education sciences

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Gender Comparison of Factors Involved in Self-Study Activities with Digital Tools: A Mixed Study Using an Eye Tracker and Interviews

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Abstract

This study investigates gender and disciplinary differences in self-directed study strategies with digital tools among university students. Grounded in Activity Theory (AT), Gender Similarities Hypothesis, and Self-Determination Theory, the research explores how students from STEM and non-STEM fields interact with digital and paper-based materials during individual study sessions. A mixed-methods design was employed, combining eye-tracking data with qualitative interviews. Forty students (mean age: 21.5; equally distributed by gender and disciplinary field) participated in 15 min study sessions using the Pupil Invisible eye-tracker. Fixation durations and heat maps were analyzed through RStudio (Version 2024.04.2+764r), while semi-structured interviews explored students' motivations, study habits, and perceptions of strategy effectiveness. A theory-driven codebook was developed to analyze interview data, incorporating cognitive, emotional, socio-cultural, and metacognitive dimensions. Results indicate that the disciplinary field plays a more decisive role than gender in shaping study strategies. Female STEM students alternated between digital and paper tools, while non-STEM females used digital tools more continuously. Among males, non-STEM students favored paper, whereas STEM students engaged more with digital materials. Interview data confirmed intra-gender variation and emphasized the influence of context, autonomy, and study planning. The integration of eye-tracking and qualitative inquiry effectively captured both behavioral patterns and students' perspectives. Findings suggest the need for inclusive, flexible educational practices that respect diverse learning preferences and disciplinary cultures.

Keywords: eye-tracking; digital learning strategies; gender and discipline differences; educational technology; activity theory

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Academic Editor: Andrea C. Borowczak

Received: 2 September 2025
Revised: 14 October 2025
Accepted: 15 October 2025
Published: 26 November 2025

Citation: Cavallaro, A., & Ligorio, M. B. (2025). Gender Comparison of Factors Involved in Self-Study Activities with Digital Tools: A Mixed Study Using an Eye Tracker and Interviews. *Education Sciences*, *15*(12), 1589. https://doi.org/10.3390/educsci15121589

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1. Introduction

The integration of digital technologies into higher education has significantly transformed students' study habits, especially following the acceleration of digital learning during the COVID-19 pandemic (Dhawan, 2020). Although numerous research studies have explored the impact of digital tools on academic performance and engagement (Bond et al., 2020), it remains unclear how students actively integrate digital materials into their self-study routines. In particular, little is known about the influence of gender and disciplinary background on study strategies in digital contexts. Filling this gap is critical to designing inclusive educational approaches that respond to diverse learning preferences.

Despite the increasing use of digital resources, there is a lack of in-depth understanding of how students interact with these tools during self-study, and whether these modes vary by gender and discipline. To analyze these dynamics in more depth, this study introduces the analysis of visual fixations as a central methodological perspective. Indeed, the use of eye-tracking technology on college students enables the collection of objective, real-time data on visual interaction with digital and paper materials during self-study. In addition to recording fixation patterns, eye-tracking enables the generation of heat maps highlighting areas of increased visual attention, thus providing an immediate and effective visual representation of the cognitive strategies adopted by students.

This approach goes beyond mere self-reported data, allowing subtle variations in attention and strategies, influenced by individual and disciplinary factors, to be captured. The study thus contributes to filling existing gaps by integrating quantitative eye-tracking data with qualitative insights from semi-structured interviews. A mixed-method approach was selected because it is able to enhance ecological validity and bridge the gap between observable gaze patterns and participants' reflective accounts, as also proved in similar previous works where visual behavior analysis has been combined with interpre- tive inquiry (Johnson & Strauch, 2024; Hu & Shepley, 2024). In this way, an innovative perspective on the intersection of gender, discipline, and digital learning is offered. Unlike much previous research that tends to view digital adoption as a homogeneous phenomenon, this work aims at highlighting the variability of study strategies, both within and across gender groups, showing how interaction with digital tools is shaped by personal preferences and the specifics of different fields of study (Becher & Trowler, 2001; Bond et al., 2020; Alemdag & Cagiltay, 2018).

2. Theoretical Framework

This study is framed within Activity Theory (AT) (Engeström et al., 1999), which, unlike traditional cognitive theories, focused on individual mental processes, interprets learning as a social and culturally mediated activity. AT is strongly grounded into Vygotsky (1978) thought, in particular to the idea that tools and signs play a central role in the construction of thinking and internalization processes. Learning, therefore, develops within historical, cultural and social contexts and cannot be understood outside of them.

Leont'ev (1978) expanded this view by distinguishing three levels within human interaction with the world: activity guided by the motivation and the intentional aim to pursue a goal; actions needed to achieve the set goal; and operations, which are automatic or habitual processes shaped by context or conditions. Building on these ideas, Engeström (1987) developed a systemic model of activity, which includes interconnected elements such as subject, object, tools, rules, community and division of labor. This model is particularly suitable for interpreting self-study as intentional, mediated and situated activity.

Therefore, according to AT, studying is not simply an individual activity, rather it is an activity aimed at achieving a goal socially recognized—for example, passing an exam or obtaining a qualification—influenced by the socio-cultural context, by the value assigned to studying and the results that can be obtained, by the tools used, and by the community—in a broad sense—within which the action takes place. In this sense, the field of study and the degree course attended can represent important cultural indicators because they imply different study paths, different objectives and different ways of approaching the study tools. As Becher and Trowler (2001) argue, academic disciplines constitute distinct "epistemic cultures" that influence not only what is studied, but also how knowledge is produced, organized, and evaluated. These disciplinary cultures imply specific backgrounds and promote different cognitive styles, communication norms, and values, which in turn shape students' learning practices and the way they engage with tools. This perspective aligns

with AT, where the community and rules of a given academic domain act as mediating elements in shaping the subject's actions and choices. A broad classification in higher education fields is the one that groups together Science, Technology, Engineering and Mathematics (STEM) and contrasts them with the humanities (non-STEM) (National Science Foundation, 2022). STEM subjects are, in contemporary Western society, highly appreciated because they are considered more suitable to the current demands of the world of work but also because they imply a problem-solving reasoning, considered transferable and useful also in other areas of life (Xie et al., 2015).

Since STEM disciplines promise greater professional success, many—both in research (Ceci et al., 2014) and in social policies (Chavatzia, 2017)—encourage and support an increase in the enrollment of women (but also of other minorities) in STEM degree courses. In this sense, it is interesting to observe whether the disparity of interest directed towards these two disciplinary fields depends on socio-cultural factors or on behavioral and cognitive modalities specific to the two genders.

From this perspective, self-study with digital tools is seen as a process in which the student pursues learning goals by actively interacting with devices, content and technological environments. Indeed, digital materials act as mediating artifacts, shaping not only access to information, but also the cognitive and behavioral strategies enacted during study (Kaptelinin & Nardi, 2006). In this perspective, the use of eye-tracking technology plays a theoretically relevant role since it makes it possible to observe the interaction between subject, object and tools in real time and to analyze how students direct their attention during their study activities. Visual fixations, gaze trajectories and heat maps become observable indicators of how the student constructs and pursues the object of the activity (Holmqvist et al., 2011). AT allows these data to be interpreted not only as mechanical reactions, but as expressions of situated cognitive processes mediated by the tools at hand.

A fundamental distinction proposed by AT is that between tools and signs. While tools mediate external activities (digital devices, texts), signs mediate internal cognitive processes (such as language, symbols, and cultural artifacts). In digital learning environments, as well as in analog settings, language is a crucial mediator, facilitating communication, reflection and knowledge construction. The internalization of digital skills—such as the ability to navigate through online discussions, interpret multimedia content or use digital tools—demonstrates how external interactions contribute to cognitive development over time (Murphy & Rodriguez-Manzanares, 2008).

To analyze gender differences, this study relies on a combination of two theoretical approaches. First, Hyde's (2005) Gender Similarities Hypothesis states that men and women exhibit very similar cognitive abilities, and that any observable differences are primarily induced by social and cultural rather than biological factors. This orientation invites the interpretation of differences in visual behaviors and study strategies as adaptive responses to different experiences and educational contexts, and not as expressions of innate abilities. Second, Ryan and Deci's (2000) Self-Determination Theory (SDT) provides a useful framework for understanding the motivations behind strategic choices in study. According to SDT, people are driven by the satisfaction of three basic psychological needs: autonomy, competence, and relationship. The perception that a digital tool fosters these needs can significantly influence how it is used (Deci & Ryan, 1985; Ryan & Deci, 2000). These perceptions may vary among students and learners, thus generating different approaches in self-study. Taken together, Activity Theory provides the socio-cultural lens through which study strategies are interpreted, Self-Determination Theory explains the motivational mechanisms driving tool selection, and the Gender Similarities Hypothesis contextualizes these patterns within socially constructed, rather than biological, gender differences. This integrated framework guided the formulation of the research questions and the mixed-

method design, supporting both the quantitative observation of visual attention patterns and the qualitative interpretation of students' self-regulated study strategies.

Such integration aligns with recent developments emphasizing how Activity Theory can be employed to analyze learning as a complex, tool-mediated process in mixed-method research contexts (Ilishkina, 2025), and how Self-Determination Theory clarifies the relationship between digital engagement, perceived autonomy, and learning outcomes in online environments (Yuerong et al., 2024).

3. Method

3.1. Objectives and Research Questions

The main objective of this study is to explore visual attention processes and cognitive strategies adopted during self-directed study activities with digital materials, with particular attention to gender differences within and across STEM and non-STEM disciplines. The research questions guiding this work are:

- Which psychological, cognitive, and contextual factors influence university students' use of digital tools during self-directed learning activities?
- How do these strategies vary across STEM and non-STEM disciplines?
- How do gender shapes students' digital study strategies?
- How do gender and field of study (STEM vs. non-STEM) intersect in determining students' study strategies?

3.2. Participants

The sample consists of 40 university students, aged between 18 and 25 years, equally divided by gender (20 F.; 20 M.) and disciplinary areas (STEM and non-STEM). In total, 20 students belong to the STEM area and 20 to the non-STEM area and in each case 10 of them are women and 10 men, schematically reported in Table 1.

Table 1. Study participants.

Area	Discipline	Total Participants (By Area)	Male (By Area)	Female (By Area)
STEM	Engineering, Biology, Medicine, Nursing	20	10	10
No-STEM	Psychology, Philology, Languages, Cultural Heritage	20	10	10

The participants were recruited at two different university sites (University of Bari and Salerno), selected based on the possibility of the researcher to collect data on these sites. All the students were fully informed about the aim of the study and voluntarily took part in the data collection, after having signed informed consent.

3.3. Instruments and Data Collection Protocol

To gather data, in this study two instruments are used:

- The Pupil Invisible eye-tracking device (Pupil Labs) was used, allowing for natural recording of eye movements without rigid calibration.
- A semi-structured interview protocol purposely developed to complement the visual data collected through eye-tracking. The interview started from the results obtained with the eye-tracking device and it was designed to elicit insights into students' cognitive, emotional, sociocultural, and motivational dimensions of learning, with particular attention to the role of digital tools in self-directed study.

The combination of these two tools allowed for a deeper understanding of students' subjective experiences and strategic choices during the study activity.

Moreover, it was developed a protocol for data collection that will be described in detail in the next paragraph.

3.4. Procedure for Data Collection

To explore students' study behaviors with digital tools, a multi-step procedure was implemented involving eye-tracking recordings and follow-up interviews.

The study was conducted in informal educational settings, such as libraries and study rooms, according to the students' preferences. The research protocol was reviewed and approved by Ethics Committee at the Department of Education, Psychology and Communication, University of Bari "Aldo Moro" (Ethics reference code: ET-24-16, Bari 17 July 2024). Participants were approached and informed about the objectives of the research. Those who agreed to take part were introduced to the eye-tracking glasses, worn by the researcher during the explanation to illustrate the functioning. The use of adhesive tags on students' personal devices (e.g., laptops or tablets) was also described, as these tags allowed accurate tracking of visual fixations.

Before starting the tracking session, each student signed an informed consent form and provided their email address for follow-up contact. Participants were then invited to carry out their usual individual study activity using their own materials and digital tools, while wearing the eye-tracking glasses.

The gaze data collected during each session were later analyzed to identify patterns of visual attention, such as fixation points and heat map distributions. Subsequently, students were contacted via email to schedule a remote individual interview on the ZOOM platform.

During the interview, the participant was shown a recording of their eye-tracking session, including heat maps and gaze paths, in order to facilitate reflection and verbalization of their study strategies. Each interview lasted approximately 15 min, was conducted with the participant's consent, and was recorded for transcription and further qualitative analysis.

During the interview phase, after a first section focused on students' general strategies for self-regulated learning, each participant was presented with the video of their own eye-tracking session. The playback included gaze trajectories and heat maps to visually represent the points of focus and attention flow during the individual study activity. This second part of the interview was structured to elicit detailed reflections on the behaviors observed: students were asked to comment on their gaze patterns, shifts in attention, the reasoning behind tool-switching (e.g., from screen to notebook), and moments of cognitive effort or disengagement.

By integrating real-time visual feedback, the interview not only deepened the understanding of students' choices and strategies, but also enabled a richer metacognitive reflection. This approach allowed participants to verbalize implicit processes—such as deciding when to pause, re-read, take notes, or change medium—that would otherwise remain unspoken. The protocol thus offered both descriptive and interpretative insights into the individual study experience, situated within each student's disciplinary and gender context.

In synthesis, three steps can be outlined as composing the data collection protocol:

1. Study sessions. Participants study as they usually do while wearing the eye-tracker, after having familiarized with it. These sessions, each lasting approximately 15 min, were entirely recorded.
2. Quantitative analysis of fixations. Raw data were downloaded from the Cloud Pupil in tabular format, containing fixation duration values. Subsequently, the data were analyzed in RStudio, creating box plots representing the fixation level of each student, interpreted as their level of attention.

3. Semi-structured online interviews. Each participant took part in a semi-structured online interview, exploring the study strategies adopted, inferred from the eye-tracking records. Particular attention was posed on the integration of digital tools and the management of distractions and breaks.

3.5. Corpus and Data Analysis

The data corpus consists of:

- 40 video recordings of study sessions totaling approximately 10 h of recording;
- Numerical dataset of visual fixations on Areas of Interest (AOI) and heat maps visualizing the areas where students' attention was most concentrated.

To analyze the data quantitative and qualitative methods are combined. Videos of eye-tracking sessions allowed not only for objective measurement of visual fixation times on digital tools, but also for direct and immersive observation of students' behaviors during self-study. This observation made it possible to capture dynamics otherwise invisible, such as moments of switching between digital and paper materials.

In addition, the semi-structured interviews made it possible to explore in depth the motivations, habits and subjective experiences that drive these behaviors, offering explanations consistent with the patterns detected in the visual tracings. The interaction between these two sources enabled reinforcing the validity of the results and allowed a rich and articulate view of the study strategies adopted by students.

Quantitative data were analyzed by processing the numerical fixation duration tables downloaded for each video recording from the Cloud Pupil and subsequently processed in RStudio by creating box plots to represent the level of visual attention of the students.

Qualitative interview data were analyzed using an exploratory qualitative analysis approach. From the analysis of the transcripts, four main dimensions, inspired by AT, were identified as structuring students' practices and perceptions: cognitive, sociocultural, emotional and metacognitive. A dedicated codebook was developed based on the interview data to categorize and interpret these dimensions, allowing for a systematic and data-driven coding process. Thematic analysis was conducted following a Grounded Theory approach (Glaser & Strauss, 1967), allowing categories to emerge inductively from the data rather than being defined a priori. We considered the development of the Codebook—based on the analysis of focus group discussions and interviews conducted after the eye-tracking sessions—as the first outcome of our research.

The final Codebook is composed of five main dimensions, each including two or more sub-dimensions. Interview transcripts were segmented into meaningful units, and each unit was assigned to a specific sub-dimension. To facilitate the organization and analysis, each macro-dimension was given a numerical identifier, followed by the sequential coding of the respective sub-dimensions.

The coding process was carried out by two independent researchers (first and second authors), who initially analyzed 10% of the data separately, achieving a 70% agreement rate. Discrepancies were discussed with a third, more experienced researcher (third author), until full consensus was reached (100%). This procedure was repeated across increasingly larger segments of data, culminating in approximately ten iterative meetings and three different versions of the Codebook, progressively refined through joint discussions and adjustments.

The final version of the Codebook includes concrete examples extracted from participants' statements, which are reported in the following tables to illustrate how categories were constructed and applied.

4. Results

4.1. Results from the Eye-Tracker

The boxplots shown in Figures 1 and 2 represent the fixation durations recorded during the study sessions for female students in STEM and non-STEM areas.

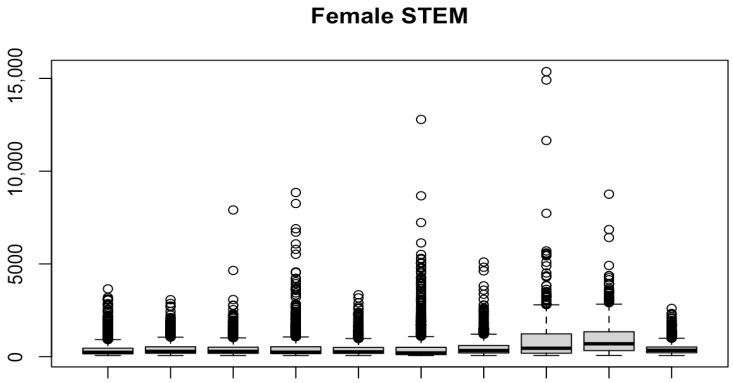


Figure 1. STEM boxplot.

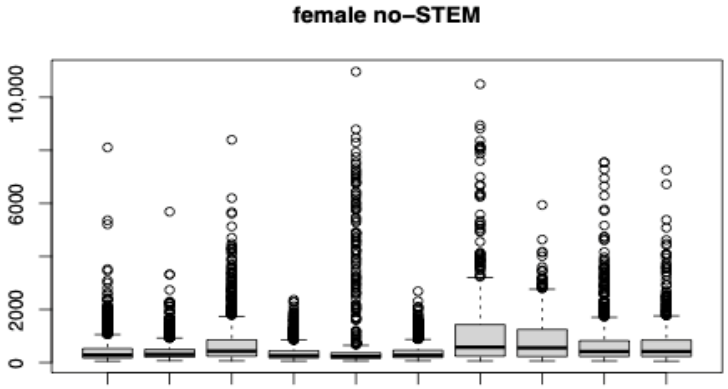


Figure 2. No-STEM boxplot.

Each boxplot corresponds to a participant and visualizes the variability and central tendency of their visual fixations on digital content. Larger boxplots indicate longer and more dispersed fixation durations, suggesting more time spent on digital materials and less frequent shifting of gaze.

Although there were no clear overall gender differences, significant intra-gender variation emerged between female students across STEM and no-STEM disciplinary areas.

Female STEM students showed narrower boxplots, indicating more uniform and shorter fixation durations. This pattern reflects what was observed also in the interview data that confirmed STEM females frequently switched between digital screens and paper-based materials. As one student explained, "*When something gets too complex on screen, I just print it or rewrite it in my notebook.*" This behavior likely led to less sustained visual engagement with the digital interface, as attention distributed across multiple supports.

In contrast, non-STEM female students displayed wider boxplots, indicating longer fixations and more continuous visual interaction with the screen. Several participants reported relying almost exclusively on digital tools for organizing and reviewing content. One noted: "*I use my laptop for everything, from taking notes to reading articles.*" This consistent use of digital media likely accounts for the more extended fixation durations recorded in the eye-tracking data.

The findings suggest that field of study plays a major role in shaping study strategies, even within the same gender. STEM students—especially females—tended to engage in multimodal study behaviors, distributing attention across digital and paper sources.

Non-STEM students, on the other hand, demonstrated more linear digital engagement, focusing primarily on screen-based materials without frequent switching.

These patterns emphasize that disciplinary context, more than gender alone, influences how students interact visually with learning tools. As such, educational strategies should consider the intersection of gender and field to better support personalized and effective digital learning experiences.

The boxplots for STEM and non-STEM male students (see Figures 3 and 4) reveal different patterns in the distribution of fixation times on digital devices. Specifically, among non-STEM males (Figure 3), the boxplots appear flatter and more compressed toward the lower range, suggesting fewer fixations recorded on digital screens. This likely reflects a preference for paper-based study materials, resulting in minimal visual engagement with the devices equipped with eye-tracking tags.



Figure 3. No-STEM boxplot.

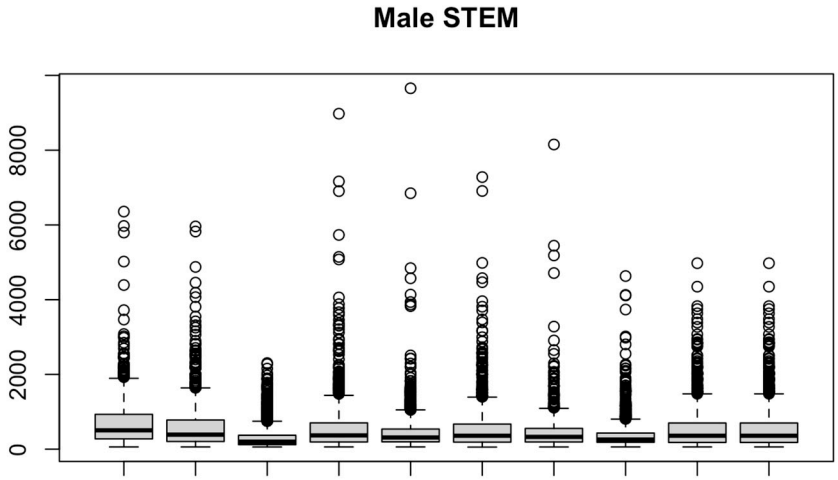


Figure 4. STEM boxplot.

In contrast, STEM males (Figure 4) exhibit wider boxplots, indicating a greater number of visual fixations on digital devices. This pattern aligns with the observed behaviors during the study sessions, where STEM students predominantly relied on laptops or tablets, maintaining longer visual focus on digital content.

In both cases, the differences captured by the boxplots are more clearly inter-group (i.e., based on disciplinary domain) than purely gender-based, reinforcing the notion that the chosen mode of study—digital vs. paper-based—plays a central role in shaping visual attention patterns.

Heat Map Analysis

To complement the quantitative data on fixation durations, heat maps were generated to visually represent the concentration and distribution of gaze across digital study materials. These visualizations offer intuitive insights into how attention is directed during study sessions.

Figure 5 shows the heat map of a non-STEM student during a digital reading activity. The image reveals a homogeneous and centralized visual focus, concentrated on the main body of the text. This pattern reflects a continuous interaction with digital content, with fewer gaze shifts, and aligns with self-reported study strategies based predominantly on screen-based resources.

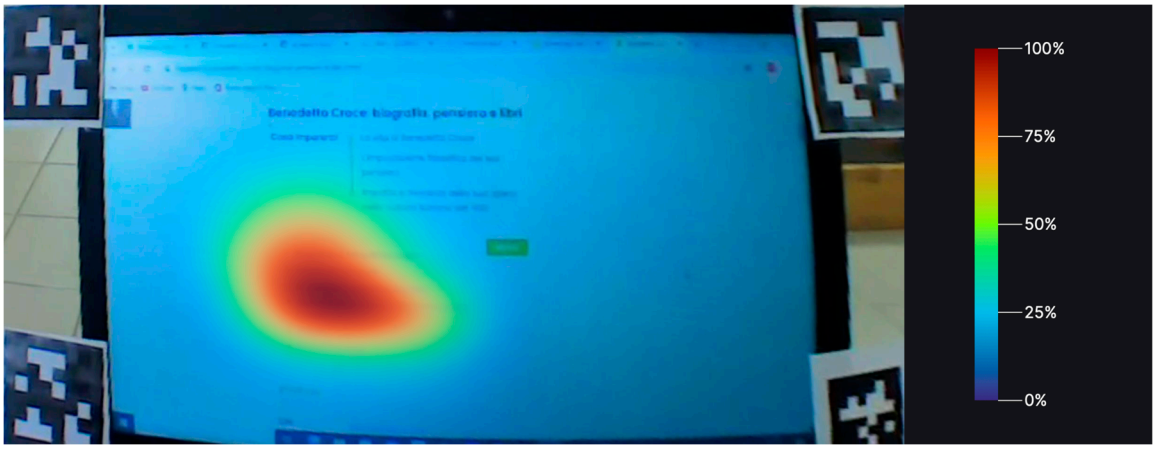


Figure 5. Heat map of a non-STEM student. The warm central area indicates sustained visual focus on digital text content.

4.2. Results from the Interviews

The finalized Codebook, presented in Table 2, represents the initial outcome of the qualitative interview analysis. It includes five main dimensions, each encompassing multiple sub-dimensions. The interview transcripts were segmented into meaningful units, as suggested by Chenail (2012), with each unit coded according to its corresponding sub-dimension.

Table 2. The Codebook.

Code	Sub-Dimension	Example Excerpts
1.C.1.a.	Use of paper for study planning	I always start by writing down what I need to study on paper. It helps me see everything clearly.
1.C.1.b.	Use of digital tools for study planning	I use OneNote or other apps to plan my study sessions.
1.C.3.c.	Digital as support for note-taking	Even if I study on paper, I take screenshots and annotate them with apps.
1.C.3.d.	Digital for organizing materials	All my study materials are in folders on my laptop, I like everything being accessible.
1.C.3.e.	Digital for specific tasks	I only use the tablet when I need to look something up quickly.
1.C.4.d.	Paper for in-depth understanding	I re-copy notes by hand when I want to truly understand something.
2.E.3.	Writing to enhance memorization	Writing by hand makes things stick more. I remember better that way.

Table 2. *Cont.*

Code	Sub-Dimension	Example Excerpts
3.C.1.	Teachers' instructions shape study choices	If a professor suggests a method, I try to follow it. They know what works.
3.C.2.	Nature of content affects strategy	If the topic is theoretical, I go digital. If it's practical, I write it out.
3.D.1.	Digital is not a distraction	I don't get distracted on the PC, I keep all notifications off.
3.D.3.	Paper gives sense of control	When I write by hand, I feel like I own the content more than typing it.
5.A.1.	Peer influence on tool choice	Everyone in my group uses digital flashcards, so I started doing it too.
5.A.4.	Autonomous male choice in digital use	I just like trying out new apps, I don't wait for suggestions.
5.B.1.	Encouragement from family or friends	My sister told me to try studying on tablet and it works great for me.

Each macro-dimension was assigned a numerical code, followed by sequential numbering for the sub-dimensions. After several iterations and consensus meetings among researchers, the final version was defined. Frequencies were then calculated to assess the recurrence of each sub-dimension across participants.

The application of the codebook at the interviews is reported in Tables 3 and 4 These tables reveal distinct patterns in the use of study tools and strategies across disciplinary areas and gender.

Table 3. Results for STEM students.

Study Strategies and Digital Use—STEM Area (n = 20)		
Category	Males (n = 10)	Females (n = 10)
Predominant use of digital tools	6 (60%)	5 (50%)
Combined use of digital and paper-based tools	4 (40%)	5 (50%)
Predominant use of paper-based materials	0 (0%)	0 (0%)
Mainly individual study	6 (60%)	6 (60%)
Group or mixed-mode study	4 (40%)	4 (40%)
Use of music or sounds while studying	5 (50%)	5 (50%)
Use of self-regulation strategies (e.g., planned breaks, Pomodoro method)	3 (30%)	3 (30%)

Table 4. Results for Non-STEM students.

Study Strategies and Technology Use—Non-STEM Area (n = 20)		
Category	Males (n = 10)	Females (n = 10)
Predominant use of digital tools	7 (70%)	6 (60%)
Combined use of digital and paper-based tools	3 (30%)	3 (30%)
Predominant use of paper-based materials	0 (0%)	1 (10%)
Mainly individual study	7 (70%)	7 (70%)
Group or mixed-mode study	5 (50%)	3 (30%)
Use of music or sounds while studying	4 (44%)	6 (60%)
Use of self-regulation strategies (e.g., planned breaks, Pomodoro method)	3 (30%)	4 (44%)

To facilitate comparison, Figure 6 provides a graphical overview of the data, showing how different sub-dimensions are distributed across groups. This visualization allows for a more immediate interpretation of within-group and between-group differences, emphasizing how fields of study and gender interact in shaping study behaviors.

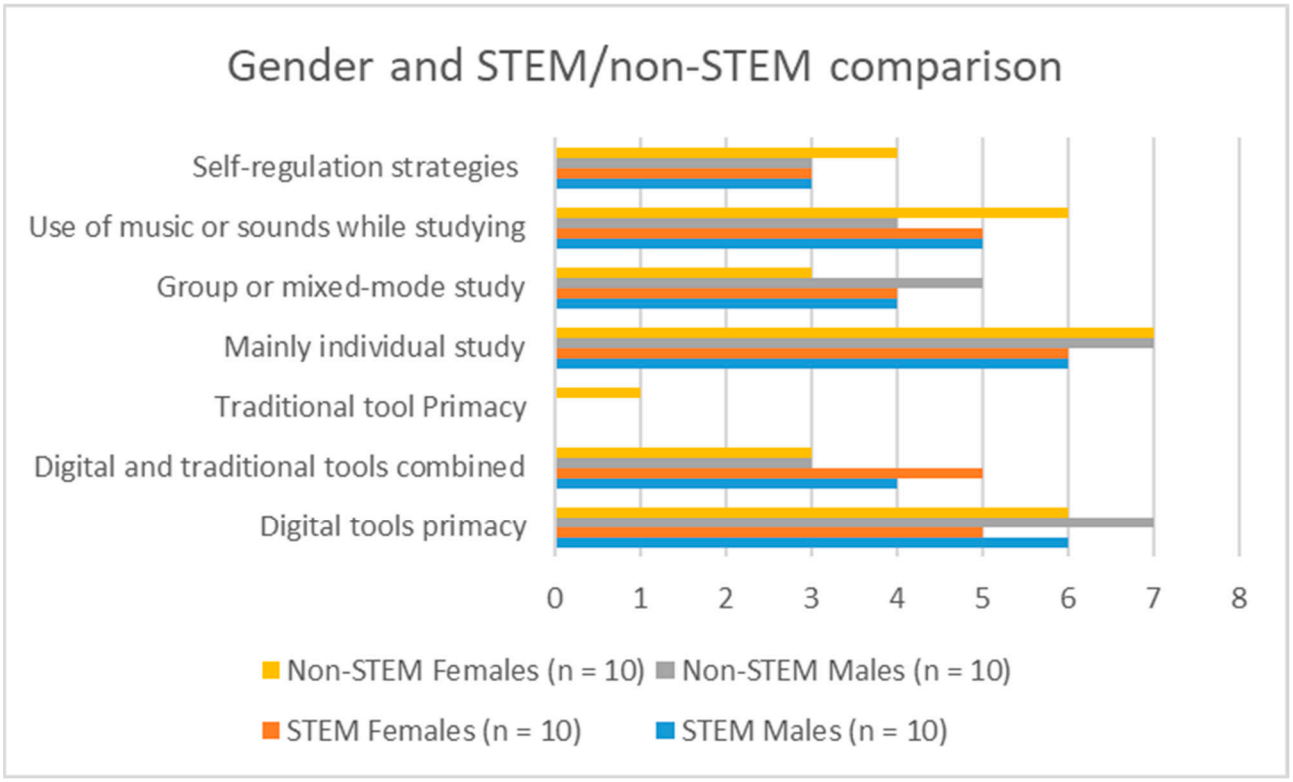


Figure 6. Distribution of interview codes by gender and disciplinary area.

In the STEM group, the majority of students reported a predominant use of digital tools, with a slightly higher proportion among male students (six out of 10; 60%) compared to female students (five out of 10; 50%). A portion of participants (four males and five females) reported combining both digital and paper-based materials, while no student reported an exclusive use of paper-based tools. Individual study was the most common mode (six males and six females), with the remaining students alternating between individual and group or mixed study modes. Listening to music or ambient sounds during study was common for half of the students (five males and five females), and 30% of both males and females adopted self-regulation strategies such as scheduled breaks or the Pomodoro technique (Cirillo, 2018)—a time management method that helps improve focus and productivity named after the tomato-shaped kitchen timer ("pomodoro" means "tomato" in Italian) (see Table 1).

In the non-STEM group, the use of digital tools appeared even more prominent, especially among male students (seven out of 10; 70%) and slightly less among females (six out of 10; 60%). The combined use of digital and paper-based tools was reported by six students (three males and three females), while only one female reported an exclusive use of paper-based materials. Individual study was predominant in both subgroups (seven males and seven females). Group or mixed-mode study was reported by five males and three females. Listening to music was more common among females (six out of 10; 60%) than males (four out of 10; 44%). Self-regulation strategies were adopted by three males (30%) and four females (44%) (see Table 3).

Female students in non-STEM disciplines often highlighted their comfort with digital organization tools. One noted, "*I use OneNote or Google Docs to keep track of everything; it helps me stay organized*." Another said, "*With the tablet, I can search keywords quickly, and that saves me a lot of time.*"

Regarding study habits and music, many students across both groups expressed a preference for background audio. As one STEM student said: "*I always listen to classical music; it helps me focus and block out distractions.*" A non-STEM student shared: "*Lo-fi beats are perfect for staying in the zone while I review my notes.*"

In terms of self-regulation strategies, comments included: "If I don't take breaks, I get overwhelmed, so I use the Pomodoro app" (STEM female), and "I time my sessions in 30-min blocks because otherwise I scroll on my phone too much" (non-STEM male).

Overall, these insights enrich the quantitative data, showing how preferences and behaviors intertwine with students' individual and academic contexts.

5. Discussion and Educational Implications

This research explored the study strategies implemented by university students during individual study sessions with digital materials, examining how these are influenced by the intersection of gender and disciplinary field. The discussion is structured around four research questions and draws on the theoretical framework of AT (Engeström, 1987) and Hyde's (2005) Gender Similarities Hypothesis enriched by the Self-Determination Theory (Ryan & Deci, 2000).

RQ1: Which psychological, cognitive, and contextual factors influence university students' use of digital tools during self-directed learning activities?

The findings show that students' choices and uses of tools are deeply shaped by multiple interrelated dimensions. On a psychological level, the perception of content complexity frequently prompts students to prefer digital media in favor of paper, which is associated with a higher sense of control and depth. From a cognitive standpoint, several students alternate tools based on task type: using digital tools for organizing materials, looking up information, and annotating screenshots, while relying on paper for deep processing, synthesis, and memorization. Rewriting by hand and repeating aloud are used to consolidate knowledge, showing a strong link between tool, function, and purpose.

About the contextual dimensions, one of the most important aspects that emerged concerns students' study planning strategies. Some students plan their sessions using digital tools like OneNote, while others rely on handwritten to-do lists to visualize their study path. These strategic decisions reflect learners' need for autonomy and competence, as outlined by Self-Determination Theory. Furthermore, the socio-cultural dimension emerges with relevance: peer interaction, family support, and cultural factors such as the impact of COVID-19 are often cited as shaping the use and meaning of digital tools. Activity Theory helps frame these choices as outcomes of purposeful activity mediated by tools within sociocultural contexts.

RQ2: How do these strategies vary across STEM and non-STEM disciplines?

The analysis reveals clear differences between students from STEM and non-STEM fields. STEM students exhibit a strong preference for integrating analog tools into their study routines. They often switch to paper when content becomes complex, using digital tools primarily for organizing materials, planning, or accessing content. This suggests a pragmatic and goal-oriented use of digital technology, aimed at efficiency and structure rather than constant engagement.

By contrast, non-STEM students tend to rely more heavily on digital tools throughout the study session. These students report longer and more sustained interaction with digital content, and a broader use of digital platforms for both planning and note-taking. Some

non-STEM students, however, still prefer analog materials, reflecting disciplinary traditions and personal comfort with paper-based tools.

These results suggest that disciplinary epistemologies and norms deeply influence how students construct their study routines, shaping both the perceived utility of digital tools and the extent to which they are integrated into learning practices.

RQ3: How does gender shape students' digital study strategies?

Gender alone does not determine digital study behaviors. However, some gendered tendencies emerged in relation to autonomy, self-regulation, and control. Female students more frequently adapted their strategies based on task difficulty and showed a reflective use of both digital and analog tools. Notably, many of them employed digital platforms for planning study sessions and constructing concept maps, underlining a proactive and structured approach to learning. Male students demonstrated more habitual and less personalized tool use.

This supports the Gender Similarities Hypothesis (Hyde, 2005), affirming that differences are more context-dependent than innate. Socialization patterns, perceived expectations, and prior experiences—rather than biological sex—are likely responsible for the observed tendencies.

Study strategies also tend to persist within predominantly single-gender groups, suggesting that social identity and group cohesion—as highlighted by AT—play a crucial role in shaping learning behaviors.

RQ4: How do gender and field of study (STEM vs. non-STEM) intersect in determining students' study strategies?

The intersection between gender and discipline provided the most nuanced insights. Female STEM students demonstrated a strong tendency to integrate both digital and analog tools, particularly shifting to paper when the content became complex. For these students, digital tools primarily served to plan, organize, and structure the study process. In contrast, non-STEM female students were the only group to use digital tools as a primary and continuous medium for studying, with minimal integration of paper-based strategies. In contrast, none of the STEM female students reported using only digital tools for learning; instead, they consistently supplemented digital media with paper-based supports.

These observations are consistent with the findings of Alemdag and Cagiltay's (2018) meta-analysis, which highlighted the high variability of gendered behavior depending on the type of task, the structure of the learning material, and the degree of interactivity involved. According to their analysis, gender-related patterns in digital learning are not fixed but emerge through dynamic interactions between the learner, the context, and the task, which resonates with the present findings.

Furthermore, internalized gender stereotypes related to STEM may partially explain why some female students in non-STEM tracks adopt more linear and passive learning strategies. As Musso et al. (2022) demonstrated, such stereotypes are negatively associated with school empowerment and engagement among both Italian and Nigerian adolescents. These beliefs may subtly influence how students approach learning tasks, particularly in digital environments where confidence and autonomy are required.

These intersecting identities influence not only strategy selection but also learners' confidence and perceived effectiveness. Peer norms also play a key role. Group homogeneity reinforces certain habits, with study behaviors often clustering along gendered and disciplinary lines. Activity Theory helps explain how these shared practices arise from community rules, roles, and identities that shape engagement with tools.

From the lens of AT (Engeström, 1987), this intra-gender variation can be interpreted as the outcome of culturally and socially mediated activities. The tools (digital platforms), rules (educational expectations), and communities (disciplinary environments) that mediate

learning practices contribute to shaping students' study behaviors in gendered yet non-uniform ways. Self-Determination Theory (Ryan & Deci, 2000) further explains these patterns by emphasizing how autonomy, competence, and relatedness may influence students' motivation and, consequently, their interaction with learning tools. These findings align with those of Lehtamo et al. (2018), who showed that students' academic emotions—such as enjoyment, frustration, and anxiety experienced during real-time learning—play a critical role in their decision to persist in or leave physics-oriented academic tracks. The emotional climate surrounding learning activities, especially in demanding STEM contexts, can therefore shape individual learning approaches and long-term academic choices.

While the findings of this study reveal subtle and situated differences between genders, particularly within disciplinary domains, the broader literature provides results that do not always align. For example, Alemdag and Cagiltay (2018), in their meta-analysis of eye-tracking studies in education, observed considerable variability across research, concluding that gender differences are highly task-dependent and influenced by the design and interactivity of learning materials. This suggests that cognitive and visual behaviors are not strictly linked to gender but rather shaped by specific features of the learning experience. Similarly, Korlat et al. (2021) found visual behavior differences between genders but reported no significant correlation with learning outcomes, emphasizing instead the role of individual psychological traits such as self-efficacy and familiarity with digital content. These findings partly resonate with our emphasis on context but diverge by focusing more on intrapersonal variables than disciplinary culture. In contrast, Heo and Toomey (2020) found that gender, the type of multimedia resource, and spatial ability influenced learning outcomes in digital environments, with males generally benefiting more from animated resources. Their results suggest that learning design features can interact with gender and cognitive traits to shape learning effectiveness.

These contrasting studies underscore the complexity of interpreting gender differences in digital learning. They highlight the importance of considering not only gender but also situational, motivational, and disciplinary variables in shaping students' engagement with educational technologies. Our findings contribute to this broader conversation by suggesting that intra-gender and context-specific factors offer a more refined lens through which to understand digital learning behaviors.

Educational Implications

The findings of this research offer meaningful implications for university teaching and instructional design. The observed intra-gender and inter-disciplinary variations in study strategies suggest that students engage with digital learning environments in highly situated and individualized ways. These behaviors are not solely the result of personal preference, but reflect broader cultural, social, and motivational structures. Therefore, instructional strategies in higher education should be designed with flexibility, allowing space for diverse cognitive styles, study habits, and tool preferences.

In particular, educators should consider integrating multimodal learning pathways that combine digital and analog supports, especially in STEM contexts, where students often switch between digital platforms and handwritten resources to manage complexity. In non-STEM fields, where digital tools are used more consistently, teaching strategies should emphasize metacognitive awareness and digital literacy to foster more intentional and reflective learning practices.

Despite the limitations of the small sample size (n = 40), which affects the generalizability of the results, the originality of this study lies in the combination of two complementary methods—eye-tracking and interview—which together allow for a deeper and more nuanced understanding of study strategies. Future research should consider replicating the

study in larger and more diverse populations to strengthen the validity of the findings and further explore how different educational contexts shape learning behaviors.

Future studies could extend this research by combining eye-tracking with additional multimodal data sources, such as screen recording, physiological sensors, or learning analytics, to obtain a more comprehensive view of students' engagement processes. A larger sample would be advisable, always maintaining a balance between genders and between STEM and non-STEM students to understand whether the trend here observed would be confirmed. It would also be interesting to compare samples from different cultures to better understand the role played by cultural context. Longitudinal designs would also make it possible to trace how digital study strategies evolve over time and in response to specific pedagogical interventions. From a theoretical standpoint, future research could further explore the integration between Activity Theory and Self-Determination Theory, examining how the interaction between autonomy, competence, and social mediation shapes the development of self-regulated learning strategies. Finally, cross-cultural comparisons could help determine whether the observed gendered patterns and disciplinary differences are culturally embedded or reflect broader, universal dynamics in digital learning.

Moreover, the persistence of gender-connoted habits and the lack of meaningful cross-gender exchange in study strategies highlight the need to foster more inclusive and collaborative environments. Learning ecosystems should actively promote interaction among diverse learners, encouraging dialogue around study methods, tool selection, and approaches to learning. From the perspective of Activity Theory, this means rethinking the organization of tools, rules, and communities that mediate higher education practices, so as to challenge gendered norms and encourage more equitable participation. Similarly, Self-Determination Theory reminds us that learning environments should be structured to support autonomy, competence, and relatedness—dimensions essential not only for motivation, but also for the emergence of self-directed and inclusive study practices.

Author Contributions: Conceptualization, A.C.; methodology, A.C.; investigation, A.C.; data curation, A.C.; writing—original draft preparation, A.C.; writing—review and editing, M.B.L.; visualization, A.C.; supervision, M.B.L.; funding acquisition, M.B.L. All authors have read and agreed to the published version of the manuscript.

Funding: This re-search was conducted as part of a national project titled "Digital learning: socio-cognitive and emotional-motivational factors in-volved in studying supported by digital materi-als" funded by the Italian Ministry of Research and led by the University of Bari (code 2022RYY2A7).

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee at the Department of Education, Psychology and Communication University of Bari Aldo Moro ET-24-16, 2024-07-17.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in this study are included in the article material. Further inquiries can be directed to the corresponding author.

Acknowledgments: The authors acknowledge the use of artificial intelligence tools (ChatGPT, OpenAI) for language editing support.

Conflicts of Interest: The authors declare no conflict of interest.

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