ1. How does visual search propensity influence learners' performance in a gamified STEM learning environment?

RQ2. To what extent does contextual familiarity (sports familiarity), enhance learners' performance and satisfaction in such environments?

To explore these questions, we conducted two experimental studies. The first was a controlled laboratory experiment in Canada that examined how visual search propensity shapes performance when interacting with a contextualized visual analytics dashboard, and how this relationship may be moderated by familiarity with the sports context. The second study, conducted in a classroom setting at a private university in India, provided an observational comparison to explore cultural

and contextual differences, particularly in relation to sports as a culturally salient domain. Overall, the findings reveal that visual search propensity contributes more strongly to learning performance when contextual familiarity is high. Learners who were more familiar with the sports context reported lower cognitive effort, greater attentional engagement, and more positive emotional states, factors that jointly enhanced task effectiveness, efficiency, and satisfaction. Participants in India, who demonstrated higher sports familiarity, consistently reported greater enjoyment and higher perceived system usability compared to the Canadian sample, who exhibited moderate familiarity with the sports context. These results underscore the importance of aligning contextual design with learners' prior knowledge and cultural relevance, and they highlight the powerful interaction between individual visual search traits and contextual familiarity in shaping learning experiences within visual analytics environments.

This article deep dives into comprehensive literature review that establishes the theoretical foundation and proposes the hypotheses. The methods section details the data-collection procedures, experimental design, and measurement instruments used across both studies. Statistical results are then presented, highlighting significant findings and relevant interactions. The discussion interprets these findings in relation to theory and practice, outlines implications for educational and analytics-oriented design, and addresses limitations and directions for future research. The thesis concludes with a summary of how the research questions were answered and the key contributions derived from the study.

2. Literature Review

This study is grounded in two complementary theoretical perspectives: Cognitive Load Theory and Self-Determination Theory. As illustrated in Figure 2.1, when gamified STEM learning platforms are contextualized with familiar concepts, in this case, sports, the learning environment becomes more intuitive and engaging. At the same time, an individual's visual search behaviour, particularly their visual search propensity, supports more efficient cognitive processing by reducing extraneous cognitive load, increasing attentional focus, and fostering more positive emotional states. In parallel, the gamified and contextualized nature of the platform enhances intrinsic motivation by supporting autonomy, competence, and relatedness, as outlined by Self-Determination Theory (Sweller, 1988). Together, these cognitive and motivational mechanisms create a reinforcing cycle in which efficient cognition promotes positive emotion, and positive emotion further enhances cognitive efficiency. Ultimately, this interaction leads to improved learning outcomes, reflected in higher performance and greater learner satisfaction. The following sections explain these theories in detail and how it is operationalizing the aspect of contextualized STEM learning.

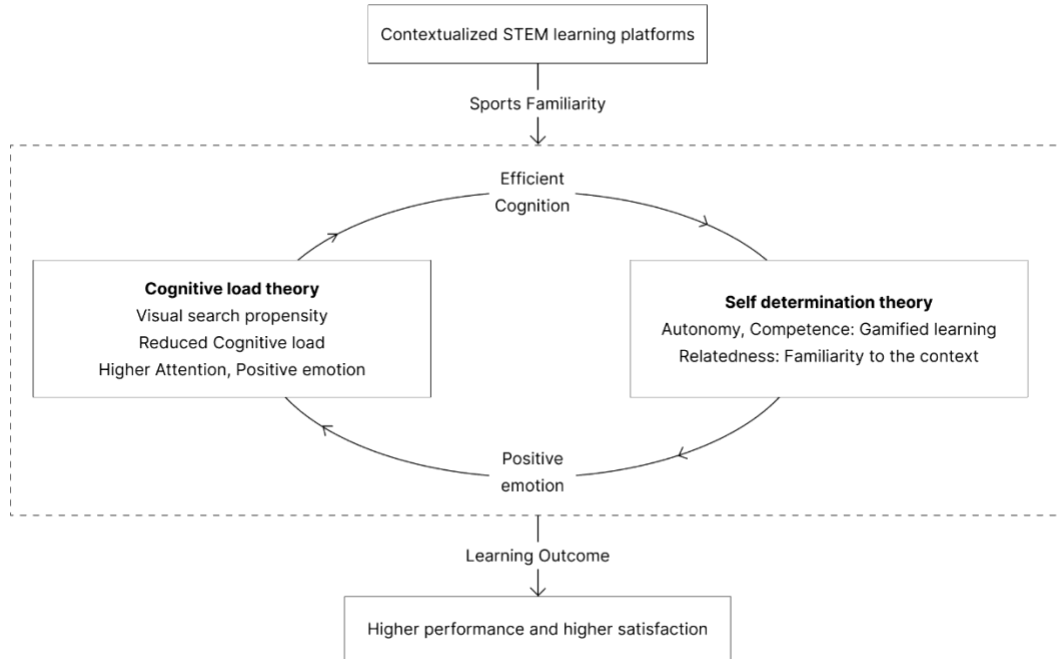


Figure 2.1. Theoretical foundation

2.1. Cognitive Load Theory

Cognitive Load Theory (CLT) describes the role of working memory in learning and how instructional design can either optimize or hinder cognitive processing (Sweller, 2020). CLT identifies three types of cognitive load: intrinsic load, related to the inherent complexity of the content; extraneous load, caused by inefficient or confusing instructional design; and germane load, which promotes learning by supporting schema construction and automation (Sweller, 1988; de Jong, 2010). The overarching goal of any instructional design is to balance these loads so that the learner's cognitive resources are fully engaged but not overwhelmed.

Recent research extends CLT beyond its original cognitive focus to consider the motivational dimension of cognitive effort. Feldon et al. (2019) propose that cognitive load can function as a motivational cost: when demands are too high, learners disengage; when optimally challenging,

they experience flow, an intrinsically motivating state of deep cognitive absorption, enjoyment, and perceived control that emerges when task demands are optimally balanced with an individual's skill level, supporting sustained engagement and learning (Conrad et al., 2019). Importantly, flow is not a static condition but a dynamic process that fluctuates as learners move through changing challenge-skill relationships during task execution (Pearce et al., 2005). In gamified or simulation-based contexts, this balance is particularly salient. Sasayama (2016) notes that task complexity, if well-calibrated, can sustain curiosity and engagement without imposing excessive cognitive strain. Furthermore, individual differences such as conscientiousness and intrinsic motivation shape how learners perceive and regulate cognitive load (De Raad & Schouwenburg, 1996). Thus, CLT provides a robust framework for understanding how visual search efficiency, contextual familiarity, and task design interact to affect learning performance.

2.2. Self-Determination Theory

Self-Determination Theory (SDT; Ryan and Deci, 2000) provides the motivational counterpart to Cognitive Load Theory by explaining why learners choose to engage with learning tasks and persist in them. According to Ryan and Deci (2020), motivation is strongest and most sustainable when it originates from within the learner, referred to as intrinsic motivation, and this form of motivation emerges when three innate psychological needs are satisfied: autonomy, competence, and relatedness. SDT argues that environments which support these needs lead to higher quality engagement, deeper learning, and more positive emotional experiences.

Autonomy refers to the learner's perception of having choice, ownership, and control over their actions. In learning contexts, autonomy is strengthened when learners can make meaningful decisions, explore content at their own pace, or manipulate interactive dashboards or gamified elements according to their preferences. When autonomy is supported, learners feel that their

engagement is self-initiated rather than imposed, which enhances intrinsic motivation and promotes greater investment in the learning process.

Competence reflects a learner's sense of capability, mastery, and effectiveness when interacting with tasks or challenges. Learning environments that provide clear goals, structured feedback, and optimally challenging tasks help learners feel more competent. In the context of STEM dashboards or gamified analytics platforms, features such as immediate feedback, performance indicators, and progressive skill development can reinforce this sense of competence. When learners perceive themselves as capable and successful, they are more motivated to continue engaging and to stretch their skills further.

Relatedness involves feeling connected to others, feeling supported, valued, and part of a community or meaningful social context. Even in individually oriented digital learning environments, relatedness can be fostered through contextualization. For instance, when learning materials are embedded within familiar domains such as sports, learners feel a sense of emotional and cultural connection to the content. This familiarity acts as a form of “psychological relatedness” by making the material feel personally relevant, engaging, and aligned with the learner's identity or interests. Support from instructors, peers, or embedded feedback mechanisms can further reinforce this sense of connection.

Collectively, when autonomy, competence, and relatedness are satisfied, learners experience stronger intrinsic motivation, more positive emotions, and deeper cognitive engagement. In the context of this study, we operationalize sports as an effective contextual element that naturally support these SDT mechanisms. By fostering a sense of relevance, personal connection, and perceived mastery, the sports theme could provide a compelling lens through which to understand

how contextualized and gamified STEM learning environments, particularly those aligned with learners' existing familiarity, can sustain engagement and enhance learning outcomes.

Contextualized STEM learning environments integrated with social features such as leaderboards and collaboration promote relatedness; performance feedback, badges, and progress tracking strengthen competence; and customization, branching scenarios, or role-based choices enhance autonomy. Empirical evidence supports that these psychological needs mediate the relationship between gamification features and sustained learning motivation (Luarn, Chen, & Chiu, 2023).

While CLT explains how learners process information under cognitive constraints, SDT clarifies why they choose to engage in cognitively demanding tasks. Integrating both offers a comprehensive perspective on learning within gamified, contextualized platforms. In this view, motivation derived from autonomy, competence, and relatedness energizes cognitive engagement and sustained attention, whereas efficient management of cognitive load ensures that this motivation translates into effective learning and performance.

2.3. Gamification

Gamification is defined as “the use of game design elements in non-game contexts” (Deterding, Dixon, Khaled, & Nacke, 2011). This concept emphasizes the selective application of design components, such as points, levels, badges, leaderboards, progress bars, or challenges, rather than the creation of complete games. These elements are purposefully adapted to enhance motivation, engagement, and user experience in otherwise non-game environments like education, business, or health. Deterding et al. (2011) argue that such “gameful” designs encourage users to experience enjoyment and commitment in performing tasks that would otherwise feel routine or abstract.

Empirical research supports this view: Leung et al. (2023) found that personalized gamification features can strengthen self-regulated learning and improve online learning outcomes, while Santhanam et al. (2016) demonstrated that well-designed competitive structures can enhance engagement and performance in technology-mediated training. Alam et al. (2023) notes higher education has shown that gamified environments, particularly when integrated into learning dashboards, can significantly improve student engagement, motivation, and achievement. Their research investigated a gamified learning analytics dashboard in a large undergraduate STEM course and found that students who used the dashboard achieved 13% higher final grades than those without access to it, highlighting the effectiveness of gamified progress trackers, rewards, and leaderboards in sustaining motivation and supporting self-regulation. Students reported that the dashboard made their coursework more organized, visually engaging, and rewarding, transforming otherwise complex material into an interactive experience.

Overall, gamification serves as a bridge between intrinsic motivation and instructional design, creating learning environments that sustain engagement and foster deeper cognitive processing. When combined with analytics or feedback systems, gamified tools not only stimulate curiosity and persistence but also make learning more transparent and enjoyable.

2.4. The Notion of Contextualization

The notion of contextualization refers to the embedding of abstract academic problems or concepts into meaningful, real-world scenarios, activities, or cultural settings that reflect learners' lived experiences. Rooted in situated cognition theory, contextualization connects knowledge with the social and material contexts in which it is developed or applied, thereby enhancing meaning-making and knowledge transfer (Bouhdana et al., 2023). When students engage with learning

materials that mirror familiar settings, whether professional, societal, or cultural, they are better able to relate to the content, sustain motivation, and perceive its relevance.

Prior research has emphasized that purely theoretical and decontextualized instruction often leads students to disengage, particularly in disciplines such as physics, where the abstract nature of the material can feel disconnected from everyday life (Rayner, as cited in Bouhdana et al., 2023). Embedding course material in relevant contexts enhances problem-solving skills, fosters curiosity, and allows learners to see how scientific principles operate beyond rote memorization. Wilkinson (1999) and Whitelegg (2002) further suggests that situating learning tasks within relatable scenarios promotes deeper conceptual understanding and encourages learners to connect knowledge to real-world applications. These benefits, however, depend heavily on the degree to which the chosen context aligns with students' interests, values, and prior experiences.

Nevertheless, Bouhdana et al. (2023) caution that contextualization is not universally effective. Using psychophysiological measures such as electrodermal activity, pupillometry, and EEG, their study found that while contextualization may influence emotional engagement, it does not always improve cognitive engagement or performance and may even introduce additional cognitive load in unfamiliar contexts. This indicates that effective contextualization must account for learners' cultural and experiential backgrounds. Contexts perceived as irrelevant or misaligned with learners' identities may hinder rather than enhance engagement. Thus, contextualization is most powerful when learners see the content as meaningful within their own social and cultural frameworks.

This study focusses on sports-based contextualization, which provides a compelling illustration of these principles. Based on Metcalf's (2008) My Sports Pulse project, implemented across five global locations, used mobile sports-themed scenarios and celebrity athlete narratives to teach

math and science concepts to middle school students. Findings from its pilot study revealed substantial gains in student engagement and interest in STEM disciplines, as learners reported higher motivation and enjoyment when lessons were tied to familiar sports events and cultural references (Metcalf et al., 2008). These outcomes suggest that contextualization through familiar concepts like sports, when combined with gamified learning methods, can successfully bridge the gap between theoretical knowledge and practical understanding, making learning both cognitively efficient and motivating.

2.5. Familiarity to the context

Familiarity with a learning context enhances engagement, lowers cognitive load, and supports better performance. When learners encounter content within a setting they already recognize, such as sports, they can process information more efficiently and stay motivated, as their prior knowledge and emotional connection reduce the mental effort required for understanding new material. This aligns with Cognitive Load Theory, which posits that familiar contexts reduce extraneous processing, enabling learners to focus on essential cognitive activities.

Recent empirical studies reinforce this relationship between familiarity and learning. Sports-themed educational interventions have been shown to heighten motivation and curiosity by connecting lessons to contexts that learners already value (Bhadra et al., 2024). Likewise, Drazan et al. (2017) found that introducing basketball analytics to underrepresented youth increased self-efficacy and STEM interest, illustrating that emotionally resonant sports contexts make abstract concepts more approachable and engaging.

Cultural background further shapes which sport or activities feel familiar, enjoyable, and emotionally meaningful. Gau et al. (2024) demonstrated that Taiwanese pupils showed

significantly greater identification and engagement with baseball, a culturally embedded sport, than with badminton, highlighting how social context and local spectatorship opportunities shape emotional connection and sustained participation. This cultural affinity creates a self-reinforcing loop of recognition, identification, and motivation, suggesting that individuals are more likely to engage deeply with learning environment framed within culturally familiar sports. Global media patterns further illustrate this point: sports fandom is highly regional, with European markets showing dominant engagement with football, while U.S. audiences concentrate their viewership around leagues such as the NFL and NBA (Nielsen, 2022). From this we propose when learners encounter data drawn from sports they culturally identify with, the learning interface feels more intuitive and personally relevant. Therefore, cultural familiarity strengthens intrinsic motivation and supports smoother cognitive processing, serving as a bridge between emotion, attention, and performance, making contextualized learning experiences both inclusive and impactful.

In this study, these cultural dynamics are particularly relevant, as participants come from two culturally distinct contexts, Canada, and India. By presenting sports-based visual analytics learning platform to both groups, the study examines whether cultural familiarity influences how effectively learners navigate the dashboard, locate task-relevant information, and experience satisfaction during the STEM learning experience leading to enhanced enjoyment and usability of the learning environment. Consequently, operationalizing culturally relevant and familiar concepts within learning environments has the potential to produce richer learning experiences and more effective outcomes, particularly in diverse, globalized educational settings.

2.6. Visualizing applied STEM concepts.

When applying STEM learning to real-world contexts, the disciplines naturally expand into data science and analytics, domains that have become essential for shaping modern technologies and

meeting today's digital demands. As Provost and Fawcett (2013) note, data science centres on extracting useful knowledge from data to improve real-world decision-making, making analytics a critical skill in contemporary professional environments. Consequently, it is increasingly important to make the learning of data science and analytics accessible, intuitive, and user-friendly for diverse learners. Learning analytics has therefore become an important component of STEM education and modern professional training, driven by the rapid expansion of information technology, artificial intelligence, and data-intensive decision environments (Islam et al., 2024; Neri, 2025; Susnjak, 2022). As organizations rely more heavily on data-driven strategies, individuals must learn to interpret large datasets, identify patterns, and generate insights that support complex problem solving.

Visual analytics, understood as the integration of computational data processing with human perceptual and cognitive capabilities, has emerged as an effective approach for developing essential data-analytic skills, including interpreting complex datasets, identifying patterns, and making evidence-based decisions (Padilla et al., 2018; Islam et al., 2024). Unlike traditional spreadsheet formats, interactive dashboards, graphs, and charts enable learners to engage with data through visual structures that support filtering, sorting, grouping, and exploratory manipulation, thereby reducing cognitive load and enhancing comprehension (Susnjak, 2022; Neri, 2025). Research shows that dashboards facilitate sensemaking by presenting complex information in visual forms aligned with human perceptual mechanisms such as pre-attentive processing, selective attention, and spatial reasoning (Borkin et al., 2013; Nielsen Norman Group, 2017). As a result, dashboards improve accessibility for novice learners while allowing experts to work more efficiently by revealing trends, anomalies, and meaningful data relationships. Across business domains, including sales, marketing, customer relationship management, and enterprise resource

planning, organizations have shifted from static tables to dynamic dashboards to support faster and more informed decision-making (Susnjak, 2022; Neri, 2025). Because effective dashboard use depends heavily on a user's ability to visually search for, locate, and interpret relevant information, developing strong visual analytics skills has become essential for both academic learning and professional practice (Pozdniakov et al., 2025). Thus, learning analytics through dashboards is not merely a pedagogical preference but a strategic requirement for preparing individuals to thrive in increasingly data-driven digital ecosystems.

In this study, our interest lies in understanding how familiar contextualized learning methods, particularly in environments where data analytics concepts are contextualized will improve comprehension and learning experience. Contextualized dashboards are designed to guide learners toward relevant information and to support efficient problem solving by structuring complex datasets visually. However, an important question arises: even when the dashboard is well-designed, do all individuals search, navigate, and extract information with equal efficiency?

In other words, is there a personal, individual difference in visual searching ability that influences how effectively a learner can make use of a dashboard? This inquiry leads to the core construct of this study, visual search propensity, which captures a user's inherent tendency and cognitive efficiency in locating, prioritizing, and interpreting visual information within complex data displays. Evidence from dashboard-use research shows that individuals with higher visualization-related abilities can interpret dashboards more deeply, rely on multiple visual representations, and construct richer explanations, whereas those with lower skills often exhibit shallower interpretations and depend on single visual cues such as colour or individual chart elements. For example, Pozdniakov et al. (2024) show that users with low visualization literacy produce "shallower dashboard interpretations," rely on single visualizations, and have difficulty

triangulating evidence, whereas high-literacy users engage in deeper, multi-visualization interpretations and more advanced reasoning about visual information. Understanding visual search propensity is therefore critical for explaining why some learners benefit more from visual analytics dashboards than others, and how individual differences shape the overall learning process.

2.7. Visual Search Propensity

Visual search propensity can be understood as an individual's efficiency in scanning, locating, and processing visual information to achieve a task-relevant goal, a capacity that varies reliably across people (Cain & Mitroff, 2013). Research in visual attention demonstrates that individuals differ in the speed and accuracy with which they identify targets, filter distractors, and navigate complex visual displays, reflecting stable cognitive-perceptual traits (Boot et al., 2006). In learning environments mediated by dashboards, gamified systems, or interactive interfaces, these differences offer insight into how attention, perception, and cognitive control shape performance and user experience.

Eye-tracking research shows that gaze behavior provides a direct window into cognitive processing. Fixations and fixation durations reflect the depth of information processing, while saccades represent shifts in attention and exploratory search strategies (Kennedy et al., 2016). As summarized by Eckstein et al. (2017), visual search efficiency is tightly linked to attentional allocation, perceptual organization, and decision-making strategies, meaning that “where learners look” provides meaningful evidence of “how they think.” Pupillary responses further index cognitive effort and arousal, offering additional insight into mental workload during information processing.

Together, fixation patterns, saccadic movements, and pupil dilation capture the dynamic interplay between perception and higher-order reasoning. These measures have been used to assess how individuals manage cognitive load, regulate attention, and adapt to visually complex learning environments (Kastrati et al., 2018). Thus, visual search propensity, operationalized as an individual's efficiency in navigating visual information, serves as a foundational mechanism underlying performance in data-rich and visually demanding learning contexts.

2.8. Visual Search Propensity and Performance

Empirical evidence demonstrates that visual attention influences both performances, the ability to locate information and solve problems, and affective states in visual analytics learning contexts (Tsai and Wu, 2021). Learners with high visual search propensity who directs visual search toward irrelevant information during online problem solving would experience higher information anxiety and lower performance, while efficient visual selection predicted better accuracy and reduced cognitive strain. Their clustering analyses identified three broad visual search patterns, Confused, Slow-thinking, and Fast-thinking, which differed in attentional control and decision speed. These findings indicate that efficient search patterns, characterized by purposeful fixations and reduced redundancy, correspond with greater cognitive efficiency and emotional stability.

Similarly, Argunşah et al. (2025) observed that learners' gaze patterns and fixation consistency correlate strongly with academic performance, particularly among students with visual learning preferences. In their study of Turkish medical students, those with stronger visual learning orientations demonstrated more stable fixation metrics and higher-grade point averages, suggesting that visual search efficiency may reflect not only perceptual skill but also broader cognitive adaptability and strategy use. This supports the notion that attentional precision and visual information integration underpin successful learning in complex, multimedia-based tasks.

When learners interact with visual analytics tasks embedded in a familiar contextualized environment, their visual search propensity is likely to improve; this enhanced ability to locate task-relevant information subsequently drives higher effectiveness, greater efficiency, and stronger satisfaction with the learning experience. In dashboard-based STEM tasks, performance is therefore understood not simply in terms of correctness or completion time alone, but through the learner's capacity to identify, extract, and integrate the visual information required to solve the problem. Performance in this environment depends on how smoothly learners navigate dashboards, filter irrelevant cues, and detect the visual patterns that support accurate and efficient decision-making.

Effectiveness refers to the learner's ability to produce correct responses within the contextualized learning environment, whereas *efficiency* reflects the time required to achieve those successful responses. Together, these measures capture both the task accuracy and task response time, providing a comprehensive assessment of task performance.

Satisfaction constitutes a complementary dimension of learning outcomes that is defined as the degree to which users' needs, expectations, and goals are fulfilled during their interaction with the learning environment (Elliott & Shin, 2002). Prior research indicates that task performance, including higher success rates and reduced completion time, is a strong predictor of user satisfaction, as efficient and competent task execution tends to evoke more positive evaluations of the learning experience (Bhattacharjee, 2001).

In this study, we are interested to see how performance, our main dependent variable, differs, based on individuals' visual search propensity. Therefore, we propose that individuals with stronger visual search propensity, those who can more effectively locate, filter, and integrate task-relevant visual information, will exhibit superior performance in dashboard-based visual analytic tasks.

H1A. Higher visual search propensity will be associated with higher performance (effectiveness and efficiency) while interacting in a contextualized visual analytic learning environment.

2.9. Visual Search Propensity and Cognitive Behaviour

Within the framework of Cognitive Load Theory, visual search propensity reflects how efficiently learners manage limited working memory resources when interacting with visually complex information. Learners with higher visual search propensity, those who can quickly discriminate relevant cues from distractors, expend less extraneous cognitive load and can allocate greater cognitive resources to meaningful information processing. This ability becomes especially critical in visual analytics environments, where dashboards, charts, and graphs must be scanned, interpreted, and acted upon under time constraints.

In the context of dashboard-based STEM learning, the cognitive challenge lies not only in reading individual visual elements but in integrating them to solve a problem. When visual search propensity is low, learners spend more time navigating irrelevant details, leading to increased cognitive effort, slower decision-making, and reduced accuracy. When it is high, learners can extract the correct information more efficiently, resulting in smoother cognitive processing and improved task performance.

Moreover, familiarity with the contextual domain equips learners with prior knowledge about where to look and what information is likely to matter, which is especially valuable in complex dashboard environments. When learners already understand the structure, terminology, and logic of a context, such as scores, player metrics, or standard rules in sports, they can more efficiently narrow their visual search to task-relevant regions of the dashboard. This reduces the need to

interpret unfamiliar terms or decode new conventions, enabling them to filter irrelevant cues and identify meaningful patterns much more quickly. In a sports-context visual analytics platform, for instance, learners who are familiar with the sport can map visual elements (e.g., run rates, player performance charts, match status indicators) to their existing mental models. This accelerates the search for solutions, increases accuracy, and strengthens the overall cognitive fluency of the learning interaction.

In this study, we assess visual search propensity using three established paradigms (Kastrati et al., 2021), antisaccade, large grid, and visual symbol search. These tasks measure the efficiency with which individuals orient their gaze, inhibit distractions, and identify relevant information under time pressure. Prior research demonstrates that such paradigms reflect attentional control and processing speed, both essential components of successful problem-solving in data-analytic environments. These paradigms will be discussed in detail in the methods section.

Thus, in the context of contextualized STEM learning, we conceptualize visual search propensity as a behavioural indicator of cognitive efficiency and attentional engagement. Consistent with this framework, we propose:

H1B. Higher visual search propensity will be associated with lower cognitive load in contextualized visual analytics learning environment.

H1C. Higher visual search propensity will be associated with higher attentional engagement in contextualized visual analytics learning environment.

2.10. Visual search propensity and Emotion

In this study, emotional experience is conceptualized through the circumplex model of affect, in which valence refers to the pleasantness of an emotional state (ranging from unpleasant to pleasant)

and arousal denotes the degree of physiological and psychological activation (ranging from low (ex: calmness) to high activation (ex: excitement or alertness) ; Posner, Russell, & Peterson, 2005; Russell, 1980, 2005, Ekman, 1999). Within visual-analytics learning environments, individuals' visual search propensity, the efficiency with which they detect and integrate task-relevant visual cues, plays a central role in shaping these emotional responses.

When learners engage in efficient visual search, they locate relevant information more quickly, ignore distractors, and navigate dashboards with greater perceptual fluency. This reduction in perceptual and cognitive friction supports smoother task execution and decreases cognitive effort. Such experiences are closely tied to positive emotional states. According to Fredrickson's (2001) broaden-and-build theory of positive emotions, positive affect arises when individuals experience clarity, cognitive ease, and situational control. These positive emotions do more than enhance momentary experience; they broaden attentional scope, facilitate exploratory behavior, and promote deeper engagement with the task. Within visual analytics learning environments, this broadening effect may manifest as increased willingness to inspect multiple dashboard components, consider alternative problem-solving strategies, and maintain sustained interaction with the system.

Conversely, inefficient visual search behavior, characterized by redundant fixations, distractor attention, or difficulty locating key elements, can increase cognitive strain and disrupt attentional flow. These conditions elevate the likelihood of negative or neutral valence and may suppress arousal, reducing the learner's engagement with the task. When learners perceive low control or high task difficulty, emotional states associated with frustration, anxiety, or disengagement become more likely (Fredrickson, 2001).

The broaden-and-build framework also suggests that positive emotion and engagement operate in an upward spiral: efficient visual processing promotes positive affect, which in turn broadens attention, increases curiosity, and enhances sustained engagement (Fredrickson, 2001).

Taken together, these theoretical foundations suggest that emotional outcomes in dashboard-based STEM learning environments are closely tied to learners' visual search patterns. Accordingly, we expect that individuals with higher visual search propensity will experience both greater positive valences, due to reduced cognitive conflict and smoother task flow, and higher arousal, reflecting increased attentional activation and engagement.

H1D: Higher visual search propensity will be associated with more positive emotional valence and higher arousal while interacting in a contextualized visual analytic learning environment.

2.11. Contextual Familiarity and Its Interaction with Visual Search Propensity

Contextual familiarity is well-established as a key factor shaping learners' cognitive efficiency and emotional engagement. When instructional contexts align with learners' prior knowledge and lived experience, they reduce cognitive load, enhance attentional fluency, and increase motivation and affective involvement (Sweller et al., 2019; Bouhdana et al., 2023). Evidence from educational psychology demonstrates that familiar contexts significantly enhance learners' ability to transfer conceptual knowledge and apply it in problem-solving tasks (Kulasegaram et al., 2012). In their study, learners performed substantially better on cases presented in familiar contexts than in novel contexts, even when the underlying concepts were identical, indicating that contextual alignment reduces cognitive burden and improves conceptual accessibility. This cognitive easing enables learners to allocate more working memory resources to germane processing, facilitating more

fluent interaction with the visual analytics dashboard. Thus, contextual familiarity can meaningfully amplify the efficiency of visual search processes by allowing learners to rely on well-established semantic schemas and attentional patterns when interacting with complex visual-analytic tasks.

Familiar contexts are also strongly associated with greater attentional stability and more positive emotional engagement, as learners tend to be more motivated and confident when interacting with materials that resonate with their existing interests or identity. Ladson-Billings (1995) emphasizes that culturally familiar and personally meaningful content strengthens learners' sense of identification and relevance, which in turn enhances motivation and sustained engagement. Cultural relevance thus becomes a powerful dimension of familiarity: learners' cultural backgrounds shape what they perceive as meaningful, enjoyable, or intuitively understandable. When learning materials incorporate culturally familiar concepts, such as widely followed sports, music, or community practices, learners experience a reinforcing cycle of recognition, identification, and motivational readiness. This cultural affinity supports smoother cognitive processing and deeper emotional involvement, ultimately making contextualized learning environments more inclusive, engaging, and effective.

In the present study, STEM learning is contextualized through a sports-based visual analytics environment, making cultural familiarity especially salient. Global media patterns demonstrate that sports fandom is highly regional, with different countries showing strong preferences for specific sports; for example, European markets display dominant engagement with football, while U.S. audiences continue to concentrate their viewership around major leagues such as the NFL and NBA (Nielsen, 2022). Such evidence supports the assumption that learners who identify strongly with a sport will process information embedded in that sporting context more fluently.

Familiar visual environments have been shown to facilitate faster target detection, more selective attention to relevant cues, and reduced distraction, thereby supporting more efficient visual search behavior (Yang et al., 2023). Similarly, visual analytics dashboard when contextualized within a culturally familiar theme like sports, learners could be better able to interpret the presented data, selectively attend to relevant cues, and suppress irrelevant distractors, ultimately improving the efficiency of their visual search behavior.

Contextual familiarity therefore acts as a supportive cognitive support, enhancing engagement, attention, and emotional experience while reducing cognitive effort (Sweller et al., 2019; Metcalf et al., 2008). Learners who are familiar with the contextual content, such as a culturally resonant sport, are more likely to sustain engagement, experience greater enjoyment, and perform more efficient information-search behaviors within visual analytics tasks, as familiarity has been shown to facilitate faster detection of relevant cues and reduce distractor interference (Gau et al., 2024; Nielsen, 2022; Yang et al., 2023).

For these reasons, contextual familiarity is conceptualized as a moderator that strengthens the relationship between visual search propensity and cognitive-emotional processes (Gau et al., 2024; Metcalf et al., 2008). Specifically, learners who possess both high visual search propensity and strong familiarity with the sports context are expected to experience greater cognitive efficiency and enhanced emotional engagement during task performance.

H2A. Higher visual search propensity will be associated with lower cognitive load when contextual familiarity is high while interacting in a contextualized visual analytic learning environment.

H2B. Higher visual search propensity will be associated with greater attentional engagement when contextual familiarity is high while interacting in a visual analytic learning environment.

H2C. Higher visual search propensity will be associated with more positive emotional valence and higher arousal when contextual familiarity is high while interacting in a contextualized visual analytic learning environment.

2.12. Cognitive and Emotional Predictors of Performance and Satisfaction

Drawing from Cognitive Load Theory and affective-cognitive models of learning, we hypothesize that visual search propensity, through its effects on cognitive load, attentional engagement, and emotional state, functions as a behavioural mechanism that directly shapes performance and satisfaction. Performance in our context, can be explained as when learners can locate task-relevant visual information quickly (efficiency) and accurately (effectiveness), they experience smoother cognitive processing, greater clarity, and fewer disruptions, which in turn promote positive emotion and enhanced engagement. Lower cognitive load enables learners to devote more resources to germane processing; higher attentional engagement supports sustained focus and more efficient information processing; and positive emotional states foster motivation, approach behaviour, and cognitive flexibility. As learners achieve successful performance under conditions of manageable cognitive demand and favourable emotional experience, they become increasingly motivated to persist with subsequent tasks under similarly optimal cognitive-emotional conditions. Thus, the effects of visual search propensity, via the mediating factors, cognitive load, attention, and emotion, improves performance with the learning experience. Thus, we hypothesize,

H3A. Lower cognitive load will be associated with higher performance while interacting in a visual analytic learning environment.

H4A. Higher attentional engagement will be associated with higher performance while interacting in a contextualized visual analytic learning environment.

H5A. More positive emotional states (higher valence and arousal) will be associated with higher performance while interacting in a contextualized visual analytic learning environment.

Secondly, satisfaction, our secondary dependent variable, represents a core evaluative outcome of learners' overall experience in the contextualized visual analytics environment. Consistent with technology-mediated learning research, satisfaction reflects the extent to which participants feel that the system met their expectations, supported their goals, and provided a positive and rewarding experience (Elliott & Shin, 2002). In this study, satisfaction is conceptualized as the culmination of learners' cognitive, attentional, emotional, and performance-related experiences while interacting with the STEM learning platform.

From a cognitive perspective, lower perceived cognitive load is expected to enhance satisfaction because tasks that feel manageable and mentally fluent tend to produce more positive evaluative judgments. When users expend fewer cognitive resources on unnecessary search or interpretation demands, they experience smoother task progression, which typically results in higher satisfaction (Sweller et al., 2019). Accordingly, we hypothesize that:

H3B. Lower cognitive load will be associated with higher satisfaction while interacting in a contextualized visual analytic learning environment.

Similarly, attentional engagement plays a central role in shaping users' overall experience. When learners can concentrate effectively on task-relevant elements without distraction, they are more likely to report higher levels of enjoyment and satisfaction (Jennett et al., 2008). Attention facilitates a sense of control, positive emotion, and immersion, which has been shown to positively influence subjective evaluations of learning interfaces. Thus:

H4B. Higher attentional engagement will be associated with higher satisfaction while interacting in a contextualized visual analytic learning environment.

Emotional experience is also a key determinant of satisfaction. Positive valence and moderate-to-high arousal promote motivational readiness, task interest, and a general sense of enjoyment, factors strongly tied to satisfaction in educational and interactive systems (Russell, 1980; Posner et al., 2005). As visual search efficiency reduces frustration, increases fluency, and produces more positive affect, learners are likely to feel more satisfied with the overall experience. Therefore:

H5B. More positive emotional states (higher valence and arousal) will be associated with higher satisfaction while interacting in a contextualized visual analytic learning environment.

Together, these hypotheses position satisfaction as a downstream experiential outcome shaped jointly by cognitive load, attentional engagement, emotional state, and performance.

2.13. Relationship between Performance and Satisfaction

In dashboard-based STEM learning environments, strong performance is expected to emerge when learners experience lower cognitive effort, higher attentional engagement, and more positive emotional states, conditions that become more likely when visual search propensity is high, and the visual analytics environment is contextualized in a familiar domain. Prior research shows that

efficient cognitive processing and successful task execution contribute significantly to learners' subjective evaluations of the learning experience, as reduced cognitive strain and smoother task progression lead to greater perceived competence and satisfaction (Bhattacharjee, 2001; Elliott & Shin, 2002). Satisfaction, as a key dimension of learning experience, reflects the degree to which learners feel their expectations, needs, and goals have been met. Therefore, consistent with the well-established relationship between performance and subjective evaluation in technology-mediated learning, we propose the following hypothesis:

H6. Higher performance will be associated with higher satisfaction.

2.14. Research Model

The proposed research model (Figure 2.2) outlines how visual search propensity and contextual familiarity jointly influence learning outcomes in visual analytics learning environment. Visual search propensity is treated as an individual trait that shapes how efficiently learners scan, locate, and process task-relevant visual information. In parallel, contextual familiarity, in this study operationalized as sports familiarity, is conceptualized as a person-specific factor that enhances comprehension, attentional readiness, and emotional engagement when interacting with a learning environment grounded in a familiar domain.

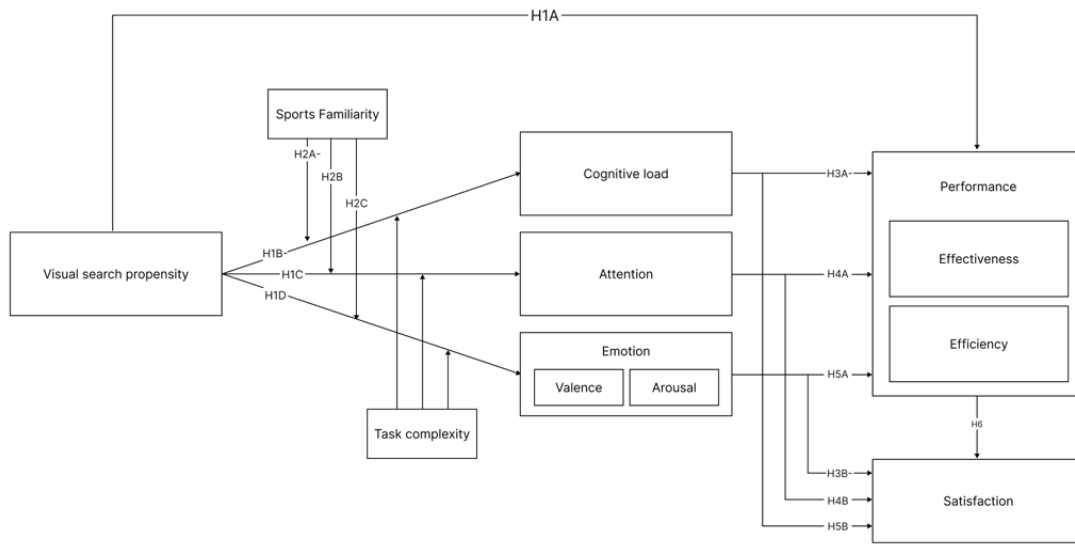


Figure 2.2. Research Model

The model posits that both visual search propensity and sports familiarity influence three core cognitive-affective processes: cognitive load, attention, and emotion (valence and arousal). These processes serve as proximal behavioural indicators of how learners experience and manage information in dashboard-driven tasks. Lower cognitive load, higher attentional engagement, and more positive emotional states are theorized to facilitate smoother information processing, enabling learners to identify relevant cues, filter distractions, and make accurate decisions more efficiently.

These cognitive-affective processes subsequently shape performance, operationalized through effectiveness (accuracy of responses) and efficiency (time taken to reach correct solutions). As demonstrated in prior research, successful performance, particularly when achieved with manageable cognitive effort, directly contributes to higher satisfaction, defined as the degree to which learners feel that the system meets their expectations and supports their goals.

2.15. Task Complexity

Task complexity is integrated as an exploratory variable that may influence the relationship between learners' individual traits and their cognitive-affective experiences. In visual analytics tasks, complexity can arise from several sources, such as the number of indicators to monitor, the need to combine multiple analytical operations, or the presence of visually dense dashboards requiring extensive search.

For instance, individuals with high visual search propensity and strong sports familiarity may or may not continue to perform effectively when task complexity increases. High-complexity tasks may require multiple steps of reasoning or multiple graphical interpretations before reaching a correct solution. Even learners with strong visual search skills may feel challenged if the interpretive demands exceed their working-memory capacity or if the visual search space becomes increasingly cluttered.

Because existing research provides limited evidence regarding how task complexity interacts with visual search propensity in dashboard-based learning environments, this study incorporates task complexity to explore whether:

1. complexity diminishes or strengthens the influence of visual search propensity,
2. familiar contexts buffer the cognitive load associated with complex tasks, and
3. performance (effectiveness, efficiency) remains stable across increasingly challenging problem-solving trials.

This exploratory angle allows the study to examine whether the theorized model holds consistently or whether complexity introduces meaningful variation in cognitive load, attention, emotion, and ultimately influencing task performance and user satisfaction.

3. Materials and Methods

3.1. Research Design

This research followed a two-phase methodological approach designed to address the two central research questions. Ethical approval for both studies was obtained (Certificates: 2025-6355 and 2025-6413). To ensure confidentiality, all personally identifiable information was removed during data handling, and participants were assigned anonymized identification numbers for post-processing of the collected data.

The first phase, conducted in Canada, addressed RQ1: How does visual search propensity influence learners' performance and satisfaction in a gamified STEM learning environment? This phase took place in a controlled UX laboratory setting, where participants' visual search propensity was measured alongside cognitive, emotional, and performance metrics using both psychophysiological sensors and behavioural indicators.

The second phase focused on RQ2: To what extent does contextual familiarity (sports familiarity) enhance learners' performance and satisfaction in a gamified STEM learning environment? This study was carried out in a classroom environment at a private university in India. It examined how contextual familiarity and cultural background shape learners' affective and evaluative responses, including satisfaction, enjoyment, and usability and provided a comparative perspective relative to the Canadian sample.

3.2. Experimental Design and stimuli

For the Phase 1 Canada sample (laboratory), the study employed a within-subject experimental design in which all participants completed a series of visual analytics tasks under standardized conditions. A quantitative approach was used to collect behavioural, psychophysiological, and

self-reported data. All participants followed a structured protocol that included a welcome briefing, informed consent procedures, an overview of the task sequence, interaction with the gamified learning platform, and completion of post-experience questionnaires.

Figure 3.1 explains the timeline of how the protocol was designed to uphold participant autonomy while maintaining consistency across all sessions.

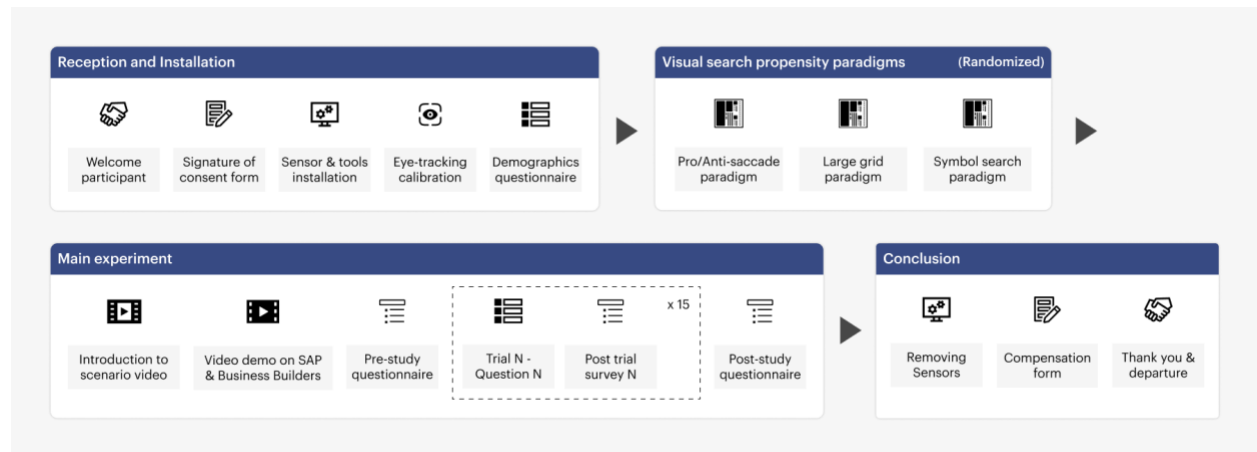


Figure 3.1. Experimental design

The primary experimental stimulus was *The Agent* by Business Builders (*The Agent game*, 2025; *Business Builders Software*, 2024), sports-context data analytics learning game developed by ERPsim Lab (Canada). This gamified STEM learning environment integrates SAP Analytics Cloud (SAC) to present a sports-themed, data-driven decision-making context. Learners assume the role of a sports agent responsible for interpreting dashboards, managing player contracts, and making financial and strategic decisions based on real-time data visualizations. The platform's design operationalizes key Self-Determination Theory (SDT) components: Autonomy through decision-making freedom in dashboard navigation and data manipulation, Competence via feedback, scoring, and visible progress indicators, and Relatedness through familiar sports-themed narratives and contextual cues.

By connecting analytic reasoning with the familiar, high-interest world of sports, this contextualized design aims to reduce extraneous cognitive load and increase engagement, aligning with the broader evidence that meaningful, culturally relevant contexts can enhance learners' motivation and performance. The choice of sports as a contextual frame is deliberate: as sports are inherently practical, engaging, and widely relatable, often fostering both interest and discipline.

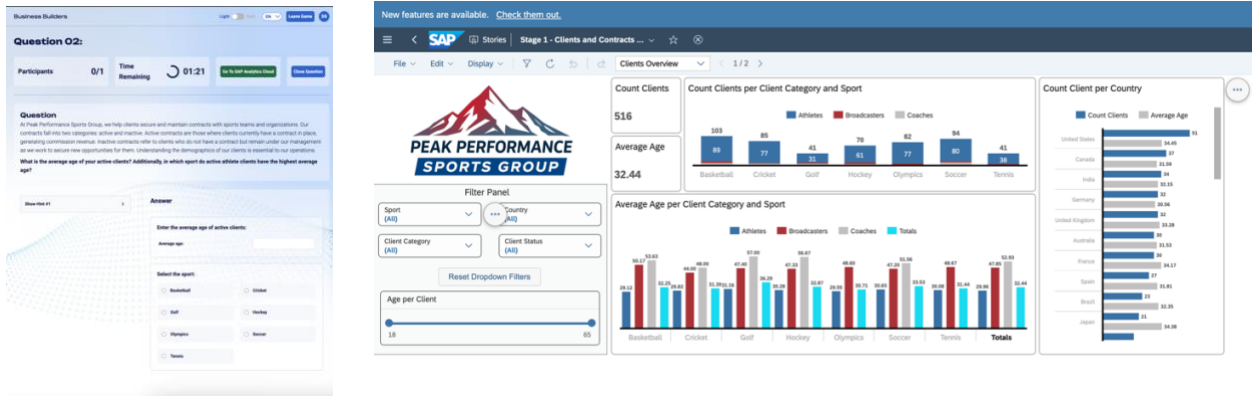


Figure 3.2. Business builders & Figure 3.3. SAP analytics cloud

Two digital interfaces employed in this study was Business Builders Quiz Environment (Figure 3.2), where participants viewed and responded to quiz questions. SAP Analytics Cloud Dashboard (Figure 3.3), containing a customized dataset, graphs and charts required to solve those questions. To establish familiarity with the game context and ensure that all participants understood how to navigate the Business Builders and SAP Analytics Cloud interfaces, an introductory video explaining The Agent game was shown, followed by a tutorial video demonstrating the task procedures and required analytical operations. These videos were presented to every participant prior to the start of the experiment.

Participants completed 15 quiz trials, each requiring them to locate, interpret, and integrate visual information from the SAC dashboards to answer the corresponding questions. During the trials,

the complexity of the tasks was systematically manipulated from easy to difficult in a sequential order, allowing us to examine whether increases in analytical and visual demands influenced participants' cognitive load, emotional states, attentional engagement, and task performance. Complexity in this study was defined as the objective number of steps required to derive the correct solution from the dashboard interface. For each trial, we calculated the minimum sequence of necessary actions, and this value served as the complexity index. This operationalization aligns with cognitive problem-solving theory, which posits that tasks involving more steps, information integration, or decision points impose greater cognitive demand (Sweller et al., 2019).

By varying the number of required steps, we evaluated how learners responded to tasks of differing complexity and whether these effects interacted with visual search propensity and contextual familiarity (sports familiarity). Higher-complexity tasks were expected to exert greater cognitive load, require heightened attentional allocation, and potentially elicit stronger emotional responses, such as increased arousal or frustration, whereas lower-complexity tasks should be processed more fluently and generate more positive affect. This design therefore enabled us to assess whether individuals with stronger visual search skills or higher contextual familiarity were better able to sustain effectiveness (task success) and efficiency (time) as task demands increased, and how complexity shaped their cognitive and emotional experience throughout the learning process.

3.3. Participants

Study 1 - Laboratory study (Canada sample, RQ1)

The first phase was conducted in a controlled user experience (UX) laboratory environment. Participants (Group A) interacted with the gamified learning platform individually while their eye-tracking and behavioral data were collected. This sample included 31 participants ($M = 26.8$ years,

SD = 6.21), of whom 19 identified as women and 12 as men. Participants were recruited through the online participant management system *Panelfox*. Eligibility criteria required participants to be at least 18 years old and to have advanced English proficiency. Participants received a \$30 compensation for their time, in accordance with ethical guidelines. Compensation was provided regardless of whether participants completed the full study, ensuring that individuals felt free to withdraw at any point without penalty. Participants represented diverse educational backgrounds: engineering, mathematics, and natural sciences (n = 13); computer science, information technology, and data science (n = 4); business and management (n = 7); and other fields (n = 6). Educational attainment levels included postgraduate (n = 16), undergraduate (n = 9), college-level (n = 4), and high school (n = 2).

Study 2 - Classroom study (India Sample, RQ2)

The second phase of the research was conducted in a classroom setting at a private university in India to complement the controlled laboratory findings from Canada sample. Unlike Study 1, Study 2 (India sample) served as an observational comparison and did not include psychophysiological or eye-tracking measures. Participants completed only the gameplay session followed by a questionnaire assessing sports familiarity, enjoyment, satisfaction, and system usability. This study enabled a cross-cultural examination of contextual familiarity(sports) among Canada and India participants. A total of 43 bachelor-level business students from the same academic cohort participated in this classroom-based session. The activity was supervised by the course instructor, and both the professor and all participating students provided informed consent prior to data collection. Participation in the study was entirely voluntary. Students were not financially compensated, and participation or performance in the activity was not graded and had no impact on course assessment or academic standing. The session was framed as a fun,

exploratory, in-class learning activity. Participants interacted with the same contextualized gamified STEM learning platform used in Study 1, but within a naturalistic classroom environment. Immediately after completing the task session, participants filled out a post-experience questionnaire on their mobile devices. This survey captured self-reported measures of sports familiarity, enjoyment, satisfaction, and system usability, enabling the exploration of how contextual familiarity influences affective responses and overall learning experience in a real-world instructional setting. No psychophysiological or eye-tracking measures were collected in this phase. The primary aim of Study 2 was to observe the cultural difference in an ecologically valid learning environment and to evaluate whether they support or differ from the Canada participants.

3.4. Visual Search Paradigms

Visual search propensity was operationalized as a visual behaviour and cognitive trait of the participant reflecting how efficiently participants detect, process, and respond to visual information. Visual search propensity was measured using the three paradigms, anti/pro-saccade, large grid, and symbol search paradigms. We extracted saccadic reaction time and directional accuracy from pro/anti-saccade paradigm, fixation latency and spatial scanning efficiency from large grid paradigm and processing speed and decision accuracy from symbol search paradigm (Kastrati et al., 2021). These indicators were then standardized and combined to generate a multidimensional visual search profile for each participant.

Before starting The Agent gameplay, participants were asked to perform 3 visual search paradigms to measure their level of visual search propensity. A Python-based software tool developed by Tech3Lab, Montreal, is used to run and measures the visual search propensity of the participant. The 3 visual search paradigm tasks are explained below:

- a) Pro- and Anti-Saccade Paradigm: The pro- and anti-saccade task followed the standardized protocol outlined by Antoniadou et al. (2013). Each trial began with a central fixation cross, followed by a peripheral cue appearing either to the left or right of the fixation point. In prosaccade trials, participants were instructed to look directly toward the cue, whereas in anti-saccade trials they were required to inhibit this reflexive movement and instead direct their gaze to the opposite side. The cue remained visible for one second before participants returned their gaze to the central fixation.
- b) Large Grid Paradigm: The Large Grid task required participants to fixate on a sequence of dots presented at 25 different positions across the screen. The central position appeared three times, resulting in a total of 27 trials per block. Each dot was displayed for 1.5 to 1.8 seconds. The spatial layout of the dots covered the full display area, enabling the measurement of anticipatory gaze shifts and the speed with which participants located each target. To reduce predictability and minimize learning effects, the order of dot presentations was pseudo-randomized.
- c) Visual Symbol Search Task: The Visual Symbol Search task assessed processing speed and selective attention. Participants viewed 15 rows of stimuli, presented sequentially. Each row contained two target symbols, five search symbols, and two response options labeled “YES” and “NO.” For each row, participants indicated whether one of the target symbols appeared among the search symbols by selecting the appropriate response.

3.5. Measures

3.5.1. Psychophysiological measurements

During the lab study, we used a combination of psychophysiological signals, pupillometry, electrodermal activity (EDA), and automatic facial emotion recognition, alongside self-reported

measurements to record participants' level of visual search, behavioural cognitive and emotional state. These psychophysiological measures are presented in detail below.

- a) **Pupillometry:** Pupil dilation, measured in terms of diameter and responsiveness is widely considered an indicator of cognitive load and the working memory required for a task (Beatty & Lucero-Wagoner, 2000; Kahneman & Beatty, 1966). As task demands increase, pupil diameter expands proportionally until reaching the limits of working memory capacity, at which point dilation may plateau or decline. Previous studies have also shown a positive correlation between performance and pupil dilation (Van der Meer et al., 2010), linking pupil size to applied effort. In educational contexts, pupil dilation has been associated with fluctuations in mental effort during uncertainty reconciliation (Pekrun et al., 2017) and with the difficulty of mental mathematics problems (Hess & Polt, 1964). Thus, pupil dilation serves as a robust correlate of cognitive engagement.
- b) **Electrodermal Activity (EDA):** EDA, typically measured through skin conductance, is a widely used and reliable physiological indicator of arousal, as emotionally stimulating events activate the sympathetic nervous system, eliciting bodily responses such as sweating (Dawson et al., 2007). Skin conductance can be divided into two components: tonic EDA, which reflects slow variations known as skin conductance level, and phasic EDA, which captures rapid fluctuations called skin conductance responses. Moderate arousal levels have been linked to improved working memory, attention, and consolidation (Critchley, 2002), while higher arousal levels have been positively correlated with exam performance (Behnke et al., 2010). Consequently, EDA is taken as an index of emotional engagement.
- c) **Automatic Facial Emotion Recognition:** Facial expression analysis provides another non-intrusive window into learners' emotional engagement. Ekman's (1992) six basic

emotions, anger, fear, disgust, sadness, surprise, and happiness, associated with distinctive facial muscle movements was encoded in the Facial Action Coding System (FACS; Ekman & Friesen, 1978). Using video recordings of participants' faces, automated expression recognition software can detect these action units in real time and infer the underlying emotional state, including valence (positive-negative). Such systems are increasingly used in educational research: for example, Wang et al. (2020) developed tools to adapt online teaching based on students' facial expressions, while Pei and Shan (2021) applied algorithms to recognize micro-expressions in classroom environments. Accordingly, emotion recognition through FACS-based software serves as an indicator of valence in our study.

In addition to these objective indicators, we also collected self-reported measures to understand how participants consciously perceived their experience at different stages of the task sequence. This dual-level approach, combining psychophysiological data with subjective evaluations, provides a more comprehensive account of how learners interact with the environment both behaviourally and perceptually.

To achieve this, data collection was structured into multiple repeated measurement points, enabling us to track fluctuations in lived cognitive load, attention, and emotional states alongside perceived ratings reported after each trial. During post-processing, all data streams were time-synchronized and aligned sequentially, allowing us to integrate sensor-based measurements with self-reported responses for a unified analytical dataset.

These self-reported measures were administered in both samples, allowing us to compare evaluative responses across the laboratory (Canada) and classroom (India) studies. Accordingly, the data derived from these measures directly inform Research Question 2 (RQ2) by capturing

how contextual familiarity influences learners' satisfaction, enjoyment, and usability perceptions across cultural groups.

3.5.2. Self-reported Measures

Sports familiarity, the contextual familiarity variable of interest, was collected at the beginning of the study through a self-reported measure. During the experiment, participants provided repeated self-reports of perceived cognitive load and emotional state at various time points. At the end of the session, they completed standard user experience scales assessing enjoyment, satisfaction, and system usability.

Familiarity to the context

Before participants began the main task, they reported their level of familiarity with sports. A 7-point Likert-type scale (1 = strongly disagree, 7 = strongly agree) measured five sub-constructs of familiarity: prior experience, positive emotion, occurrence frequency, level of processing, and retention rate (Zhang, Wang et al., 2021). The scale was implemented in Qualtrics.

The scale items were adapted to the sports context and included:

- a) I have much prior experience with sports (heard of, searched for information, or have participated in sports activities).
- b) When I think about sports, the emotions I feel are extremely positive.
- c) I frequently come across sports in my daily life.
- d) Before today, I had a clear understanding of how sports function and their role in daily life.
- e) I have done sports very recently.

Higher scores reflect greater contextual familiarity with sports. This measure was common with both the studies conducted in Canada as well as India.

Cognitive load, valence, and arousal

During each task trial, participants' behavioural responses, captured through psychophysiological tools, were used to index cognitive load, attention, and emotional states (valence and arousal). To complement these objective indicators, participants also provided self-reported assessments using two validated instruments: the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988), which measures perceived cognitive workload across dimensions such as mental demand, effort, and frustration, and the Affective Slider (Betella & Verschure, 2016), a non-verbal digital tool that independently captures perceived valence and arousal. This dual-level measurement strategy enables comparison between lived physiological responses and participants' conscious perceptions of their cognitive and emotional experience. Aligning behavioural and perceptual data allows us to explore whether both converge or diverge under varying task demands, an important consideration given that subjective workload reports and physiological indicators can sometimes respond differently to the same stimuli (e.g., Morris, 1995). These measures were synchronized at the trial level during post-processing to ensure temporal alignment between psychophysiological signals and corresponding self-reported states.

Enjoyment

After completing the main experiment, participants responded to a short self-report questionnaire assessing their enjoyment of the gameplay experience. Enjoyment was measured using selected items from the Game User Experience Satisfaction Scale (GUESS), a validated instrument

designed to capture player satisfaction across multiple dimensions of game experience (Phan, Keebler, & Chaparro, 2016)

These items assessed the extent to which participants found the game enjoyable, whether they would choose to play it again, and whether they would be likely to recommend it to others in a 7-point Likert scale. The GUESS scale has demonstrated strong psychometric properties and broad applicability across different game genres, which makes it an appropriate tool for comparing user enjoyment across our two diverse samples (Canada and India). Using this validated measure enhances the reliability of our analysis related to RQ2, particularly when examining how contextual familiarity influences perceived enjoyment in a gamified STEM learning environment.

System Usability

After measuring participant enjoyment, we assessed system usability to evaluate how participants perceived the contextualized visual analytics learning environment. Usability was measured using the System Usability Scale (SUS), a widely adopted, reliable, and technology-agnostic instrument for evaluating perceived system usability (Brooke, 1986). The SUS consists of ten items that capture users' subjective impressions of complexity, ease of use, integration of functions, learnability, and confidence when interacting with a system. Items include statements such as "I think that I would like to use this system frequently," "I found the system unnecessarily complex," "I felt very confident using the system," and "I needed to learn a lot of things before I could get going with this system." Participants rate their agreement with each statement on a 5-point Likert scale.

Using the SUS allowed us to examine whether users' visual search behavior and contextual familiarity (sports familiarity) contributed to differences in perceived usability. Because usability

perceptions often reflect cognitive effort, task fluency, and the intuitiveness of interaction, this measure provides important complementary insight into how effectively participants engaged with the visual analytics platform.

Satisfaction

Lastly, we measured participants' overall satisfaction with the learning experience using the Customer Satisfaction (CSAT) scale (Farris et al., 2010) in a 7-point Likert scale from unsatisfied to satisfied. This measure allowed us to assess how positively learners evaluated the contextualized visual analytics platform after completing the tasks. Satisfaction is an important experiential indicator and provides insight into how learners' cognitive and emotional states shape their overall evaluation of the environment. This measure enabled us to test whether lower cognitive load, higher attentional engagement, and more positive emotional states contribute to stronger satisfaction, as proposed in our hypotheses (H3B, H4B, H5B). By linking satisfaction with these cognitive and affective factors, the CSAT scale helped clarify how the learning environment was perceived holistically and how users' internal states shaped their final judgments about the system.

Performance data

Performance data (effectiveness and efficiency) were measured through task success scores and completion time. Participants could earn a maximum of 1,500 points (100 points per trial) and were allowed up to 180 seconds per trial. If a trial was not completed within 180 seconds, it was automatically submitted, and participants forfeited the remaining points. Trials with two- or three-part questions could be partially successful, allowing participants to earn partial credit.

3.6. Analysis

For the Canadian participant group ($n = 31$), a total of 465 task-trial datasets were collected. Psychophysiological data including eye-tracking, facial expression analysis, electrodermal activity, and data from visual search paradigms were processed and synchronized using Cobalt Photobooth software (Léger et al., 2018). In contrast, the Indian participant group relied solely on self-reported data following the task trials. Statistical analyses were conducted using the SAS Academic platform. A total of 40 statistical tests were performed at the task level using linear regression models with random intercepts, and 8 statistical tests were conducted at the subject level with the same modeling approach to see the relationship between the variables. To compare the two user groups, T-tests were applied to assess the statistical significance of differences between the Canadian and Indian samples. The Bonferroni correction was applied to adjust p-values for multiple comparisons. Statistical analyses were done in SAS (version 9.4) via the Proc Glimmix procedure at a significance level $\alpha = 0.05$.

4. Results

The results are presented in two parts. Study 1 reports findings from the laboratory experiment that examined how visual search propensity influenced learning performance and satisfaction (RQ1). Study 2 presents results from the cross-cultural observational study conducted in India, which compared how contextual familiarity (sports familiarity) influenced engagement, satisfaction, and usability (RQ2).

4.1. Study 1

Descriptive Statistics

The below table 4.1 shows the descriptive statistics for study 1 happened in the controlled lab setup (Canada). Participants had an average age of 26.87 years ($SD = 6.12$), reflecting a young adult sample. Sports familiarity scores suggested moderate familiarity overall ($M = 4.53$, $SD = 1.42$). Task performance showed a mean success rate of 0.61 ($SD = 0.42$), and the average task completion time was 114.86 seconds ($SD = 44.07$), indicating considerable variability in how quickly participants solved the data-analytics tasks.

User-experience outcomes were generally positive. Satisfaction (CSAT) averaged 4.45 ($SD = 1.52$) on a 7-point scale, system usability (SUS) averaged 57.74 ($SD = 20.09$), and enjoyment averaged 4.68 ($SD = 1.61$), suggesting that participants perceived the contextualized visual analytics environment as usable and enjoyable.

Psychophysiological indicators reflected moderate attentional engagement (k-coefficient: $M = 0.13$, $SD = 0.17$), low-to-moderate cognitive load as indexed by adjusted pupil dilation ($M = 0.17$, $SD = 0.27$), slightly negative physiological valence ($M = -0.07$, $SD = 0.11$), and a negatively skewed distribution of arousal ($M = -4.64$, $SD = 3.04$). Because the arousal and valence indicators

were baseline-adjusted and log-corrected, values closer to zero indicate higher physiological activation and more positive affect.

Self-reported measures revealed moderate perceived workload (TLX: $M = 39.52$, $SD = 26.56$), neutral perceived valence ($M = 51.53$, $SD = 18.22$), and moderate perceived arousal ($M = 54.24$, $SD = 22.17$). Compared with the psychophysiological measures, these subjective indicators provide a complementary perspective on cognitive and emotional experience during the task.

Performance-related variables showed non-normal distributions. Task success was right-skewed, with many participants achieving full success across trials and fewer instances of partial success. Task-completion times were also right-skewed, ranging from 16 to 180 seconds, with several participants approaching the upper time limit. This pattern suggests that tasks were sufficiently challenging to require the full duration for some participants while others solved them more efficiently.

Together, these descriptive results illustrate meaningful variability across cognitive, emotional, and behavioral dimensions, establishing the foundation for subsequent hypothesis testing. Sports familiarity serves as a moderator in later analyses, while user-experience outcomes (satisfaction, enjoyment, usability) enable comparisons with the India classroom sample in Study 2.

Table 4.1

Descriptive Statistics for Study 1 (Canada laboratory sample)

Variable	Mean	Median	SD	Min	Max
Age	26.87	26	6.12	18	45
Sports familiarity	4.53	4.6	1.42	1	7
Success	0.61	0.67	0.42	0	1
Time (seconds)	114.86	113	44.07	16	180
CSAT	4.45	5	1.52	2	7
SUS	57.74	55	20.09	20	92.5
Enjoyment	4.68	5	1.61	1	7
Attention	0.13	0.13	0.17	-0.52	0.6
Cognitive load	0.17	0.17	0.27	-0.37	0.97
Valence	-0.07	-0.06	0.11	-0.56	0.26
Arousal	-4.64	-3.85	3.04	-14.85	0.32
TLX (Cognitive Load)	39.52	35.33	26.56	0.33	100
Perceived Valence	51.53	50	18.22	0	100
Perceived Arousal	54.24	57	22.17	0	100

Hypothesis Testing

To examine the role of visual search propensity and contextual familiarity in shaping learners' cognitive, emotional, and performance outcomes, a series of linear regression model for random intercepts were conducted. These analyses evaluated both the direct effects of visual search propensity (H1a to H1d) and its interaction with sports familiarity (H2a to H2c), followed by investigations of how cognitive load, attention, and emotion predicted performance and

satisfaction (H3a to H6). All models included random intercepts to account for repeated-measures trial structure in Study 1.

Main Effects of Visual Search Propensity (H1a to H1d)

The first set of analyses examined whether visual search propensity directly predicted learners' performance, operationalized by task success and efficiency in the contextualized visual analytics environment. Visual search propensity did not significantly predict task success or task completion time ($p > .05$), indicating that higher visual search skill did not translate into better accuracy or faster performance. Accordingly, H1a was not supported.

Similarly, there was no significant relationship between visual search propensity and psychophysiological indicators of cognitive load or attention ($p > .05$). However, a noteworthy pattern emerged for perceived cognitive load: individuals with stronger visual search propensity reported significantly lower subjective workload ($\beta = -0.29$, $p = .014$). This finding suggests that while objective load remained unchanged, learners with higher search skills experienced the tasks as mentally easier. Thus, H1b received partial support, whereas H1c was not supported.

Emotional responses showed a similar trend. Visual search propensity did not significantly predict either lived or perceived valence or arousal ($p > .05$), demonstrating no direct emotional benefit associated with stronger search skills. Therefore, H1d was not supported.

Overall, these results show that visual search propensity alone did not directly enhance performance or emotional states, and only modestly reduced perceived cognitive load.

Moderating Role of Contextual Familiarity (H2a to H2c)

Sports familiarity significantly moderated the effect of visual search propensity on perceived cognitive load. At high levels of sports familiarity, greater visual search propensity predicted substantially lower perceived cognitive load ($\beta = 67.26$, $p = .014$). As shown in Figure 4.1, the slope for highly familiar learners is strongly negative, indicating that contextual familiarity allows learners to make more efficient use of their search capabilities and reduces the mental effort required to interpret the dashboards. In contrast, among learners with low sports familiarity, individuals with higher visual search propensity experienced greater perceived cognitive load suggesting that increased search activity in the absence of relevant contextual knowledge imposes additional processing demands. Although the interaction coefficient is positive, the simple slope analysis (visualized in Figure 4.1) reveals that cognitive load decreases with higher visual search propensity only when sports familiarity is high. The interaction term reflects the difference between slopes, not the direction.

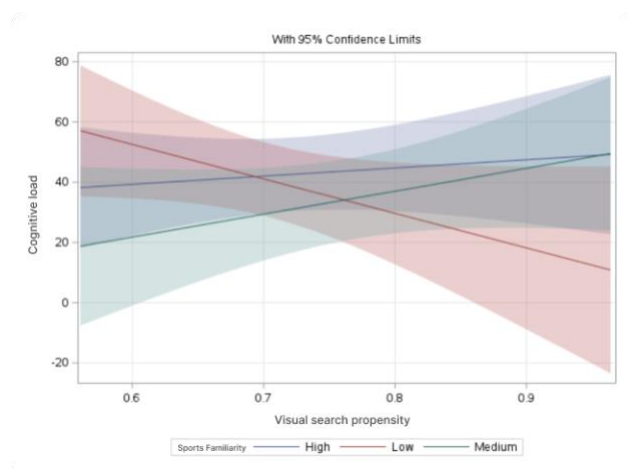


Figure 4.1. Interaction of sports familiarity with visual search propensity on perceived cognitive load

Sports familiarity also moderated the relationship between visual search propensity and physiological arousal. While visual search propensity alone did not predict arousal, learners with higher sports familiarity showed significantly higher activation levels when their search propensity was strong ($\beta = 7.8433$, $p = .0123$). This enhanced engagement supports H2b.

A marginal pattern emerged for emotional valence (perceived valence: $\beta = 25.062$, $p = .0991$; lived valence: $\beta = -0.1924$, $p = .0991$), indicating a weak but non-significant trend suggesting that higher visual search propensity may be associated with more positive emotional responses when sports familiarity is high. Although neither effect reached conventional significance ($p < .05$), the direction of both coefficients aligns with the hypothesized pattern, providing marginal but inconclusive support for H2c.

An additional noteworthy interaction appeared for attention which is shown in figure 4.2: participants with low sports familiarity exhibited increased attentional engagement as visual search propensity rose, whereas participants with high familiarity showed a weaker or reversed pattern ($t = -3.67$, $p = .0011$). This indicates that familiarity shapes how learners allocate visual attention in complex environments.

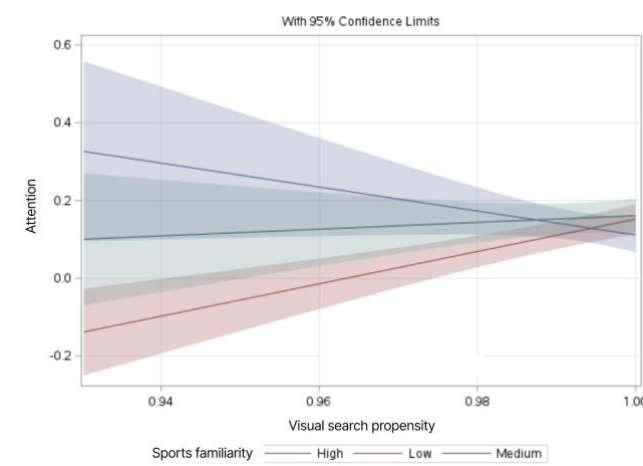


Figure 4.2. Interaction of sports familiarity with visual search propensity on attention

Together, these findings demonstrate that contextual familiarity amplifies the cognitive benefits of visual search, supporting the hypothesis that familiarity serves as a meaningful facilitator in visual analytics learning.

Cognitive and Emotional Predictors of Performance (H3a, H4a, H5a)

Performance was strongly shaped by cognitive and emotional dynamics during task execution. Perceived cognitive load was significantly and negatively associated with task success ($p < .0001$), indicating that learners who experienced higher mental demand were less likely to answer correctly. Task completion time also increased significantly with both perceived ($p < .0001$) and lived ($p = .0186$) cognitive load, confirming that heavier cognitive demand slowed performance. These findings fully support H3a.

Emotional variables were also significantly associated with performance outcomes. Both perceived and physiological arousal were negatively related to task success (perceived arousal $p = .0122$; lived arousal $p = .0485$), and perceived arousal was associated with longer completion times ($p = .0133$). Although arousal is theorized as a facilitator of engagement, the present findings suggest that heightened arousal may instead reflect increased task difficulty or emotional responses following performance feedback. As emotional measures were collected post-task, the directionality of these effects cannot be conclusively established. Consequently, H4a was not supported.

Valence displayed a more adaptive pattern. Higher positive emotional valence predicted significantly greater task success for both perceived ($p < .0001$) and lived emotion ($p = .02$). Moreover, higher valence predicted faster completion times (perceived valence: $\beta = -0.88340$, $p <$

.0001; lived valence: $\beta = -67.0997$, $p = .0152$). These relationships align directly with H5a, which was supported.

Overall, performance outcomes were strongly shaped by subjective cognitive load and emotional valence, while arousal exerted a detrimental effect.

Cognitive and Emotional Predictors of Satisfaction (H3b, H4b, H5b)

Satisfaction was likewise shaped by learners' cognitive and emotional experiences. Perceived cognitive load exerted a significant negative effect on satisfaction ($p = .04$), demonstrating that the more mentally taxing the tasks felt, the less satisfied learners were. Lived cognitive load showed no such effect. Thus, H3b was supported, but only for perceived load.

Attention, however, did not significantly predict satisfaction ($p > .05$), providing no evidence for H4b.

Emotional valence showed the strongest relationship with satisfaction. Higher perceived valence significantly predicted greater satisfaction ($p < .0001$), whereas lived valence showed no effect, reinforcing that subjective emotional experience, not physiological response, drives satisfaction. Thus, H5b was supported. Arousal did not significantly predict satisfaction ($p > .05$), further supporting that emotional positivity, rather than intensity, shapes learners' overall evaluation.

Relationship Between Performance and Satisfaction (H6)

A significant positive relationship emerged between task success and satisfaction ($\beta = 0.31$, $p = .03$). Learners who performed better reported substantially higher satisfaction with the visual analytics environment. Task completion time did not predict satisfaction ($p > .05$), suggesting that

learners valued accuracy more than speed. These results support H6, highlighting performance as a key determinant of user satisfaction.

Manipulation Check: Task Complexity

Finally, the manipulation check tested whether increasing the number of steps required to derive the correct answer influenced learners' cognitive experience. As task complexity increased, perceived cognitive load rose significantly ($\beta = 8.9042$, $p = .004$), confirming that participants were sensitive to task difficulty. Lived cognitive load, however, did not vary with task complexity. This pattern validates the effectiveness of the difficulty manipulation and confirms that subjective mental effort increases when tasks become more analytically demanding. Table 4.2. shows the overall hypothesis breakdown for all hypotheses.

Table 4.2

Hypothesis breakdown

H	X (Predictor)	Moderator	Y (Outcome)	Estimate	p-value	Result	Interpretation
H1A	Visual Search Propensity	-	Performance (task success/time)	0.08	> .05	Unsupported	No direct effect on performance.
H1B	Visual Search Propensity	-	Cognitive load			Unsupported	No direct effect
H1C	Visual Search Propensity	-	Attention			Unsupported	No direct effect
H1D	Visual Search Propensity	-	Emotion			Unsupported	No direct effect
H2A	Visual Search Propensity	Sports Familiarity	Perceived Cognitive Load	-0.29	0.014	Supported	High familiarity + high VSP → lower cognitive load.
H2B	Visual Search Propensity	Sports Familiarity	Arousal (physiological)	0.33	0.0123	Supported	High familiarity amplified arousal.
H2C	Visual Search Propensity	Sports Familiarity	Valence (positive emotion)	0.18	0.099	Unsupported	Weak trend toward higher valence with familiarity.
	Visual search propensity	Difficulty	Perceived cognitive load	8.9042	0.004	Supported	Higher the difficulty, higher the perceived cognitive load
H3A	Cognitive Load	-	Performance (task success)	-0.47	< .0001	Supported	Higher load → lower success.
H3B	Cognitive Load	-	Satisfaction	-0.25	0.04	Supported	Higher load reduced satisfaction.
H4A	Arousal (perceived/lived)	-	Performance (task success)	-0.21	.0122 .0485	Unsupported	Higher arousal lowered success (opposite direction).
H4B	Arousal	-	Satisfaction	0.07	> .05	Unsupported	No relationship between arousal and satisfaction.
H5A	Valence (perceived/lived)	-	Performance	0.42	< .0001 .02	Supported	Positive emotion improved success and reduced time.
H5B	Valence	-	Satisfaction	0.38	< .0001	Supported	Positive valence strongly predicted satisfaction.
H6	Performance	-	Satisfaction	0.31	0.03	Supported	Task success increased satisfaction.

4.2. Study 2

Exploratory Analysis: Cultural Familiarity and Learner Experience (Canada and India)

An exploratory comparison was conducted between participants in Study 1 (Canada) and Study 2 (India). This exploratory analysis had the objective to understand the role of contextual and cultural familiarity in learners' interactions with the sports-based visual analytics system. As an exploratory analysis, no formal hypotheses were posited for this phase. Regardless, we argue that this analysis provides valuable insight into how cultural alignment may influence user experience, affective engagement, and perceptual judgments. Descriptive statistics are presented in the table 4.3.

Table 4.3

Descriptive statistics of Canadian and Indian participant groups

Variable	Canada (n = 31)				India (n = 43)			
	<i>M</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>	<i>M</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>
Enjoyment	4.68	1.61	1	7	6.38	0.95	4	7
Usability	57.74	20.4	20	92.5	88.59	13.03	57.14	100
CSAT	4.45	1.55	2	7	6.09	1.29	1	7
Sports Familiarity	4.53	1.44	1	7	5.76	1.62	0.07	7

Descriptive statistics revealed consistent differences between the two groups across all key subjective experience measures. Participants in India reported higher enjoyment, higher usability, and higher satisfaction ($M_{enjoyment} = 6.38$, $M_{usability} = 88.59$, $M_{satisfaction} = 6.09$) compared to their Canadian counterparts ($M_{enjoyment} = 4.68$, $M_{usability} = 57.74$, $M_{satisfaction} = 4.45$). Sports familiarity also differed substantially between cultures, with Indian learners reporting markedly higher familiarity ($M = 5.76$) than Canadian learners ($M = 4.53$).

A series of t-tests were conducted to understand the differences among Indian and Canadian learners. Results show that Indian participants significantly reported higher sports familiarity ($t(1,72) = -3.38, p = .0012$), enjoyment $t(1,72) = -5.70, p < .001$), perceived usability ($t(1,72) = -7.94, p < .001$), and satisfaction ($t(72) = -4.97, p < .0001$) compared to their Canadian counterparts.

Table 4.4

Mean Differences in User Experience Outcomes Between Canada and India

Outcome	Canada M (SD)	India M (SD)	Mean Diff	t	df	p
Sports familiarity	4.53 (1.44)	5.76 (1.62)	-1.23	-3.38	72	0.0012
Enjoyment	4.68 (1.61)	6.38 (0.95)	-1.70	-5.70	72	< .0001
Usability	57.74 (20.40)	88.59 (13.03)	-30.85	-7.94	72	< .0001
Satisfaction	4.45 (1.55)	6.09 (1.29)	-1.64	-4.97	72	< .0001

Indian participants consistently reported higher sports familiarity, enjoyment, satisfaction, and more favorable usability perceptions compared to their Canadian counterparts. This pattern might show that sports can be more culturally meaningful for Indian participants, as compared to Canadian learners. This pattern might inform the creation of context-relevant contents to amplify learners' emotional resonance, enhance perceived relevance, and elevate overall user experience. However, these results should be taken cautiously and reproduce to confirm which topics might be more interesting for both populations, controlling for additional cultural differences, such as patterns in responding self-reports, i.e., ease reporting higher scores in the case of Indian participants.

5. Discussion

This research examined whether individuals' visual search propensity, their characteristic ability to efficiently locate, filter, and process task-relevant information, enhances performance and satisfaction within a gamified STEM learning environment. Additionally, the study investigated how contextual familiarity, operationalized as familiarity with a sports-based scenario, supports cognitive efficiency, emotional engagement, and overall user experience. Together, the two studies provide a nuanced understanding of how personal cognitive traits and contextual design features jointly shape learning in visual analytics environments.

Across analyses, visual search propensity alone did not significantly predict performance, cognitive load, attention, or emotional responses when familiarity with the context was not considered. These findings diverge from much of the prior literature, which suggests that individuals with strong visual search skills typically experience reduced cognitive load, more efficient attentional allocation, and improved performance, patterns consistent with Cognitive Load Theory (CLT; Sweller et al., 2019) and eye-tracking evidence linking gaze efficiency to cognitive fluency (e.g., Tsai & Wu, 2021; Argunçah et al., 2025). In contrast to these expectations, our results indicate that visual search expertise alone is not sufficient for effective learning in complex visual analytics dashboards. Without contextual support, even individuals with strong visual search capabilities did not consistently translate their perceptual advantages into improved outcomes.

In contrast, contextual familiarity exerted robust and consistent effects, confirming its central role in supporting cognitive, emotional, and behavioral engagement. Familiarity with the sports context significantly moderated the relationship between visual search propensity and multiple cognitive and emotional outcomes. When contextual familiarity was high, individuals with stronger visual

search propensity experienced lower perceived cognitive load, higher arousal, and marginally higher emotional valence. In addition, contextual familiarity independently predicted enjoyment, usability, and satisfaction (Study 2), with effects substantially stronger among participants in India, where sports, particularly cricket, hold deep cultural significance. These findings align with Self-Determination Theory (SDT; Deci & Ryan, 2000), suggesting that contextual relevance enhances intrinsic motivation, perceived competence, and emotional resonance by fulfilling the psychological need for relatedness. In this sense, contextual familiarity functions as a motivational substrate that enables cognitive skills, such as visual search, to be expressed more effectively.

5.1. Attention and Context Familiarity

A notable pattern emerged with respect to attentional engagement. Although higher sports familiarity improved user experience (enhanced enjoyment, usability, and satisfaction), it was also associated with reduced attentional demand and lower visual search effort. At first glance, this appears paradoxical; however, it reflects what CLT terms attention efficiency. When learners operate within a familiar semantic domain, they can rely on pre-existing schemas and domain knowledge, thereby reducing the cognitive resources required to interpret contextual cues (Sweller, 1988). Instead of disengagement, the decrease in visual search effort signals a more automatic and fluent cognitive process. Learners no longer need to devote effort to deciphering the context; they can allocate their attentional resources directly to problem solving. This result also mirrors findings from expertise-based visual search research, in which domain familiarity reduces search time and fixation redundancy by enabling top-down processing strategies (Wolfe, 2020).

These findings illuminate the dual role of contextual familiarity: it not only enhances learners' emotional responses, producing greater enjoyment, usability, and satisfaction, but also facilitates more efficient perceptual and cognitive processing within the visual analytics task. In other words,

familiarity improves both how learners feel and how efficiently they think, suggesting that contextual alignment can act as a powerful catalyst for cognitive fluency in data-driven learning environments.

5.2. Cultural influence in sports

A key finding from the study concerns the role of cultural background in shaping learners' experiences within contextualized STEM environments. When comparing user-experience measures across Study 1 (Canada) and Study 2 (India), both groups demonstrated that higher sports familiarity was associated with greater enjoyment, satisfaction, and perceived usability. However, this effect was substantially amplified in the Indian sample. Participants from India reported significantly higher sports familiarity, which in turn produced stronger emotional engagement and more favorable evaluations of the system. These results suggest that culturally embedded domains, such as sports, music, or films, function as motivational scaffolds that elevate learners' connection to and engagement with instructional content. Embedding STEM learning within culturally resonant narratives not only enhances intrinsic motivation but also facilitates smoother cognitive processing by providing familiar semantic frameworks. In the present study, this cultural alignment enabled learners to navigate tasks more fluently and to derive greater satisfaction and usability from the learning platform. Thus, culturally meaningful contexts appear to serve as powerful catalysts in contextualized learning design, strengthening both emotional resonance and cognitive accessibility.

5.3. Implication for theory

The findings of this research contribute several important theoretical insights that address the gaps identified in the literature regarding how cognitive mechanisms, motivational factors, and

contextual familiarity jointly influence learning in gamified STEM environments. Prior research has often examined these dimensions in isolation, visual search in cognitive psychology, contextualization in education, and motivation in gamification, without integrating them into a unified framework. By combining Cognitive Load Theory (CLT), Self-Determination Theory (SDT), and visual search research within a contextualized visual analytics environment, this study advances theoretical understanding in several keyways.

Integrating Cognitive Load Theory with Contextualized Learning

Cognitive Load Theory traditionally argues that learners with stronger perceptual and attentional skills, such as those with higher visual search efficiency, would experience lower cognitive load and better performance. However, the present study challenges this assumption by showing that visual search propensity did not directly predict behavioral cognitive load, attention, emotion, or task performance when examined independently. These results indicate that cognitive traits alone are insufficient to explain learning effectiveness in complex, real-world visual analytics learning environment. Importantly, visual search propensity exerted meaningful effects only when contextual familiarity was high, suggesting that familiarity activates schema-based processing that enables cognitive skills to be utilized more efficiently. This finding extends CLT by demonstrating that contextual familiarity functions as a moderating cognitive scaffold, shaping how learners interpret visual information and how cognitive resources are allocated. Thus, CLT models of learning in data-rich environments should incorporate contextual and semantic familiarity as core components influencing cognitive efficiency.

Extending Self-Determination Theory in Gamified STEM Learning

Self-Determination Theory posits that motivation and engagement arise when learning environments satisfy autonomy, competence, and relatedness needs. The present study contributes to SDT by demonstrating that contextual familiarity, here, sports familiarity, enhances these motivational states, leading to increased enjoyment, usability, and satisfaction. Learners who found the sports context culturally resonant reported higher affective engagement and more positive evaluations of the system, especially in the India sample, where sports familiarity was significantly higher. These results highlight the role of contextual relevance as a motivational catalyst, showing that familiar domains amplify the psychological needs that sustain engagement in gamified environments. This extends SDT by illustrating that meeting learners' needs is not solely a function of game elements or interactivity but also depends on how deeply the learning context aligns with learners' identities, interests, and cultural backgrounds.

Advancing Visual Search Theory in Contextualized Environments

Visual search research traditionally examines how individuals locate task-relevant information based on perceptual cues. However, these models rarely consider how semantic familiarity influences visual search efficiency. The current findings provide evidence that visual search propensity interacts strongly with contextual familiarity: while higher visual search propensity improved attentional engagement for learners with low familiarity, this relationship weakened or reversed for learners with high familiarity, who relied more on prior knowledge and schema-driven expectations. This demonstrates that visual search efficiency is context-dependent, moderated by learners' understanding of the domain rather than governed solely by perceptual skill. Accordingly, the study expands visual search theory by showing that familiarity with the thematic

context modifies search patterns, reduces extraneous search effort, and shifts learners' cognitive strategies from perceptual scanning toward semantic interpretation.

Overall, the study demonstrates that learning within contextualized visual analytics environments is governed by the interplay of cognitive mechanisms, motivational factors, and contextual or cultural relevance. This contributes to the suggestion for an integrated theoretical model that unites CLT's emphasis on cognitive resource allocation, SDT's motivational principles, and visual search theory's perceptual foundations. The findings show that effective learning emerges not from any single factor alone but from their interaction, with contextual familiarity playing a pivotal role in enabling cognitive and motivational processes to jointly enhance performance and satisfaction. This integrated perspective contributes a novel theoretical framework for understanding learning in data-driven, gamified environments and addresses the central research gap by demonstrating how contextualization, visual search propensity, and cognitive-emotional processes co-regulate learning outcomes.

5.4. Implication for practice

The findings of this study offer several practical implications for the design of STEM learning environments, particularly those involving data analytics and visual, dashboard-based platforms. Whether through sports, music, everyday activities, or community-specific examples, familiar contexts can reduce cognitive load, increase emotional engagement, and make complex concepts more accessible. These results align with established best practices in data literacy education, which emphasize the use of real-world data embedded in engaging and personally relevant contexts to foster deeper engagement, improve learning outcomes, and support the development of lifelong learning skills (Ridsdale et al., 2015). Overall, the findings demonstrate that effective

learning does not depend solely on learners' cognitive abilities, but also on how meaningfully the learning context aligns with their interests, prior knowledge, and cultural background.

The strong influence of contextual familiarity suggests that STEM learning environments should integrate highly familiar and culturally relevant scenarios. Whether through sports, music, everyday activities, or community-specific examples, familiar contexts can reduce cognitive load, increase emotional engagement, and make complex concepts more accessible. Not only data analytics, pedagogic materials in physics, chemistry, biology, etc., can leverage this by embedding real-world examples that resonate with learners' interests and experiences. The value of contextualized visual analytics extends beyond traditional pedagogy. The same principles can inform workplace training, driving or safety simulations, and post-COVID online learning environments, where attention, engagement, and cognitive load remain major challenges (Wester et al., 2021). By aligning learning tasks with culturally or professionally meaningful contexts, educators and organizations can improve motivation, usability, and learning efficiency across diverse populations.

The findings also highlight the need to support learners who naturally vary in their visual search efficiency. Although visual search propensity did not independently predict performance, its strong interaction with contextual familiarity indicates that learners with lower search skills can still perform effectively when the environment provides sufficient contextual cues. This underscores the importance of designing visual analytics platforms with universal accessibility and adaptive support. In practice, this includes simplified visual layouts with reduced clutter, guided attention cues that highlight task-relevant information, and built-in scaffolds such as progressive disclosure of complex elements. Additionally, integrating AI-driven adaptive interfaces can further enhance accessibility. AI systems can dynamically adjust visual complexity, provide real-time guidance,

generate personalized hints, or identify when a learner is visually overwhelmed using gaze or interaction patterns. Multimodal accessibility formats, such as text-to-speech, audio narration, automated video walkthroughs, and gesture-based navigation, ensure that learners can engage with the material using diverse sensory channels. Together, these design principles enable learners to gradually build stronger visual literacy and analytic fluency, ultimately fostering the development of more effective visual search habits, a critical competency in modern data-driven environments.

5.5. Limitations and Directions for Future Research

Firstly, Study 1 was conducted in a controlled laboratory environment with a relatively small sample ($n = 31$). While this allowed precise measurement of visual search and physiological indicators, the artificial setting may limit ecological validity. Conversely, Study 2 adopted a classroom-based observational design ($n = 43$) in India without physiological measures, which restricts direct comparison of cognitive variables across cultures. Future research could integrate both modalities, eye-tracking and self-report, within the same cross-cultural sample to provide a richer, triangulated understanding of learning behavior.

Secondly, the current work examined short-term engagement within a single interaction. Longitudinal studies could investigate whether the positive effects of contextual familiarity persist over time and whether repeated exposure strengthens transfer of analytical skills.

The findings relating to task duration point to a promising direction for future research. Several participants exceeded the three-minute trial limit without realizing that the timer had expired, suggesting irregularities in temporal awareness and attentional allocation. One plausible design explanation is that the countdown timer was not persistently visible, as it disappeared during scrolling. Future work should experimentally evaluate alternative timer designs, such as a floating,

always-visible countdown element, to determine whether continuous temporal feedback improves performance, reduces missed submissions, or alters cognitive load. Such modifications may stimulate a healthy sense of urgency, potentially increasing arousal, and engagement, but could also introduce anxiety or heightened cognitive demand. Empirical studies should therefore examine the cognitive and emotional consequences of enhanced timer visibility, including its effects on workload, focus, and visual search patterns. Investigating temporal feedback mechanisms in this way would extend current knowledge on how interface-level design choices shape user experience and learning outcomes in gamified visual analytics environments.

Finally, future research should explore personalization models that dynamically adapt both cognitive load and contextual features based on learners' real-time attention and emotional feedback. Combining visual search analytics, affective computing, and adaptive gamification could lead to next generation learning systems that are simultaneously cognitively efficient and emotionally resonant.

6. Conclusion

This research set out to examine whether individuals' visual search propensity, their characteristic ability to efficiently locate, filter, and process task-relevant information, enhances learning performance and satisfaction within a gamified STEM visual analytics environment. In parallel, the study investigated how contextual familiarity, operationalized through a sports-based scenario, supports cognitive efficiency, emotional engagement, and overall user experience. By combining a controlled laboratory experiment (Study 1) with a culturally complementary observational study (Study 2), this research provides a comprehensive understanding of how personal cognitive traits and contextual design elements jointly influence learning in data-driven, visually complex environments.

RQ1: How does visual search propensity influence learners' performance and satisfaction in a gamified STEM learning environment?

Findings from Study 1 demonstrated that visual search propensity does not exert a direct effect on task performance; however, it plays an important indirect role through learners' cognitive and emotional states. Higher context-familiar participants with their visual search propensity exhibited lower perceived cognitive load, more stable attentional engagement, and more positive affect, which in turn enhanced their satisfaction. These results align with theories of cognitive efficiency described in Cognitive Load Theory (Sweller et al., 2019) and visual expertise research (e.g., Harsh et al., 2019), which suggest that proficient search behavior optimizes working-memory allocation and supports smoother interaction with complex displays. Rather than guaranteeing higher task success, visual search propensity appears to function as a cognitive mechanism that facilitates how learners manage complexity and how they feel during the process.

RQ2: To what extent does contextual familiarity (sports familiarity) enhance learners' performance and satisfaction in a gamified STEM learning environment?

Across both studies, contextual familiarity emerged as a strong, consistent, and direct predictor of learners' emotional and experiential outcomes that supports learner's visual search propensity. Participants from the Indian sample, who demonstrated higher sports familiarity, reported greater enjoyment, perceived usability, and satisfaction. These results reinforce long-standing evidence in the contextualization literature (Bouhdana et al., 2023; Metcalf et al., 2008) and culturally relevant pedagogy (Ladson-Billings, 1995), which argue that familiar contexts reduce extraneous cognitive load, enhance meaning-making, and increase sustained motivation. Contextual familiarity therefore did not merely make the learning environment more “appealing” but also supported more efficient cognitive processing and a more positive affective experience.

Together, these findings demonstrate that visual search propensity and contextual familiarity serve as complementary drivers of learning in visual analytics environments. Visual search propensity shapes how efficiently learners navigate complex displays, while contextual familiarity shapes how learners engage and how positively they evaluate the experience. Their interaction creates optimal learning conditions characterized by reduced cognitive load, focused attentional engagement, and more positive emotional states. This integrated perspective advances current theoretical understanding by showing that effective learning requires an alignment between cognitive mechanisms and motivational relevance. Cognitive Load Theory explains the importance of reducing extraneous cognitive demands, whereas Self-Determination Theory illuminates how familiar and culturally resonant contexts fulfill psychological needs for competence, autonomy, and relatedness. When these mechanisms align, learners not only perform more effectively but also connect more meaningfully with the learning environment.

More broadly, the findings contribute to ongoing discussions in STEM education and visual analytics research by demonstrating that complex data-driven tasks become more accessible and engaging when grounded in contexts that learners understand and care about. Learning platforms that integrate cognitive scaffolds with culturally meaningful narratives may therefore be particularly effective in supporting diverse learners in data-rich domains.

In sum, this study shows that learners' visual traits and contextual relevance do not operate in isolation but work together to shape learning outcomes in visually complex environments. By bridging the cognitive efficiency of visual search with the motivational power of contextual familiarity, the research offers a holistic explanation of how learners interpret, engage with, and succeed in gamified STEM learning environments. These insights provide a valuable foundation for designing learning systems that are not only cognitively accessible but also culturally inclusive and emotionally resonant, enabling learners to navigate the demands of modern data-driven education with greater confidence and satisfaction.

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Conclusion

This thesis set out to understand how two key factors, visual search propensity and contextual familiarity, shape learning in a contextualized visual-analytics STEM environment. The findings showed that visual search propensity alone does not directly predict performance, its influence emerged clearly through cognitive and emotional pathways, and contextual familiarity proved to be a powerful amplifier of engagement, usability, and satisfaction. Together, these results extend prior work by showing that effective learning in complex data-driven environments depends on the interaction of cognitive efficiency and contextual or cultural resonance, confirming the importance of theoretically grounding STEM learning design in both Cognitive Load Theory and Self-Determination Theory.

Translating these insights into practice, the findings emphasize that contextualized STEM learning platform, especially those using visual dashboards and analytics, should be deliberately aligned with the interests, media environments, and cultural backgrounds of their users. Familiar contexts reduce extraneous cognitive load, enhance attentional fluency, and generate more positive emotional engagement. For designers and educators, this means selecting contextual domains that resonate with learners, whether sports, music, gaming, cinema, or local cultural narratives is highly instrumental.

In today's post-COVID-19 world, the importance of data-literate citizens has become even more evident. Traditional tools such as spreadsheets and static databases, while foundational, but are increasingly insufficient for managing the scale, complexity, and speed of contemporary data operations. Studies show that interactive dashboards and visual analytics tools can significantly enhance data accessibility, reduce cognitive effort, and support more intuitive decision-making compared to conventional spreadsheet-based workflows. For Gen Z learners, who are accustomed

to highly interactive digital environments, visually rich and gamified dashboards offer an engaging pathway to develop data literacy without the steep cognitive demands associated with traditional data manipulation tools. When designed to be motivating, contextually relevant, and cognitively supportive, such platforms can accelerate data-literacy development and better prepare learners for the analytical demands of modern academic and professional environments.

Furthermore, because learners differ naturally in their visual search fluency, visual analytics environments should provide multimodal frameworks: simplified layouts, progressive disclosure of information, guided cues, optional walkthroughs, and AI-driven personalization that adapts to the learner's cognitive profile. These considerations are especially relevant as STEM education moves increasingly toward data-driven workflows, dashboards, and exploratory analytics, skills that now function as core literacies in the modern digital economy.

Several lessons emerged from the design and implementation during this research. First, contextual familiarity had stronger effects when learners interacted in a more naturalistic, socially shared environment, as seen in the Indian classroom sample. Conducting the Canadian study in an individual laboratory setting may have reduced ecological validity, competitiveness, and the motivational benefits of peer presence. Future studies could therefore incorporate collaborative or group-based conditions, mirroring real-world analytics work and authentic classroom practice. Second, the sports dataset used in this study emphasized business-side analytics (contracts, revenue, income, etc), which aligned more with management domains. Data dashboards grounded in athletic performance, match statistics, or predictive modeling may have yielded deeper personal resonance, particularly learners who reported high sports familiarity. Third, the participant sample included some data analytics professionals and PhD grads who found the system too easy; future research should target younger learners or novices, who represent the population most likely to

benefit from such systems. These adjustments would improve measurement sensitivity, ecological realism, and generalizability.

Future work could systematically test how different contextual domains (sports, music, movies, sustainability, healthcare, etc.) interact with visual search propensity to shape cognitive load, attention, and emotional engagement. Additional studies could experimentally manipulate contextual familiarity to determine whether it can be trained or primed, rather than merely measured. Temporal design elements also warrant investigation: participants frequently exceeded the task duration without noticing, partly because the timer disappeared during scrolling. Testing a persistent floating timer could reveal how temporal feedback shapes workload, arousal, and strategic behavior in data-rich tasks. Finally, cross-cultural comparative studies should continue to explore how cultural identity and media ecosystems shape familiarity, motivation, and the interpretation of learning environments, providing insight into how globalized learning platforms can remain culturally adaptive.

Beyond academics, these findings also hold practical value for workplace learning and professional training. Many industries rely heavily on complex visual-analytics tools such as SAP, Tableau, and Power BI, where employees need to be trained in less time to make data-driven decisions. Integrating contextualized and familiar scenarios into employee trainings may enhance user engagement, reduce cognitive effort, and improve overall task efficiency. In this sense, the principles demonstrated in this thesis extend beyond academic settings and suggest meaningful pathways for improving data literacy and analytic performance in modern organizational environments.

Despite the limitations of this thesis, like, the absence of physiological data in the Indian sample and the controlled laboratory conditions used for Canadian participants, the findings provide a

meaningful foundation for future work. These constraints can be addressed in subsequent studies to build a more comprehensive understanding of how contextual familiarity and visual search propensity interact across cultures. The cultural pattern observed in this thesis, based primarily on self-report and surface-level perceptual indicators, suggests the need for deeper cross-cultural investigation using eye-tracking and other psychophysiological tools.

A particularly promising direction concerns how cultural reading conventions shape visual search behavior. Research shows that individuals who read from right to left (e.g., Arabic or Hebrew readers) or top to bottom (e.g., traditional Chinese readers) develop distinct scanning biases and perceptual habits that influence how they navigate interfaces, allocate attention, and search through visual displays (Chokron & Imbert, 1993). Integrating these cultural visuospatial tendencies into future research could reveal how learners from different linguistic backgrounds engage with visual analytics dashboards. Such insights would add a critical new dimension to contextualized STEM learning design and further illuminate how culture, cognition, and interface interaction intersect.

In its broader contribution, this thesis demonstrates that visual analytics learning cannot rely solely on cognitive skill development; it must also speak to the learner's identity, interests, and cultural world. Visual search propensity explains how learners process information, while contextual familiarity explains why they engage, persist, and attribute meaning to the experience. When these mechanisms align, learning becomes not only more efficient but also more emotionally resonant and personally meaningful. As education continues to evolve in an era of shortened attention spans, rapid media consumption, and increasingly digital learning ecosystems, the findings of this thesis underscore a key imperative: teaching methods must adapt to the cognitive realities and cultural landscapes of contemporary learners. Just as previous generations reshaped education to meet their times, today's educators must design learning environments that are interactive, contextualized,

culturally responsive, and cognitively supportive ensuring that STEM education remains not only relevant but genuinely empowering for the next generation.

Appendix A

Measurements scales

Satisfaction - CSAT

Farris, P. W., Bendle, N., Pfeifer, P., & Reibstein, D. (2010). Marketing Metrics: The Definitive Guide to Measuring Marketing Performance. Pearson Education

1. How satisfied were you with the online learning experience?

(7-point Scale: 1 = Unsatisfied, and 7 = Satisfied)

System Usability (SUS)

Lewis, J., Utesch, B., Maher, D. (2013). UMUX-Lite: When There's No Time for the SUS. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2099-2102

1. I think it is easy to learn how to play the game.
2. I feel the game provides me the necessary information to accomplish a goal within the game.
3. I think the information provided in the game (e.g., onscreen messages, help) is clear.

(7-point Scale: 1 = Strongly Disagree, 7 = Strongly Agree)

Enjoyment (GUESS)

Phan, M., Keebler, J. and Chapparo, B. S. (2016). The Development and Validation of Game User Experience Satisfaction Scale (GUESS), Human Factors: The Journal of the Human Factors and Ergonomics Society, (58:8).

1. I enjoy playing the game.

2. If given the chance, I want to play this game again.
3. I am likely to recommend this game to others.

(7-point Scale: 1 = Strongly Disagree, 7 = Strongly Agree)

Cognitive Load Nasa-TLX (Task Load Index)

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. *Advances in Psychology*, 52, 139-183.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. *Advances in Psychology*, 52, 139-183

1. How mentally demanding was the task?
2. How hurried or rushed was the pace of the task?
3. How successful were you in accomplishing what you were asked to do?
4. How hard did you have to work to accomplish your level of performance?

(Percentage Slider: 0 = Low, 100 = High)

Emotional appeal (WEBQUAL)

Loiacono, E. T., Watson, R. T., & Goodhue, D. L. (2007). WebQual: An Instrument for Consumer Evaluation of Web Sites. *International Journal of Electronic Commerce*, 11(3), 51-87

1. I feel happy when I use the system.
2. I feel cheerful when I use the system.
3. I feel sociable when I use the system.

(7-point Scale: 1 = Strongly Disagree, 7 = Strongly Agree)

Familiarity (Instrument for Exergame Familiarity)

PsycTESTS Citation: Zhang, H., Wang, D., Wang, Y., Chi, Y., & Miao, C. (2021). Familiarity

Instrument for Exergames [Database record]. Retrieved from PsycTESTS. doi:

<https://dx.doi.org/10.1037/t78955-000>

<https://psycnet-apa-org.proxy2.hec.ca/fulltext/9999-78955-000.pdf>

1. I have much prior experience with this task. (heard of, searched for information, owned and played).
2. While remembering this task, the emotions are extremely positive.
3. I frequently do this task in my daily life.
4. Before today, I had a deep impression and fully understood the rules and skills of doing this task.
5. I have done this task very recently.

(7-point Scale: 1 = Strongly Disagree, 7 = Strongly Agree)

Appendix B

Experimental stimuli

Business Builders

<https://businessbuilders.hec.ca/>

SAP analytics cloud

<https://www.sap.com/products/data-cloud/cloud-analytics.html>

Analysis tool for hypothesis testing

Statistical Models: SAS OnDemand for academics

<https://welcome.oda.sas.com/>

Video Tutorial

<https://youtu.be/83hajE1hSqc>

Study Demo Video

https://youtu.be/DVs_18KjXb4?si=U8Tj8_CVervUWN19

Appendix C

Laboratory setup

Participant Room



Figure C1. Participant setup

The participant station consisted of multiple synchronized components (Figure C1). A central monitor displayed the experimental interfaces: the Business Builders platform with The Agent game (2025) on the left side, and SAP Analytics Cloud (SAP SE, 2025) on the right. Both platforms were accessed through Google Chrome (Google LLC, 2025). A Tobii eye tracker (Tobii AB, 2025) was mounted at the bottom of the monitor to record gaze behaviour, and a webcam was positioned at the top to capture facial expressions. Participants interacted with the system using a standard keyboard and mouse. External speakers placed on either side of the

monitor allowed them to hear moderator instructions and tutorial videos. A table-mounted microphone enabled participants to communicate with the moderator, while an under-table speaker relayed audio from the moderator in real time. A tablet was provided for reviewing and signing the consent and compensation forms. The Bluebox system (Courtemanche et al., 2018) was also situated in the participant room, including the Bluebox device, a synchronization unit that transmitted timing signals, and the EDA sensors used to collect electrodermal activity data. Medical tape and gloves were available to secure the sensors when required.

Moderator Room



Figure C2. Moderator setup

The moderator room was equipped with two high-performance computers connected to three monitors (figure C2). The central monitor mirrored the participant's screen, which also served as

an extended display for task monitoring. One of the side monitors operated Tobii Pro Lab (Tobii AB, 2025), allowing the moderator to track and record eye-movement data throughout the session. The other monitor ran the Capture platform, enabling the moderator to initiate and stop webcam recordings.

Additional equipment included a microphone for communicating with the participant, speakers for listening to participant responses, and a printed copy of the study protocol for reference. A supplemental reading light was positioned above the central monitor to ensure visibility of the protocol during low-light observation conditions.