

# “Maybe We Need Some More Examples:” Individual and Team Drivers of Developer GenAI Tool Use

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## Abstract

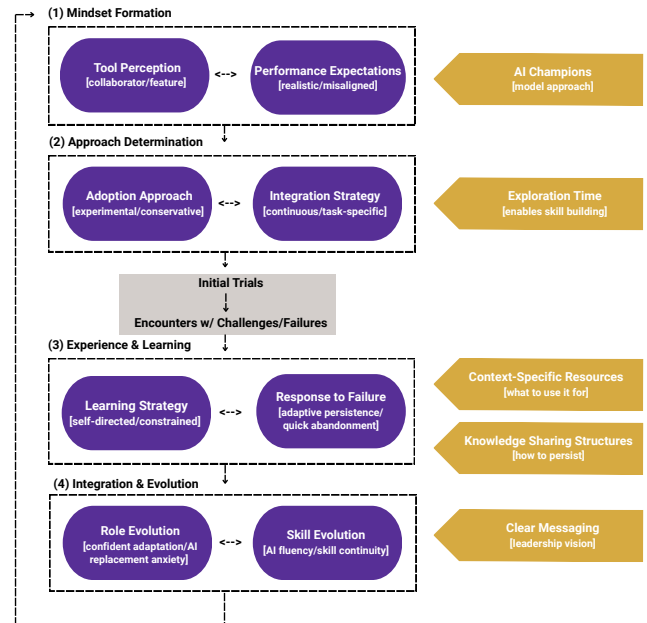
Despite the widespread availability of generative AI tools in software engineering, developer adoption remains uneven. This unevenness is problematic because it hampers productivity efforts, frustrates management’s expectations, and creates uncertainty around the future roles of developers. Through paired interviews with 54 developers across 27 teams – one frequent and one infrequent user per team – we demonstrate that differences in usage result primarily from how developers perceive the tool (as a collaborator vs. feature), their engagement approach (experimental vs. conservative), and how they respond when encountering challenges (with adaptive persistence vs. quick abandonment). Our findings suggest that widespread organizational expectations for rapid productivity gains without sufficient investment in learning support can create a “*Productivity Pressure Paradox*,” undermining the very productivity benefits that motivate adoption.

## 1 Introduction

The field of Artificial Intelligence (AI) has experienced several historic hype cycles where failed returns on investment led to AI Winters [43]. During the expert systems boom of the 1980s, global investments exceeded \$2.5 billion [31, 70, 80], but when these systems failed to deliver the expected returns, funding was dramatically cut, precipitating the second AI Winter [80, 89]. Today, AI experts and some economists argue that the transformational promise of Generative AI (GenAI) will create significant lasting impact across industry sectors [19, 49]. GenAI’s ability to augment processes that were previously difficult to digitize has led to widespread optimism and the rapid deployment of GenAI tooling by many organizations, often with minimal strategic planning and high expectations regarding productivity gains and subsequent cost savings [61, 64, 65, 90].

Like many others, the software engineering (SE) domain has been profoundly impacted by the introduction of GenAI tooling [23, 81, 85]. GenAI tools in SE show great potential, with some projections estimating productivity increases between 20% to 55% [19, 50, 75]. Yet despite these projections, studies report strikingly mixed outcomes in real-world usage [8, 41, 62]. While some developers achieve the promised productivity gains [84], others experience decreased efficiency when attempting to integrate these tools [13].

In the face of these challenges, a rapidly-evolving body of research focused on the adoption, usage, and integration of GenAI development tools has emerged in the past several years cataloging both enablers and barriers [5, 9, 55, 62]. Much of this work relies on individual-level models such as the Technology Acceptance Model



**Figure 1: Conceptual theoretical framework. Purple ovals == individual factors, yellow arrows == external factors.**

(TAM) [24] and Unified Theory of Acceptance and Use of Technology (UTAUT) [92]. While such lenses surface beliefs like perceived usefulness, they rarely hold constant the external realities - such as codebase complexity and management - that strongly shape tool adoption [13, 35, 58]. With the goal of understanding what differentiates developers who are frequent versus infrequent GenAI development tool users within the same team contexts, we begin by exploring the research question (RQ):

**RQ1** What individual factors distinguish frequent and infrequent users of Generative AI development tools?

Early discussions revealed that organizational practices appeared to shape individual factors for some developers (cf. Figure 1), leading us to explore these emergent results with a second RQ:

**RQ2** How do individuals report team and organizational practices influence their Generative AI development tool usage?

We utilize a paired interview design, conducting sequential semi-structured interviews with 54 developers representing 27 pairs from the same team matched on key factors—primary programming language, role, and seniority- but who exhibit contrasting usage patterns (one frequent user, one infrequent), identified using telemetry

data from Microsoft. This matching strategy ensures that both developers share the same team-level context—codebase, manager, policies—so we can directly compare the context-specific blockers an infrequent user faces with the work-arounds their frequent teammate has discovered. In doing so we trace how organizational conditions are interpreted and acted on rather than assuming purely individual causes, providing an empirically-grounded sociotechnical account of GenAI tool usage.

We identified key differences in approaches frequent and infrequent users (cf. Figure 1): frequent users often conceptualized the tooling as a collaborative partner, adopted continuous and experimental integration approaches, and leveraged adaptive persistence when facing challenges, while infrequent users more often viewed it as a utility feature, maintained conservative integration patterns, and more often quickly abandoned tools when facing challenges. Our analysis also identified key commonalities between the two groups: many developers reported that organizational practices actively shaped these individual factors through an amplification effect, e.g., team-specific demonstrations of applying GenAI tools on common development tasks can transform a developers' perception of tool usefulness. Most critically, we identified a phenomenon which we refer to as the *Productivity Pressure Paradox*: increased productivity expectations from management without corresponding support often create a paradoxical effect, where developers lack the time necessary to develop the skills that would save time. This finding challenges the prevailing GenAI tool deployment strategy across the software industry, which frames the challenge of figuring out how to use these tools to yield the expected productivity gains as the responsibility of individual developers [61, 64, 65, 90]. Like historical technological transformations in manufacturing and software engineering, we argue systematic productivity gains require systematic organizational change, not individual workflow optimization [12, 26]. The “deploy and figure it out” strategy where companies invest billions into GenAI tools without investing in the corresponding support structures necessary to enable the systematic evolution of development workflows that would potentially yield a return on investment, are largely driven by competitive pressures and repeat past failures to recognize that transformative technologies demand transformative organizational approaches [26, 44, 88].

In summary, this paper makes the following contributions: (1) a conceptual theoretical framework detailing the differences in individual factors between frequent and infrequent GenAI tool users; (2) a taxonomy of the ways developers report different team and organizational practices may interact with individual factors that influence usage; and (3) the concept of the *Productivity Pressure Paradox* and recommended strategies organizations can adopt to overcome it.

## 2 Background and Related Work

Given the rapid permeation of these tools in development work, the factors that affect developers' adoption and integration of GenAI tools have become a focal topic in the SE research community.

### 2.1 Individual Factors Affecting Adoption

Research has explored why developers use GenAI tools or not, often by adapting or extending classic technology acceptance theories (e.g., UTAUT [92, 93]). Early evidence suggests that traditional

adoption factors do not fully apply in developer-GenAI tool interaction contexts. For example, Russo [81] found that GenAI tool compatibility with a developers' workflow drives early adoption, outweighing traditional UTAUT factors such as effort expectancy.

Trust has emerged as a critical factor in the design and adoption of these tools [47, 94]. Choudhuri et al. [17] found that system quality, functional value, and goal alignment increase developers' trust in GenAI tools, which—combined with risk tolerance, self-efficacy, and intrinsic motivations significantly influences adoption.

Additionally, empirical studies highlight the significant challenges developers face with current GenAI tooling support including inconsistent performance, poor code/output quality, suggestions that fail to meet contextual requirements, alongside interaction friction and sensemaking difficulties [16, 18, 55, 62]. These issues force developers into a cycle of constant re-prompting and result verification, placing a heavy burden on the user [13, 18]. Developers must often invest high cognitive effort into crafting prompts and frequently edit or debug AI-generated code; actions which disrupt their “flow” state and can negate potential productivity gains [8, 84, 86]. They also raise ethical and legal concerns, including uncertainty about code provenance or licensing for AI-generated code, as well as concerns about biases or security vulnerabilities introduced by AI contributions [5, 9].

Task differences can further complicate adoption [46]. Lambiasi et al. [58] found that adoption drivers are not one-size-fits-all; they vary by task and can even negatively impact adoption in certain cases. For instance, peer opinions correlate with higher GenAI tool usage for decision-making tasks. Yet, strong social influence can backfire: developers might develop high expectations that the tool then fails to meet [58]. Moreover, some developers fear that over-reliance on AI could erode their own skills or even threaten job security in the long run [55]. Indeed, expectations play a crucial role in guiding appropriate tool usage. How developers conceptualize the AI's capabilities can influence how they integrate it in their work [45, 96]. Prior work indicates that fostering an accurate understanding of an AI's capabilities (and limitations) improves user trust and helps foster appropriate usage [3, 96].

Overall, the literature paints a narrative in which developers adopt GenAI tools when it demonstrates value, integrates smoothly into workflows, and earns user trust. However, existing studies largely treat developers as a relatively uniform group or focus on formative adoption intentions. This framing limits the understanding of the presence of substantial environmental confounds such as team culture, codebase complexity, managerial attitudes, tool availability, and organizational norms, among others, which often vary across developers, making it difficult to disentangle individual attitudes from environmental influences. As a result, it remains unclear whether observed adoption patterns stem from personal disposition or from differences in the surrounding environment.

Our study addresses this gap directly through its paired interview design. By interviewing matched pairs of developers; each working on the same team and project, and with access to the same GenAI tools; we can directly compare the blockers an infrequent user faces with the work-arounds their frequent teammate has discovered. This design allows us to isolate the individual-level mindsets, strategies, and responses that shape divergent usage patterns, while revealing the reported influences of team and organizational

scaffolding based on developer experiences. We move beyond the individualistic lens of prior work and offer a sociotechnical account of GenAI usage that is both empirically grounded and practically actionable.

## 2.2 Environmental Factors Affecting Adoption

Beyond individual attitudes, the environment in which a developer works (their team and organization) plays a critical role in GenAI adoption [54, 56, 77]. Decades of socio-constructivist research have shown that technology uptake is not merely a function of individual utility but a deeply sociotechnical process shaped by social context, organizational norms, and collective sensemaking [48, 72, 79]. Fulk’s theory of the social construction of technology, for instance, emphasizes how coworkers’ beliefs and organizational cues shape perceptions of technological value [35].

In the SE domain, emerging studies echo these insights. Peer influence and leadership support have been shown to shape developers’ trust in GenAI tools [15, 54]. For example, while top-down mandates alone do not guarantee adoption, strong managerial support (e.g., providing resources and training) can significantly boost trust [54]. Similarly, Cheng et al. [15] show how developers in online communities collectively interpret GenAI tooling through shared experiences, with success stories boosting confidence and widely reported failures fostering caution.

However, some recent empirical work has also found mixed results when examining these dynamics [57, 81]. For instance, Russo [81] found limited support for the influence of organizational stance (external encouragement), a result that contrasts with broader theoretical expectations in organizational communication [35, 36, 82]. One explanation is that these studies are able to capture static slices of environmental influence through individual attitudes (e.g., survey item on management support), failing to reflect how multifaceted team dynamics and organizational support influence adoption. This limitation can lead to counterintuitive findings (e.g., a lack of significant evidence for role of organizational stance) that conflict with broader theoretical expectations (e.g., Fulk’s work showing co-worker beliefs strongly guide technology perceptions [35]). Also, many studies focus on aggregate trends or initial intentions [57, 58].

We address this gap by taking a comprehensive, in-situ approach. By interviewing matched pairs of developers who share the same team and context but have contrasting usage patterns, we can directly ask frequent users how they overcame the context-specific barriers faced by their peers. In doing so, we extend beyond affirming that “environment matters” to unpacking which aspects of the environment—organizational/peer support, learning resources, etc.—make a difference to developers. This nuanced understanding helps explain the divergence in usage trajectories even among developers in similar contexts. Identifying these differences can guide teams and organizations in creating environments that support sustained, effective GenAI tool use in software development.

## 3 Research Design

To understand what distinguishes frequent and infrequent GenAI tool users within similar organizational contexts, we performed semi-structured interviews with 54 developers representing 27 pairs from different teams across Microsoft. Below, we detail ethical considerations, study design, analysis strategy, and limitations.

### 3.1 Ethical Considerations

We recognize that studying technology adoption in contexts with strong organizational pressure requires exceptional and up front care to protect participants’ wellbeing and privacy. Given the company’s culture of heavily promoting GenAI tool adoption, we implemented multiple safeguards to protect all participants.

**Telemetry Data and Privacy.** Tool usage telemetry is collected on an opt-out basis, with developers able to disable collection at any time. In sensitive contexts, opting out is explicitly encouraged.

**Protecting Within-Team Anonymity.** To ensure participants from small teams were not identifiable to colleagues (especially infrequent users), we did not disclose that we interviewed other team members. We further framed the study as exploring “diverse developer experiences with GenAI tools.”

**Ensuring Non-Judgmental Interview Environments.** We aimed to create psychological safety for participants whose usage or beliefs might diverge from organizational expectations, by vetting all questions for neutrality in terms of tool usage, reviewed by our team and external researchers. The first author, who is not affiliated with any tooling teams, conducted all interviews, emphasized confidentiality and ensured a thorough anonymization process.

### 3.2 Identifying and Recruiting Participants

Our study employed a paired interview design, recruiting developers from the same teams who exhibited contrasting usage patterns. This approach minimized the influence of team-specific factors—codebase complexity, development practices, and organizational culture—that have confounded previous studies [5, 13, 51, 58, 62, 81]. By comparing developers in closely similar environments, we isolated individual-level factors affecting usage patterns.

**Identifying Pairs of Developers.** To identify developer pairs with contrasting usage patterns but similar environments across the company, we extracted data about developers (that had not opted out) from internal telemetry databases containing demographic attributes and tool usage. Across the company, Github Copilot is the officially sanctioned and freely available GenAI development tool [1]. The telemetry usage data for each developer indicates the number of days each developer used GitHub copilot during an eight-week observation window (from April 1st to May 31st 2025). We also collected their job title, career stage, employee level, geographic area code (i.e., country), team within organizational hierarchy (i.e., their management chain from the CEO down to their direct manager), and primary programming language.

Using this data set, we implemented a multi round pairing algorithm using the Hungarian method for optimal assignment and `scipy.optimize` [68, 83]. First, the algorithm grouped developers by career stage, job title, employee level, country, and direct manager—creating groups with similar professional contexts. Within each group, the algorithm split developers into two subgroups at the median usage level before applying the assignment algorithm to maximize usage difference between pairs.

Once the pool of pairs had been identified, we filtered it to ensure each pair shared relevant characteristics while exhibiting significant differences in usage. Specifically, we selected pairs that had same primary programming language and a usage gap in the top third

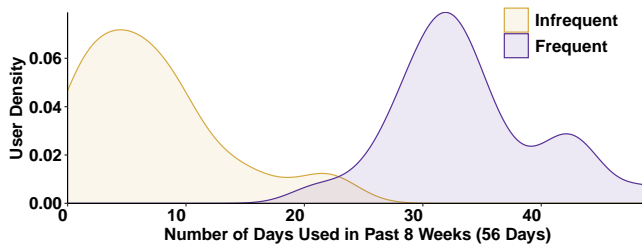


Figure 2: GenAI Tool Usage Distributions

across all pairs (measured by the difference in days of GenAI tool usage between the pair’s frequent and infrequent user).

Note our definitions of frequent and infrequent users are relative to their teams’ usage (not to all developers across the company). We use the terms “infrequent-AI users” and “frequent-AI users” to refer to the two groups of developers that represent the less frequent and more frequent users from each pair respectively. The median usage frequency for the infrequent and frequent groups was 5.5 days and 33 days during our observation window (cf. Figure 2).

**Participant Recruitment.** We recruited candidate pairs from engineering teams globally through an internal company chat, due to regulatory reasons we excluded pairs from Germany and Norway. We reached out to each developer individually, only interviewing developers from pairs where both agreed to participate.

### 3.3 Interview Protocol

Our interview protocol strategically leveraged the paired design. For each pair, we first interviewed the infrequent user to understand their perspectives, any barriers, and specific challenges they face. We then interviewed the corresponding frequent user from the same team, exploring how they may have navigated similar challenges and their broader experiences. This sequencing allowed us to probe the frequent users about context-specific barriers their teammates faced, revealing divergent responses and strategies they may have followed to overcome shared obstacles. The interview protocol evolved iteratively while maintaining consistency in core questions to ensure comparability across participants.<sup>1</sup>

Our interview protocol initially drew from the UTAUT framework [92], a well-established lens in prior technology adoption research [58, 81, 92]. UTAUT’s four core constructs—performance expectancy, effort expectancy, social influence, and facilitating conditions—provided a systematic foundation for understanding usage behaviors in organizational contexts.

We began with 30-minute interviews exploring these constructs through questions on perceived tool benefits (e.g., “What are your current expectations about how GitHub Copilot can help with your development work?”), ease-of-use and integration challenges, alongside team influences, and organizational support. However, early interviews revealed patterns beyond traditional adoption factors—differences in how the two groups conceptualized and approached AI tool usage. To explore these emergent themes, we extended interviews to 60 minutes and supplemented UTAUT questions with new

probes about participants’ tool perceptions, integration strategies, learning approaches, and evolving skill perceptions.

## 3.4 Data Collection and Analysis

Table 1: Participant Demographics

	Location	Role	Copilot Use
United States	36 (66.7%)	Senior SWE	32 (59.3%)
China	6 (11.1%)	SWE II	18 (33.3%)
Kenya	4 (7.4%)	SWE	4 (7.4%)
Canada	2 (3.7%)		1-2 years
Estonia	2 (3.7%)		2-3 years
Ireland	2 (3.7%)		
Romania	2 (3.7%)		

The interviews took place over video conferencing. From 670 invitations, 315 developers agreed to participate. Of those that agreed, 152 were from 76 pairs where both members agreed. We scheduled interviews with pairs on a first-come, first-served basis once both developers had agreed to participate, but were limited by protocol scheduling logistics, busy developer schedules, and time zones. In total, we conducted 56 interviews (labeled PID1-56), with 54 participants (27 matched pairs) included in the final analysis. Two participants were excluded when their pair partners dropped out. We summarize the participant demographics in Table 1.

We qualitatively analyzed interview transcript data using inductive iterative thematic analysis following the guidance of Braun and Clarke [10], and the procedure described by Cresswell [21]. Our process was guided by Lincoln and Guba’s trustworthiness criteria [40], as described by Nowell et al [71]. During this process, we followed a commonly recommended strategy [60]: throughout the process we switched between the different stages of analysis – jumping between exploring the rich transcripts, engaging with and analytically memoing the data [66], coding, searching for themes, and refining the codes and coding framework. While UTAUT guided our interview questions and early memoing to organize emergent barriers, our actual coding framework was developed through iterative inductive analysis.<sup>2</sup>

To leverage contextual richness, we coded both interviews from each pair in the same session, following the interview sequence (infrequent user first, then the frequent user). This paired approach allowed us to track how developers from closely similar team contexts responded differently to similar challenges. The analysis began with the first author performing open-ended inductive coding of each interview as data collection progressed. After eight interviews, all authors came together and performed an in-depth analysis of the codes and coding framework. Iterative adjustments to the coding framework and interview guide were made as necessary. Once the framework stabilized, the first author re-coded all transcripts, with uncertain cases being reviewed with another author’s assistance. We used HeyMarvin for qualitative analysis, facilitating code organization and pattern evolution tracking [2]. We ended the interviewing process when we reached our saturation criterion [33], which we defined as two consecutive interview pairs without learning any new major insights (i.e., 4 interviews). For higher-level theme

<sup>1</sup>The complete interview guide is available in the supplementary material.

<sup>2</sup>The complete coding framework and manual are available in the supplementary material.

identification, we shifted focus from individual pairs to patterns distinguishing the two broader groups—frequent and infrequent users. This analytical pivot allowed us to identify systematic differences in how developers perceive, approach, and respond to GenAI tools despite shared organizational contexts, revealing individual factors that transcend team-specific circumstances. We report qualitative findings organized into emergent categories. We avoid discussing frequency counts or percentages in line with established guidance against quantifying qualitative data [28].

### 3.5 Member Checking

Following data analysis, we validated our findings through member checking with interviewees to ensure our interpretations accurately reflected their perspectives and experiences [20]. We sent all interviewees a draft of the paper’s introduction, methods, results and discussion along with a list of questions asking for their extent of agreement with and/or the relevance of the findings, alongside additional thoughts and feedback. Participant feedback confirmed our findings, with some providing additional clarifications, but no new insights or disagreements emerged e.g., *“I think it accurately reflects my experiences”* (PID34).

### 3.6 Limitations

Our interview study is affected by several limitations commonly experienced in interview research. The transferability of our findings may be influenced by self-selection bias among participants [63, 78], as there could be differences between those invited and those who participated. All participants were engineers at a large software company vocally committed to GenAI adoption, with GitHub Copilot as the only officially sanctioned tool. This limits generalizability to engineers at smaller or larger companies without GenAI promotion, or to open source development contexts. Despite this limitation, we argue our findings are still of value to the broader community because historically, it has been shown that single-case case studies can provide meaningful contributions to scientific discovery [32], and are an essential type of research in addition to research that studies broader populations as championed by Basili [6]. A limitation to construct validity is that we measured tool usage through GitHub Copilot invocations only. Engineers using general-purpose GenAI tools (e.g., internal OpenAI models) or non-compliant tools (e.g., Cursor, Windsurf) could be classified as infrequent users despite potentially heavy usage elsewhere. As discussed in Section 3.1, Microsoft’s strong pro-GenAI culture may have influenced participants’ responses. Finally, throughout this discussion, we occasionally use causal language (e.g., ‘leads to’) for clarity and readability. These phrasings should not be interpreted as statistical causal claims, as our qualitative design does not support formal causal inference. Because both members of each pair shared the same organizational context, our data does not support causal claims about which practices ‘made a difference’ in adoption; instead, RQ2 synthesizes participants’ own interpretations of how these practices shaped their experiences.

## 4 RQ1: What Distinguishes Frequent and Infrequent GenAI Development Tool Users

During our analysis, we identified distinct patterns in how frequent and infrequent users perceive, approach working with, and

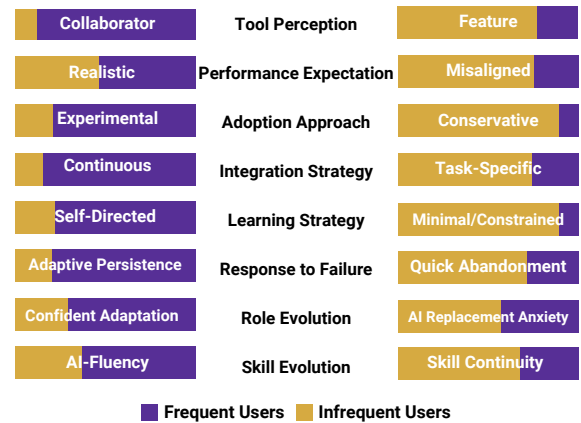


Figure 3: Distributions of user type proportions by factor.

respond to challenges using GenAI development tools— even among developers in similar organizational contexts (cf. Figure 3). Figure 1 illustrates our conceptual framework showing how individual tool integration progresses through distinct stages, with external factors influencing this process throughout (note that while arrows connect to specific stages for visual clarity, external factors impact the entire adoption journey).

### 4.1 Mindset Formation: Initial Perceptions Shape Usage Patterns

We observed two primary diverging patterns in tool perception that appeared to influence subsequent usage behaviors.

**4.1.1 Tool Perception: Collaborator vs. Feature.** Many frequent-AI users described their interactions with the tooling using collaborative language and partnership framing, using terms like “teammate,” “collaborator,” or “assistant.” e.g., *“I use GitHub as a colleague to discuss ‘OK, this is what I’m trying to look at, this is the high level task, these are the my plans to go about implementing this feature, Do you see any gaps in that?’”* (PID2). This tool as a collaborator perception appeared to encourage deeper engagement as they invested time understanding its capabilities and strengths, as they would when onboarding a new team member. Infrequent-AI users more often described these tools as enhanced features such as advanced code completion or search functionality e.g., *“I’m not going to say that I find it completely without value, but it’s about as useful to me as a stack overflow search.”* (PID7). This utility framing appeared to limit engagement patterns— these developers tended to approach the tool with transactional expectations rather than collaborative ones. The limiting nature of the utility framing is evident when comparing PID7 with their teammate PID23, who despite facing similar technical challenges, developed a more engaged usage pattern e.g., *“we have to write a lot of thorough tests that we can run on our gates periodically. So setting up those tests, writing the basic framework for them is just a lot of boilerplate code that GitHub Copilot helps me come up with... So that’s one of the places I use it.”* (PID23).

**4.1.2 Performance Expectations: Realistic vs. Misaligned.** Perception also appeared to influence performance expectations. Frequent-AI users who viewed the tool as a collaborator often expressed realistic expectations, expecting assistance rather than replacement,

similar to a junior colleague who provides value yet requires oversight: *“I just have to type what I’m trying to do and then it gets me like 90% of the way there and I have to just change a couple things.”* (PID16). Infrequent-AI users who viewed it as a feature often held misaligned expectations, either anticipating minimal value or expecting near-perfect functionality: *“If I write a function, I would expect it to be able to write a perfect unit test for it.”* (PID48). Both types of misaligned expectations appeared to lead to limited exploration or early abandonment when initial attempts failed.

**Key Insights:** Frequent-AI users view GenAI as a collaborator. Infrequent users see it as a more or less useful developer tool.

## 4.2 Approach Determination: How Developers Choose to Engage

Following initial mindset formation, developers exhibited different interconnected approaches to tool usage (Figure 1), with experimental mindsets seemingly leading to broader usage patterns and conservative mindsets to isolated task-specific patterns.

**4.2.1 Usage Approach: Experimental vs. Conservative Patterns.** We observed two distinct approaches that shaped usage depth. Often frequent-AI users took an experimental approach, proactively trying new features, pushing tool boundaries, and experimenting to identify effective use cases e.g., *“at first actually I just give every [one] of my tasks to the to the agent mode and ask him to write the code.”* (PID55). This experimental approach by PID55 contrasts with their teammate PID54’s more conservative usage pattern, illustrating how risk tolerance and experimentation vary even among developers working on the same codebase. Frequent-AI users tended to treat the tool as having undefined potential, actively seeking new applications and unconventional use cases. *“I started using images as well for doing CSS. Like, I’ll open Paint and draw the layout I want, screenshot it, and feed that to Copilot to generate the CSS. It’s very good.”* (PID38). This experimental approach led to continual usage with tools becoming deeply embedded in their daily workflows, reflecting a view of the tool as a general-purpose collaborator. The willingness to experiment created a positive feedback loop— with successful use cases encouraging the exploration of others.

Alternatively, infrequent-AI users were more likely to take a conservative approach, limiting tool usage to conventional well-vetted applications e.g., *“Something I’ve heard from a lot of people who’ve been using it is the first thing they tried out is writing tests using GitHub Copilot and I think that’s probably the first thing that I actually tried out.”* (PID8). A conservative approach appeared to couple naturally with task-specific usage limited to particular well-defined use cases, e.g., *“It is potentially useful for generating what I would describe as boilerplate code, and I find it frankly dangerous to use for anything beyond that.”* (PID7).

**Key Insights:** Tool perception shapes use: collaborative framing by frequent-AI users drives exploration, utility framing by infrequent-AI users limits use to specific development tasks.

## 4.3 Encounters with Challenges: Universal Experiences, Divergent Responses

All participants reported encountering challenges with tool usability, particularly around prompt engineering and identifying effective use cases. The divergence emerged not in whether they faced difficulties, but rather in how they interpreted them and responded.

**4.3.1 Response to Failure: Adaptive Persistence vs. Quick Abandonment.** Many frequent-AI users demonstrated adaptive persistence when facing limitations, continuing with modified approaches and treating failures as solvable puzzles requiring refinement strategies—such as breaking tasks into simpler subtasks or leveraging GenAI to improve their prompts e.g., *“If I give a big enough task to Copilot, it would hallucinate a lot. So it often needs to be broken down into smaller components. And once I do that, at times it does a pretty decent job.”* (PID27). In the face of poor tool performance for a particular task, they were also more likely to strategically select tasks for tooling assistance based on the tool’s strengths and weaknesses, rather than abandoning or writing off the tooling entirely e.g., *“It’s more just working with it, not exactly that I found a way to optimize it or make it better, but more like, ‘OK, these are the limitations, how do I work with it?’... These are some tasks that it can do. So OK, let me use it for those specific purposes.”* (PID2).

Many infrequent-AI users showed different response patterns to identical challenges. Compared to frequent-AI users who rarely exhibited quick abandonment when facing a challenge, infrequent-AI users were much more likely to do so (cf. Figure 3) e.g., *“I did something recently with the agent... It involved changing a lot of files in a similar manner. And it did the the change, let’s say changing 15 files, but I had some compile errors and then I gave up on this approach and I took the slow and methodic way.”* (PID24). This quick abandonment is particularly striking when contrasted with PID24’s own teammate PID26, who faced similar prompt engineering challenges but evolved their approach: *“At the beginning I was using more the Google style. Write a sentence or a few words about what I want to search but... when using GitHub Copilot you need to tell a short story. Here is what I want to do. Here is what I tried so far. I failed with this. What would be another option [to go] about it?”* (PID26). Particularly among infrequent-AI users with pessimistic tool expectations, many appeared to interpret these failures as confirmation of tool limitations, rather than as learning opportunities.

**4.3.2 Learning Strategies: Self-Directed vs. Constrained Engagement.** Patterns in response to failure appeared to directly connect to learning strategies. Many frequent-AI users were self-directed learners pursuing adaptive persistence who naturally sought multiple learning resources. *“I spent time reading blog posts, watching YouTube videos, even looking at how other people structure their prompts on GitHub. There’s actually a lot to learn about how to use these tools effectively.”* (PID8). This multi-modal approach—combining formal documentation, community resources, and peer examples—accelerated skill development. As with any tool, the learning curve to proficiency takes time and a common pattern among frequent-AI users was the recognition that carving out the time to do so, even when impending deadlines made it difficult, was worthwhile.

Conversely, infrequent-AI users were more likely to be engaged in minimal or constrained learning often due to time, resource, or motivational constraints e.g., *“Exploration wise it’s been minimal. It kind of just whatever is obvious from the chat window and then mainly just that or completion. So stuff that’s kind of like very low friction.”* (PID6). Without dedicated learning efforts, some infrequent-AI users remained stuck in limited usage patterns, reinforcing their perception of minimal tool value within their development workflows.

**Key Insights:** When challenged, frequent-AI users persist and engage in self-directed learning, while infrequent-AI users disengage with GenAI tools more quickly.

#### 4.4 Integration and Evolution: Long-term Professional Impact

Developers exhibited different visions of GenAI’s impact on their professional identity and skills, which appeared to shape their integration efforts and skill development priorities.

**4.4.1 Role Conceptualization: Evolution and Competitive Pressure.** Both frequent and infrequent users recognized GenAI’s potential to transform the developer role, though their responses differed. For many infrequent-AI users the impact of this paradigm shift manifested as generalized concerns regarding GenAI making certain developer roles obsolete: *“I think it will take entry level jobs now [that] it has reached the level where you can assign GitHub Copilot a ticket on Azure DevOps and it can create a pull request for you itself.”* (PID44). The introduction of GenAI has created uncertainty regarding career progression especially for some early-career developers: *“I am a junior developer right now, what does that mean in three years, four years? I do not know. I don’t know if it’s still coding and being technically viable or is it a different skill? So I think it has introduced a very important conversation on yeah, maybe pivoting.”* (PID25).

For frequent-AI users, concerns regarding the disruptive potential of GenAI often manifested as motivation to stay as in-the-know as possible. Many were motivated to improve their proficiency with the tooling so they could stay competitive with other developers—whomst they viewed as the immediate threat e.g., *“At the end of the day everyone is using it and everyone is being more productive and you wanna be one of those [people] otherwise [you’re] gonna be left behind.”* (PID20). Frequent-AI users recognized the same threat as infrequent-AI users but often channeled it into motivation for skill development. They often exhibited confident adaptation, believing GenAI would enhance rather than replace their role, with some actively reframing their mindset positively given the perceived inevitability of tool integration *“Viewing it as an extension of myself and trying to make the most of that versus trying to not be replaced... I think using it that way has been encouraging because if I view it as just amplifying me, multiplying me, not replace me, that gives me more encouragement, more energy to pursue it freely and not having that fear in the back of my head or these negative thoughts.”* (PID6). This belief also appeared to suggest a full circle impact back onto tool perception as visualized in Figure 1 *“I would think of it as a helper to make work efficient and easier and faster. So I’ll say the job description would be software developer helper or assistant.”* (PID29).

**4.4.2 Skill Evolution: AI-Fluency vs. Continuity.** The different responses to competitive pressure manifested in contrasting approaches to skill development. Most frequent-AI users recognized GenAI fluency as an essential new competency requiring active cultivation e.g., *“I think it’s really important that you know how to prompt well and ask the right questions. I think that’s gonna be very useful for the future.”* (PID12). They invested in developing prompt engineering abilities, context management skills, and judgment about when and how to leverage GenAI assistance. Infrequent-AI users often prioritized traditional skills while acknowledging potential changes.

**Key Insights:** Developers see GenAI as transformative, but frequent users pursue fluency and advantage, while infrequent-AI users focus on job security and preserving traditional skills.

### 5 RQ2: Self-Reported Team and Organizational Practices That Influence Tool Usage

While our paired interview design revealed why developers in closely similar contexts showed different usage patterns by exploring context-specific barriers, these external factors do not affect all team members uniformly. Emergent findings from our analysis revealed that, according to participants, team and organizational practices do not just support or constrain usage— they appear to actively shape individual factors for some. Yet in every pair we studied, one developer was a frequent tool user, the other was not. Initially, we expected that developers within similar contexts might show more uniform responses to these shared conditions. Instead, this emerging finding illuminated something more nuanced: These shared organizational practices interact with the individual differences identified in RQ1 in complex, emergent ways. Social construction theory demonstrates that individuals within the same work group systematically interpret organizational influences differently depending on factors such as personal characteristics and social positions [35, 74]. Our results mirror this: we see how similar team contexts produce divergent responses through differential sensemaking processes [74, 92, 95]. This sociotechnical dynamic manifested through several interconnected mechanisms that appear to influence developers’ usage journeys from initial perception through long-term integration. We now describe how participants reported that organizational practices influenced their usage.

#### 5.1 Leadership Communication

Participants reported that clear encouragement and communication from leadership regarding tool usage and value provided them with the confidence, permission, and motivation to invest resources into learning and exploration. As one frequent-AI user explained: *“Encouragements at the org level itself to share examples of how AI is making you better at work I think that was like a big thing”* (PID2). Some participants described how managers sharing concrete examples and tips provided practical value that motivated their exploration: *“I mean, they’ve shared tips and tricks that they found useful, which honestly have been helpful at times.”* (PID23). The regularity and consistency of messaging also appeared to matter in some cases. After stalling in their usage after experiencing challenges, one developer found renewed motivation through recent communications from management: *“there’s been more messaging in the last month to try it out so I’m going to get back into it and*

see if I can find a way of using it that actually makes me more productive” (PID48). Conversely, some participants reported that the absence of clear messaging left them uncertain about whether to integrate GenAI tools into workflows and what the value add would be. Several infrequent-AI users described environments where they received minimal guidance which they felt reinforced limited usage patterns: “Just it’s a tool, [if] we can use then use it. But [leadership] haven’t really been pushing... So we haven’t really done much with that” (PID37).

**Key Insights:** Participants reported that consistent leadership messaging encouraged their GenAI exploration. Without it, some described being hesitant to use GenAI.

## 5.2 Providing Context-Specific Resources

Many developers struggled with filtering through the large volume of ever-changing learning resources available to identify relevant resources worth investing their limited time into e.g., “Some weeks I have 10+ meetings show up on my calendar about AI learning from all sorts of different places. And I can’t go to all 10 so it becomes almost a little overwhelming where you just don’t want to do any of them.” (PID33). While some found resources on general topics like the basics of prompt engineering helpful, especially in early learning stages, many participants reported that such resources often failed to help them through the transition between tool experimentation and meaningful effective integration into their workflows in practice. Many frequent and infrequent users expressed the need for context-specific guidance, calling for team-specific resources identifying suitable use cases and step-by-step implementation instructions, which one participant described as ‘AI-onboarding’ e.g., “I mean like magic wand would be a comprehensive guide of how to use it for the specific projects that we work in with like example tasks that you could accomplish with it.” (PID48).

A lack of context-specific guidance created uncertainty about tool capabilities and appropriate use cases even among highly-motivated developers e.g., “everyone wants to try GitHub Copilot, but right now they’re still confused [about] what Copilot can do and how they can achieve their goals through [it].” (PID52). Particularly when combined with strong encouragement to use the tool, a lack of concrete relevant guidance lead to frustration for some developers e.g., “So this is where I get a bit jaded. A lot of the time what we hear from leadership is just ‘use AI, use AI, and AI is going to solve everything.’... I see a lot of talking about ‘we should use AI’, I don’t see a lot of useful collaboration.” (PID17).

Team-specific demonstrations were perceived as quite valuable and informative, with both participants from one team discussing a demonstration from a colleague who presented a shared-screen style step-by-step tutorial on how they used the tooling to accomplish a specific task commonly performed by the team “there’s a very common pattern and structure that we have and he was showing how to do the prompts to use agent mode to make a brand new UX component and it saves a lot of time and so it was a very helpful demo.” (PID6). The specificity of these demonstrations—showing exactly how to accomplish common team tasks—made the value immediately apparent and addressed the critical question of which tasks to use GenAI tools for and how.

**Key Insights:** Developers struggle to connect generic GenAI guidance to their work; team-specific demos can show how GenAI may apply to their work.

## 5.3 Building Social Learning Structures

Participants described how social learning structures helped create environments where individual discoveries benefited entire teams. When teams had robust sharing practices, individual discoveries could create momentum for broader adoption. Knowledge sharing took various forms, from formal sessions to informal exchanges, and these structures built collective competence and resilience in multiple ways.

Different structures may serve complimentary purposes. Some participants described how AI evangelists and champions helped them set realistic expectations about tool capabilities. By openly sharing both successes and limitations, they helped calibrate expectations appropriately.

Formal sessions provided structured learning and helped support skill development for some developers: “I would say [the] majority of my learning is from attending those sessions because most of the work we do is very similar in nature and it’s quite applicable” (PID43). When teams created spaces for shared learning, it transformed individual struggles into collective problem-solving opportunities. However, peer influence operates differently even within teams. For example, PID48 found peer recommendations highly motivating: “Just hearing the recommendations from one of my co-workers is very motivating because if we’re working as a good team, then we’re all like having similar processes.” (PID48). Yet their own teammate PID35 remained an infrequent user despite this collaborative environment.

Participants reported that informal knowledge sharing through daily interactions also shaped adoption journeys and enabled continuous micro-learning: “Sometimes you just get stuck, you go to somebody else and they’re like, ‘Have you tried this feature?’ And you’re like, ‘I have not. Did it work for you?’ And they’re like, ‘Yes.’ And that’s how you end up trying [the feature], because somebody else tried it.” (PID18). Micro-interactions accumulated into substantial support over time, creating an environment where exploration was socially reinforced. However, developers without access to such structures faced different experiences. Some described learning in relative isolation: “I never share with anyone and I never received anything from my colleagues as well. I guess we all just kind of sit here and try to think that everyone else can use it.” (PID10). Without contextual examples or peer support, the learning burden fell entirely on individuals e.g., “I won’t ask question on my team because I feel like using Copilot is more personal. It’s not something my team can help me [with]” (PID56).

**Key Insights:** Participants reported that social learning structures helped turn individual struggles into shared competencies; while knowledge isolation may reinforce limited usage patterns.

## 5.4 Unexpected Interactions: Time, Expectations, and Developing Proficiency

Sufficient learning time appeared crucial for both initial adoption and advanced skill development. Many benefited from formal time allocations: “Our org has dedicated days to learn. We have around

three to five days per semester where we can spend time on learning” (PID22). This legitimized exploration and removed guilt about skill development. Others leveraged scheduling flexibility to carve out their own time: “After seeing how powerful it is, I wanted to try it out myself. So one day I just thought OK... I will give one day [to] just focus on it. Try to learn what it is.” (PID21). Time during day-to-day work without deadline pressures proved essential for effective skill development and identifying effective use cases for many developers. However, this individual initiative varies dramatically within teams. PID21 proactively carved out a full day for exploration, while their teammate PID8 took a more conservative approach, limiting exploration to use cases that others had validated.

A common theme among participants was experiencing increased productivity expectations from management because they have access to these tools e.g., “I know that management is expecting us to produce code faster. And I know that the bar is gonna be raised every year because now, even though it’s true or not true, [they] think that we should be much much more productive because we have these tools.” (PID20). Some managers appeared to assume tool access automatically enabled rapid effective integration into existing workflows and immediate productivity gains, overlooking the significant learning effort and time investments required. Many developers reported experiencing a circular challenge: “There’s a skill gap among all of us about prompt crafting. The impression is that if I get better at prompt crafting then the Copilot could increase my productivity. But how do I get to that? How much productivity do I need to put into prompt crafting in order to increase productivity in my workflow? So there’s a chicken or egg problem.” (PID46).

Increased productivity expectations which often translated into tighter deadlines prohibited many developers from doing the exploration necessary to learn how to use the tools effectively, instead falling back on their tried-and-true methods e.g., “I do really feel the pressure of deadlines and trying to get stuff out and so feel less of the freedom to explore... The few times I’ve tried it, being discouraged, I’m like, OK, well, let me just get this done and then I’ll get to it. That’s been the hindrance.” (PID6). Without time for exploration, many developers felt they couldn’t understand the tool’s full capabilities or how to use it most effectively: “we don’t have so much time to learn about it because we are already overburdened with the tasks that we need to do” (PID44).

These contradictory experiences—heightened productivity expectations, significant learning time requirements, pressure-induced reversion to familiar methods, and limited support—formed a consistent pattern across many developers, suggesting systemic challenges in how some organizations approach GenAI tool integration.

**Key Insights:** Participants reported that when organizations expected immediate gains from GenAI without learning support, the resulting pressure blocks the desired productivity benefits.

## 6 Discussion and Implications

### 6.1 The Productivity Pressure Paradox

Many organizations invest in GenAI tools expecting productivity returns [4, 19] while simultaneously treating adoption and integration into existing systems as an individual responsibility [61, 64, 65, 90]. Yet within the context of knowledge work, the evolving capabilities

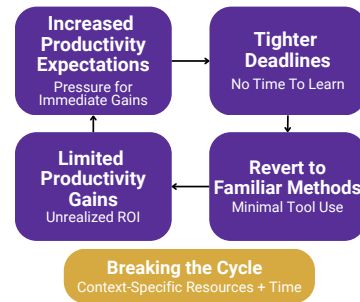


Figure 4: The Productivity Pressure Paradox.

of these tools create a “jagged technological frontier,” where they improve certain workflow tasks but can harm performance when applied to other seemingly comparable tasks [25]. Many organizations are implicitly asking developers to navigate this jagged edge on their own while maintaining or increasing their productivity.

This contradictory set of experiences participants described—where they must simultaneously maintain velocity, learn new tools, determine integration strategies, and navigate tool capability boundaries without systematic support—creates what we term the *Productivity Pressure Paradox*. This paradox creates a self-perpetuating organizational dynamic (cf. Figure 4): participants described how increased productivity expectations hindered the skill development investments needed to achieve those very gains through effective workflow integration, a challenge many participants faced (Section 5.4). Cognitive science reveals the underlying mechanism: Time pressure fundamentally shifts individuals from flexible exploration to rigid exploitation patterns [98], leading many developers to default to familiar approaches rather than discovering optimal integration strategies (Section 4.3).

We posit that the paradox operates bidirectionally: first, productivity pressure prevents the temporary productivity dip necessary for learning; second, this organizational approach places the burden on individuals to solve organizational optimization challenges.

**Increasing Productivity: From Systems to Individual Burdens.** The *Productivity Pressure Paradox* exemplifies how the knowledge sector uniquely places “onto the individual worker the burden of improving output produced per unit of input” [69, 76]—a departure from established principles regarding productivity optimization which demonstrate that productivity improvements come from optimizing systems, not individual heroics [26, 44, 88]. Henry Ford did not expect workers to individually discover how to build cars faster, he systematically redesigned the entire production process, investing significant time and effort into pioneering a reimagined system and building new tools to make it happen. The continuous-motion assembly line wasn’t an incremental improvement from worker tinkering but a comprehensive system redesign that allowed individuals to focus on execution within an optimized workflow. Workers were largely uninvolved in the optimization process; their productivity increased as a consequence of systemic change.

While the labor involved in pre-industrial automotive factories differs significantly from knowledge work like software engineering, this same principle is echoed in canonical software engineering literature. In the Mythical Man Month, Fred Brooks argues that adding developers to a late project does not speed it up but rather slows it down by adding layers of complexity [12]. To gain efficiency,

**Table 2: Recommended Team Interventions for GenAI Tool Adoption**

Intervention	Target Stage	Mechanism	Implementation Examples
<b>Clear Organizational Messaging</b>	Mindset Formation	Sets expectations; legitimizes exploration	Leadership demos; documented value propositions; success metrics
<b>AI Tool Champions</b>	Approach Determination	Models usage; provides guidance; reduces risk	1–2 designated team experts with 10% time allocation for peer support
<b>Context-Specific Use Cases</b>	Experience & Learning	Translates capabilities to team workflows	Team wiki with domain examples from actual repositories
<b>Knowledge Sharing Infrastructure</b>	Experience & Learning	Accelerates learning; normalizes challenges	Dedicated channel; “AI wins/fails” in standups; pair programming
<b>Protected Learning Time</b>	Throughout	Enables pressure-free experimentation	“AI Fridays”; sprint time allocation; hackathons
<b>Collaborative Sessions</b>	Experience & Learning	Transforms individual struggles to team learning	Weekly demos; monthly challenges; brown bags

better systems are needed. Brooks recognized that productivity improvements on a systematic level require systematic approaches rather than simply adding resources. The parallels become clearer when examining how many organizations approach GenAI integration today. Just as adding developers to a late project increases complexity without corresponding capability, adding GenAI without systematic support creates new coordination challenges and learning requirements (Section 4.3). Yet many organizations expect individual developers to navigate this complexity while maintaining delivery velocity, precisely the individualized approach to productivity that has proven ineffective across domains [14, 42, 53, 59]. We provide evidence for and echo the argument that the obligation to optimize productivity through GenAI integration should be shifted away from individuals and back toward systems.

## 6.2 Implications for Organizations

Our findings suggest that organizational practices can moderate individual usage patterns—reinforcing success when present or exacerbating difficulties when absent. Participants reported that these organizational approaches influenced their ability to navigate usage challenges.

Additionally, participant challenges align with key *technostress* factors [11, 91]. *Techno-overload*, i.e., demands on working more and faster when using technology, manifested as increased productivity expectations regardless of actual proficiency. *Techno-complexity*, i.e., steeper learning curve due to multifaceted and continuously changing technology, emerged through evolving tools creating steep learning curves. *Techno-insecurity*, i.e., nervousness and insecurity in using and interacting with technologies due to lack of experience and training, appeared as developers struggled to integrate tools into workflows without clear guidance. Research demonstrates these factors harm productivity but can be mitigated through organizational support [34, 37, 91]. Task-technology fit theory shows that aligning technology capabilities, task requirements, and individual abilities requires systematic organizational intervention rather than individual adaptation alone [39].

Organizations should reconceptualize how they assign responsibility for GenAI productivity optimization. The gap between what organizations expect and the support they provide can create a counterproductive cycle, where the pressure for productivity gains risks undermining the desired results. History offers a cautionary tale: the expert systems boom collapsed in part because organizations failed to provide adequate support infrastructure despite

investing \$2.5 billion back in the 1980s, leading to the second AI winter when maintenance proved costlier than anticipated benefits [22, 70, 80]. Our findings echo this pattern, which suggests that organizations investing billions into GenAI technology might better realize returns by actively shaping systematic tool integration and investing in context-specific scaffolding that fosters usage and integration [89].

### *Increasing Productivity by Increasing Support.*

Based on our findings, we identify interventions that helped participants navigate GenAI tool usage challenges. Table 2 summarizes these recommended approaches. Participants indicated that effective organizational messaging shaped both their tool perception and adoption. When tools were framed as collaborative ‘partners’, developers often reported more successful engagement patterns. Participants shared that champions were often beneficial, translating abstract capabilities into practical applications. These informal leaders created communities of practice where developers shared failures and successes without productivity judgment. *“We share everything—the prompts that work, the ones that fail spectacularly, and most importantly, why”* (PID47).

Context-specific resources resonated more than generic documentation. Developers reported benefiting from domain-specific patterns, use case repositories tailored to their tech stack, and debugging strategies relevant to their codebase. Protected experimentation time, e.g., ‘AI Fridays’ or temporarily suspended velocity expectations, enabled pressure free exploration without deadline pressures. These interventions appear to reinforce each other. The *Productivity Pressure Paradox* emerges when support fails at any level, putting individuals in a situation where they have to bear organizational optimization burdens.

## 6.3 Implications for Research

Our findings raise important questions about temporal dynamics in GenAI adoption. While technology adoption is inherently dynamic [79, 93], longitudinal research could reveal whether initial struggles give way to fluency as expertise theory suggests [30], or if rapid GenAI innovation disrupts traditional learning curves. Does the *Productivity Pressure Paradox* diminish as developers internalize usage patterns, or does it transform as tools evolve and expectations escalate? Research on technostress suggests pressures may compound rather than resolve [87], indicating the paradox may evolve rather than disappear.

The mechanisms through which team practices shape individual approaches warrant deeper investigation. While team support amplifies adoption success or failure, specific mechanisms remain underexplored. Team influences alter individual behaviors through social learning [52], and organizational values cascade through levels [29], yet how this shapes GenAI tool usage remains unclear. Teams interpret mandates through local contexts [73]—understanding these dynamics could inform more nuanced adoption strategies.

The distinction between viewing GenAI as “collaborator” versus “feature” reveals how mental models profoundly impact adoption trajectories. Research should explore how these models form through prior experiences, initial interactions, or social influences [38], and whether interventions like training or mentorship can shape productive mental models to prevent abandonment patterns [97].

Finally, our findings about shifting roles, from “code producers” to “AI orchestrators”, highlight the need to rethink developer education. Successful GenAI adopters developed meta-cognitive skills: knowing when to use GenAI, crafting prompts, and critically evaluating outputs. Yet educational programs remain focused on traditional coding [7]. How should we teach students to view AI as a partner rather than merely a tool [27]? Research on these pedagogical shifts could prepare developers to navigate both the productivity pressure paradox and evolving development work.



## 7 Conclusion

Our study of 54 software developers across 27 teams reveals that GenAI tool use is shaped by individual factors, e.g., how developers perceive the tool (collaborator vs. feature), their engagement approach (experimental vs. conservative), and their response to challenges (adaptive persistence vs. quick abandonment). Developers who viewed GenAI as a collaborative partner, experimented broadly, and treated failures as learning opportunities showed markedly different usage trajectories than those who approached the tool as a utility feature. Yet individual factors alone do not explain usage outcomes. Developers reported that team and organizational practices, e.g., leadership messaging, context-specific guidance, and social learning structures, interacted with these individual factors in ways that could either amplify success or reinforce limited usage patterns. We also identify a *Productivity Pressure Paradox*, where organizational expectations for immediate gains without corresponding support for learning can undermine the very productivity benefits these tools promise. Our study challenges the prevailing narrative that GenAI tool adoption is solely driven by individual initiative, revealing instead that successful adoption also depends on the sociotechnical scaffolding provided by teams and organizations. Indeed, to realize GenAI’s potential, we argue for a systemic shift in responsibility—from individuals to organizations; calling for environments that foster experimental learning through clear messaging and context-specific support. Ultimately, the future of GenAI in software development will not be determined by tool capabilities alone, but by how well we design our support infrastructures around them.

## 8 Data Availability

Interview guide, codebook, and codebook manual are available in the publicly available supplemental materials artifact hosted on Zenodo [67]. DOI [10.5281/zenodo.17822096](https://doi.org/10.5281/zenodo.17822096)

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