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# Exploring Technical Reasoning in Digital Tool Use

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## ABSTRACT

The Technical Reasoning hypothesis in cognitive neuroscience posits that humans engage in physical tool use by reasoning about mechanical interactions among objects. By modeling the use of objects as tools based on their abstract properties, this theory explains how tools can be re-purposed beyond their assigned function. This paper assesses the relevance of Technical Reasoning to *digital* tool use. We conducted an experiment with 16 participants that forced them to re-purpose commands to complete a text layout task. We analyzed self-reported scores of creative personality and experience with text editing, and found a significant association between re-purposing performance and creativity, but not with experience. Our results suggest that while most participants engaged in Technical Reasoning to re-purpose digital tools, some experienced “functional fixedness.” This work contributes Technical Reasoning as a theoretical model for the design of digital tools.

## CCS CONCEPTS

• **Human-centered computing** → **HCI theory, concepts and models.**

## KEYWORDS

human tool use, tool re-purposing, technical reasoning

### ACM Reference Format:

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## 1 INTRODUCTION

Tool use is ingrained in our interaction with the physical world [41]: Physical tools mediate our interactions with the environment, becoming extensions of our hands [25], and we routinely use objects as tools beyond their assigned function [17], e.g., using a knife as a screwdriver, a phenomenon we call *tool re-purposing*. The Technical Reasoning hypothesis [40] in cognitive neuroscience posits that human tool use is based on the ability to reason about the mechanical interactions among physical objects. It models human tool use as a

product of matching *abstract* knowledge about mechanical principles and properties of objects, e.g., a *sharp* blade can cut through an orange’s *soft* skin. Technical Reasoning therefore provides an elegant model to understand the re-purposing of physical tools as the transfer of abstract mechanical principles to other interactions among analogous abstract *properties*.

Is this model also at play when interacting in digital environments? Computer applications often use a tool metaphor, whereby the user can select the best tool for the task from a tool palette and apply it to objects of interest, and computers have been referred to as “tools for the mind”<sup>1</sup>. Beaudouin-Lafon [3] has introduced instrumental interaction, an interaction model based on digital tools, called instruments, that mediate the interaction between the user and domain objects in the system. The HCI literature also features examples of users re-purposing tools in ways unexpected by their designers [16, 17]. However, while these observations seem to support a parallel between physical and digital tool use, we also observe that digital tools often work with a limited set of target objects, hindering users from taking advantage of the flexible nature of digital interactions. For example, the *Eraser* tool in Adobe Photoshop is designed to delete pixels —by making them transparent— but produces no effect on vector-based objects, which must be deleted with a different tool.

This paper addresses the question of whether Technical Reasoning can be used to study digital tool use and re-purposing. To the best of our knowledge, the Technical Reasoning hypothesis has not been brought forward before in Human-Computer Interaction as explanatory theory, and while tool re-purposing has been observed in HCI, its underlying cognitive mechanisms have not been studied. A better understanding of digital tool re-purposing could offer a new path towards the design of innovative interaction techniques based on malleable digital tools that users can own in less application-centric environments. Our contribution is therefore both theoretical and methodological. After introducing the Technical Reasoning hypothesis and a review of related work, we present a study using an experimental environment to observe if and how participants re-purpose text-editing digital tools, and how it relates to their experience and creative personality. We discuss the results in light of the Technical Reasoning hypothesis and conclude with avenues for future work.

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<sup>1</sup>Steve Jobs referred to the computer as “the equivalent of a bicycle for our minds” in the documentary film *Memory & Imagination* by Michael R. Lawrence

## 2 THE TECHNICAL REASONING HYPOTHESIS

Osiurak et al. [40] present substantial evidence that humans have the ability to perform *technical reasoning* to use tools. The reasoning-based approach to human tool use posits that humans solve tool-based problems by applying *technical laws or principles*—as opposed to absolute, objective knowledge—to devise interactions with physical objects [41]. For example, we know that sharp objects can cut softer ones, rather than the specific list of objects that a specific knife can cut. More precisely, Technical Reasoning relates *mechanical principles to object properties* to make sense of their suitability for a task. For example, writing with a pencil consists of using the *tracing* principle, which requires a friable object, e.g., a pencil lead, to be rubbed against an abrasive surface, e.g., a piece of paper [41]. A corollary of this approach is that Technical Reasoning supports humans in choosing suitable replacements for tools that are not at hand. To continue with the previous example, if we do not have a pencil nearby, our knowledge of how the “friability” principle works can lead us to pick up a crayon to continue writing on paper.

Technical Reasoning is therefore based on *mechanical knowledge* about technical principles tied to *object-based knowledge* about physical properties, acquired by experience with the physical world [38]. The reasoning-based approach states that as a subject chooses a technique to transform an object, e.g., slice a carrot by cutting it, the subject seeks a tool that matches the properties of the object based on the principle that drives the technique, e.g., the cutting principle requires pressing a *sharp* and *hard* tool against a *softer* but *solid* target object. This is not to say that humans need to understand the cutting principle to use it, nor that they need declarative object-based knowledge of the surface properties of objects every time they seek the appropriate tool. Instead, mechanical and object-based knowledge are defined as abstract knowledge, analogous to that of naïve physics, which humans understand without necessarily being able to put into words. As stated by Osiurak and Badets, “humans did not have to wait for Newton’s discovery of the law of gravity to apply it in everyday life” [39].

Other works on tool use have put forward that the manipulation of tools is powered by *sensorimotor knowledge*, what Osiurak and Badets distinguish as the manipulation-based approach [39]. Sensorimotor knowledge refers to non-declarative knowledge of motor actions associated with using physical objects, activated by visual stimuli produced by the structure of such objects [9]. Based on these accounts, it would suffice to visualize the shape, size, and other structural properties of a screwdriver to activate the motor procedures necessary to manipulate it in a useful manner [39]. The reasoning-based approach challenges this notion [39], suggesting that effective tool use requires reasoning about the appropriate interaction between the tool and the target object, i.e., one should know how to manipulate the screwdriver for the object and task in question. In this regard, the authors distinguish between *familiar* vs. *novel* tools, i.e., those we know vs. those that we handle for the first time [41], and *usual* vs. *unusual* uses of tools, i.e., those based on their assigned function vs. those that are improvised [40]. Osiurak et al. [40] hypothesize that the inability to perform technical reasoning should impair both usual and unusual uses of tools. They conducted experiments with patients suffering from tool use

impairments who were asked to demonstrate conceptual and practical knowledge of usual uses of tools and in particular, the *Unusual Use of Objects* test, where they demonstrate, among other unusual uses, how to use a fork to eat yogurt, i.e., using the handle part as a spoon. Their results show a strong correlation between the correct demonstration of usual uses of tools and that of unusual uses of tools, supporting their hypothesis [40]. Technical Reasoning then models the participants’ ability to reify a fork’s handle into a spoon as the transfer of abstract knowledge about the technique behind using a spoon [41], namely, “scooping up” or “digging.”

In sum, the Technical Reasoning hypothesis models the unusual use of physical tools, which we call *tool re-purposing*, as matching the mechanical principles that govern the interactions in the environment, i.e., mechanical knowledge, with object properties, i.e., object-based knowledge. Therefore, in order to explore Technical Reasoning in digital environments, we want to find cues of the users’ mechanical and object-based knowledge, in particular, to re-purpose digital tools.

## 3 RELATED WORK

We examine previous work related to the similarities between physical and digital tools. We start by characterizing digital tool use and how it is addressed in the HCI literature. Next, we review studies that establish cognitive similarities between physical and digital tool use and discuss them from a re-purposing perspective. We then present evidence of digital tool re-purposing from the HCI literature. Finally, since tool re-purposing can be seen as a case of creative problem solving, we review related work from the literature on creativity.

### 3.1 Digital Tool Use

St Amant and Horton [44] define tool use as actions towards controlling an object with the intention of altering the physical properties of a target, or else of “mediating the flow of information between the tool user and the environment.” HCI has a long history of discussing digital tools as mediating means for the interaction between the user and target objects, in particular with Bødker’s early work on the socio-cultural approach to HCI, incorporating activity theory to user interface design [10]. Taking this wider perspective, Bødker [10, 11] characterizes digital tools as artifacts that mediate our activity within computers. Also drawing from this approach, Béguin and Rabardel [5] characterize *instrumental genesis*—the process of incorporating artifacts into work activity— by contrasting the evolution of the artifact itself with the change in the way it is used, namely “instrumentation” vs. “instrumentalization” processes. In particular, instrumentalization processes “extend the artifact’s intended use,” regardless of its predefined purpose, e.g., when using a knife as a screwdriver. In line with these authors, Beaudouin-Lafon [3] introduces instrumental interaction as both an analytic and generative model for post-WIMP interfaces where user interactions with domain objects are mediated by digital instruments. This model draws on the conceptual similarity between digital and physical tool use. While a mediated perspective of instrumental interaction can provide insights about its relevance as a model to support instrumentation and instrumentalization processes, a cognitive perspective would offer additional support to model the

spontaneous deviation from the social conventions around artifact uses, i.e., their re-purposing.

Other work has focused on *perceptual* similarities between physical and digital tool use. For example, Bérard and Rochet-Capellan [6] study the sensorimotor similarity between physical and digital interactions with a target-acquiring task designed to measure the transfer of a motor skill required for a physical task after training with one of three digital setups (touchscreen, mouse, trackpad). The authors find that the group that trained with the touch screen experienced a significant transfer from the digital setup, while the groups that trained with the mouse or trackpad did not. In another study, Bergström et al. [7] assess tool extension [12] in a digital environment through the difference in response time between congruent and incongruent simultaneous visual and tactile stimuli in a pointing task using a trackpad or a mouse. The authors conclude that participants experienced tool extension using both the trackpad and the mouse. Singley and Anderson [43] study negative transfer of knowledge between two versions of the same text editor, differing in the shortcuts associated with the same commands. Their results show significant positive transfer between the editors despite differences in the command layout. However, the authors argue that “*declarative knowledge, [i.e., conscious knowledge] of a special sort must have contributed to transfer.*” The first two studies provide evidence that users experience effects similar to physical tool use in a digital environment, in terms of sensorimotor knowledge. The last study provides evidence of transfer of knowledge to use digital commands across digital environments. However, they do not address the cognitive processes leading to selecting and using digital tools to interact with target objects.

### 3.2 Re-purposing of Digital Tools

Dix [17] frames re-purposing as a form of improvisation to “work with what we have to hand.” As an example, the author compares using an email server for sharing files within an organization to using a screwdriver for opening paint cans. We also find references to re-purposing in digital environments under concepts such as *customization* [35], *appropriation* [17, 19], *co-adaptation* [33] or *ambiguity* [24], to name a few. Work on these concepts focuses on understanding users’ practices around technology [35] and the need to adapt digital tools to their activity [33]. However, while these works address the design of systems that offer flexibility for its users, they do not focus on the cognitive abilities that make users leverage such flexibility.

Re-purposing is also observed anecdotally in some user studies. For example, during a user study of *StickyLines* [14], a graphical editor that manages shape alignment through persistent, “tweakable,” magnetic guidelines, the authors observed that some participants spontaneously used guidelines as a tool for grouping shapes rather than as an alignment tool. Similarly, in a study of *Textlets* [27], a system that supports the reification [4] of text into persistent objects with various behaviors, the authors report a participant discussing a search textlet to highlight occurrences of words that he should *not* use. We note that in both these cases, observations of tool re-purposing occurred spontaneously and in open-ended tasks that gave participants the liberty to use the tools in that way.

In summary, while we find evidence of re-purposing strategies where digital tools are used in unexpected ways, these have not been studied systematically and we still do not understand why and how users come up with these unusual uses of digital tools.

### 3.3 Factors in Tool Re-purposing

Fitts and Posner [22] posit that motor skill acquisition goes from a stage of consciousness to one where no conscious cognitive effort is necessary to, for example, operate a tool. This is in line with Anderson’s [2] distinction between *declarative knowledge* and *procedural knowledge*. According to Anderson [1], all knowledge is acquired in declarative form and can gradually become “proceduralized” so as to perform actions in a direct way, without interpretation or conscious effort, i.e., procedurally. If computer users operated based *only* on procedural knowledge, they would have difficulty finding alternative ways to complete tasks or devising new uses for software. Similarly, activity theory [32] distinguishes between *actions*, which are conscious, and *operations*, which are subconscious: actions become operations through practice, but operations can become actions when a problem occurs. This is consistent with the work by Ericsson et al. [21], who present evidence that “deliberate practice” over an extended period of time amounts to expert performance. Since experience with a tool amounts to skillful use, it is possible that it would play a role in tool re-purposing.

However, Duncker and Lees [20] show evidence that humans experience *functional fixedness*, i.e., bias from knowledge of the assigned functions of tools, when facing a novel task requiring the creative use of a familiar object. That is, humans unconsciously associate functions with objects and therefore require a less conscious effort to use them, which becomes the source of an unconscious bias in creative problem-solving situations. Therefore, a tool user is likely to experience functional fixedness when required to use a familiar tool in an unusual way, i.e., to re-purpose it. This phenomenon has been acknowledged in HCI, for example, in Oh and Findlater’s work on gesture customization [36]. Therefore we can expect functional fixedness to hinder tool re-purposing for experienced users.

Furthermore, re-purposing can be studied as a creative solution to a tool-based problem [45]. Coughlan and Johnson [16] argue that novel outcomes in creative settings are “produced from novel processes and tools” for which “the malleability of tools and their ability to be appropriated is key.” For example, in the *StickyLines* and *Textlets* studies mentioned earlier, the participants did not get to train or familiarize themselves with the environment for more than a few minutes, yet some spontaneously found creative solutions by re-purposing the tools. Therefore we can expect creative individuals to exhibit tool re-purposing behavior. This also suggests that prolonged experience and practice with tools may not be a requirement for spontaneous re-purposing.

To the best of our knowledge, cognitive models of re-purposing, appropriation or creative use of tools have received little attention in HCI. We are interested in the Technical Reasoning hypothesis because it explains tool re-purposing without the need for any manipulation knowledge. Therefore, in this work, we assume the validity of this hypothesis for human use of physical tools and seek to assess its applicability to digital tool use.

## 4 STUDY: COMMAND RE-PURPOSING IN TEXT EDITING

We want to observe whether and how participants elicit declarative mechanical and object-based knowledge about text editing. By focusing on declarative knowledge about a task, i.e., what participants express about their actions, we can analyze the motivations and reasoning towards their use of commands, in particular, unusual uses. For this purpose, we created a simplified text editing environment where we control the availability of its commands, e.g., insert characters, paste text, or change color. Participants perform an identical task repeatedly but with an increasingly limited set of commands. By progressively reducing the commands available to solve the same task, we want to induce participants to find alternative techniques that rely on the remaining commands, which we expect will lead them to re-purpose one or more of them.

Our design borrows from the Unusual Use of Objects Test by Osurak et al. [40]. We expect participants to use familiar techniques before exploring and effectively re-purposing commands. We also expect experience and creativity traits to be associated with finding unusual techniques to complete the task. Finally, we expect participants to elicit knowledge from past experience with other digital environments to find ways to re-purpose text-editing commands.

### 4.1 Design of the Task

We sought a task for which participants were unlikely to find a direct equivalent in the physical world, i.e., a “purely digital” task with low risk of transfer from experience with physical tools. Arguably, text editing nowadays falls under this condition, given that most computer users have experience typing on keyboards, but few (if any) have experience with physical typesetting. This led us to design a task that requires participants to set the indentation of a paragraph, following a visible guideline shown at a specific distance from the left margin (Figure 1b). Participants have access to basic formatting, layout and editing commands (Figure 1c) to complete the task. As the session progresses, we disable these commands to force participants to devise new techniques to complete the task, based on the remaining commands. Our protocol follows a similar principle to that used by Maier [34], in which participants had to repeatedly demonstrate alternative techniques to solve the same problem, performing unusual uses of objects available in the environment. More recently, O’Hara and Payne [37] offer an example of a design controlling the availability of a command, disabling it for a fixed amount of time for certain participants.

To design the set of commands, we ran 6 pilot testing sessions with participants recruited from our lab. We asked each participant to show us as many alternative techniques as they could to complete the task. We identified 5 recurring approaches, listed in Table 1. Every technique is coded with the primary command that it uses. For example, `Color` consists of inserting arbitrary characters and making them invisible by coloring them the same as the page’s background color. Its primary command is therefore the `Color` command.

We observed uses of both the Tab key and the Spacebar during pilot testing. However, because of the similarity between these approaches, i.e., both insert a blank character to indent, we designed the tabulator character to be wider than the required indentation.

The result is an indentation larger than necessary, making the Tab key a poor solution and ultimately forcing participants to resort to the Spacebar for a more precise technique.

### 4.2 Participants

We recruited 18 adult computer users but had to discard data from two participants: **P6** faced a code defect that led her to finding techniques that were not consistent with what is possible with a standard word processor; **P8** received instructions that led him to understand what type of technique would produce interesting results for the study, thus making the entire session invalid. Of the 16 remaining participants, 9 self-identified as male, 7 as female. 14 were between 30 and 39 years old, one between 18 and 29 years old, and one between 50 and 59 years old. Participants’ backgrounds included 5 in computer science (**P2, 5, 10, 12 and 14**), 3 in social sciences (**P3, 9 and 11**), 2 in sales (**P15 and 17**), 2 in architecture (**P1 and 18**), 2 in graphic design (**P4 and 16**), 1 in economics (**P7**) and 1 in mathematics (**P13**).

### 4.3 Setup

The setup is designed to carry out the study remotely due to the Coronavirus pandemic of 2020. We developed an experimental text editor (Figure 1a) that runs in web browsers with a JavaScript interpreter, with functionality based on that found in commercial text editors. The application is hosted on a virtual server running on our lab’s infrastructure. A unique URL is generated for each participant and shared via email to run a local copy of the editor on their browser and collect the associated data in the server for later analysis. A back-end system lets the experimenter control the editor functions available to the participant.

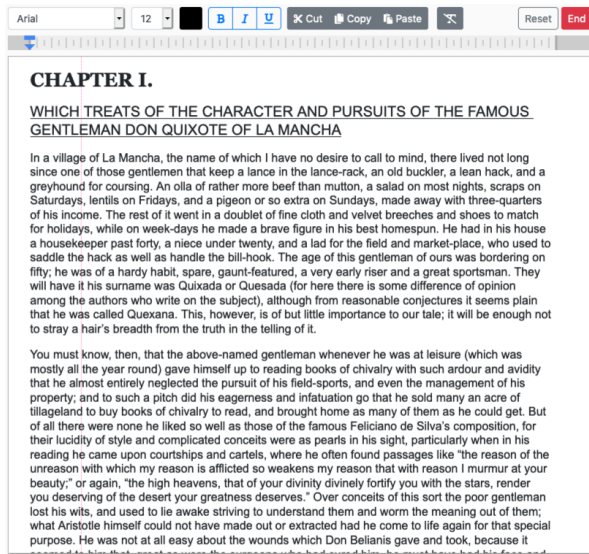
The editor interface includes a toolbar with widgets to change the text’s font face, size, color and variations (bold, italic and underlined), as well as buttons to cut, copy or paste a selection, and one to clear the selection’s format, i.e., set it back to the default style (Figure 1c). Underneath the toolbar, a ruler lets users change the page margins, current paragraph’s margins and current paragraph’s indentation (Figure 1c). Operation requires a keyboard and a pointing device such as a mouse or track pad; the environment is not designed for touch interfaces. Additionally, the editor supports undo/redo using keyboard shortcuts and the browser’s or operating system’s contextual menu. Cut, copy and paste also work using the traditional keyboard shortcuts (`Ctrl+X`, `Ctrl+C` and `Ctrl+V`).

The initial state contains a pre-loaded text over which the participant performs the task (Figure 1a). Every new trial presents the editor in this state. Two separate buttons to the right of the toolbar allow the participant to *Reset* the document to the initial state and *Finish* the ongoing trial to jump to the next one or finish the session when they have reached the last trial (Figure 1c).

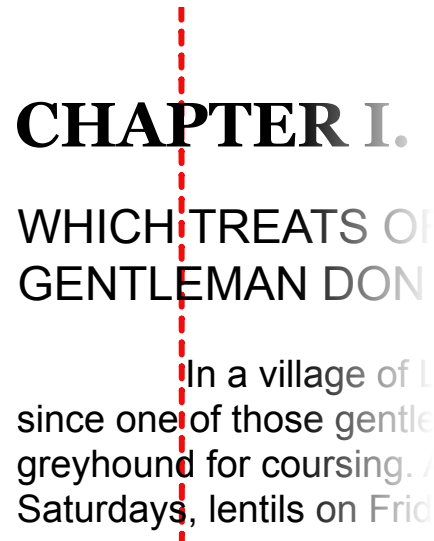
### 4.4 Procedure<sup>2</sup>

Using a video conferencing app with support for screen sharing, the participant shares a video stream of the browser window where they run their local copy of the environment. Participants start by filling out a pre-session questionnaire about their experience with text editing. Next, the experimenter introduces the task and the editor

<sup>2</sup> This protocol was approved by Inria’s Institutional Review Board (COERLE).



(a)



(b)



(c)

Figure 1. (a) The editor in its initial state. (b) The goal state showing the indentation of the first sentence of the paragraph with the length indicated by the guideline. (c) The complete toolbar and ruler when all commands are enabled.

Table 1. Techniques we expect participants to use, identified during pilot testing. The names correspond to the primary commands for the technique to succeed. Techniques marked *Familiar* involve familiar use of the primary command, while those marked *Re-purpose* involve re-purposing it. The one-letter code is used as a shorthand to identify each technique.

Code	Name	Use	Procedure
R	Ruler	Familiar	Use the paragraph indentation control to set the indentation of the first line as necessary.
S	Spacebar	Familiar	Position the text caret at the beginning of the paragraph and use the Spacebar on the keyboard to insert spaces that push the sentence to the right.
T	Tabulator	Familiar (poor)	Position the text caret at the beginning of the paragraph and use the Tab key to insert a tabulation character to push the sentence to the right. The tabulator size is designed to <i>not</i> match the indentation of the goal state and therefore it is considered to produce a bad result.
C	Clipboard	Re-purpose	Select and copy an existing space or series of spaces, position the cursor at the beginning of the paragraph and paste the copied spaces, reproducing the effect of the Spacebar.
X	Color	Re-purpose	Position the text caret at the beginning of the paragraph and insert arbitrary characters until the beginning of the sentence is at the desired position. Then, color the arbitrary characters with the same color as the document background to make them invisible to the eye.

interface, containing a document with a title, subtitle and several paragraphs. The participant is asked to indent the first paragraph of the document as indicated by the guideline (Figure 1b), using any command supported by the editor. After the task is considered

complete, the participant finishes the trial and answers the post-trial questionnaire while a new trial is added to the session. The participant receives identical instructions to complete the same task in every trial.

Before starting the next trial, the experimenter identifies the technique used to complete the task in the previous trial (see Table 1) and uses the back-end control of the session to disable the key command of the technique for all subsequent trials. For example, if trial 1 is solved with the technique *R*, i.e., the participant’s technique is based on using the ruler, the ruler is disabled for every trial  $n > 1$ . The participant sees a list of the commands that will be disabled in the editor and presses a *Continue* button to start the next trial. This list is not shown in the first trial because all the commands are enabled (Figure 1c). History commands, i.e., undo and redo, are not controlled and thus are always available.

Participants are asked to think aloud [28] throughout the entire session whenever they are working in the editor. A participant ends a trial by pressing a *Finish* button on the screen when they consider the task complete. The number of trials at the end of a session is the same as the number of different techniques that the participant used to solve the task before a 30-minute countdown runs out. The countdown only runs when the participant is working on the editor, and is stopped between trials. Participants may end a trial before completing the task, thus giving up and finishing the session.

At the end of the session, participants answer a demographics questionnaire including their age range and gender. A post-session questionnaire assessing creative personality is sent within 24 hours after the session. The reason for this delay is to minimize the effect of their performance during the session on the self-perception of their creative personality. We do not use the questionnaire before the session to avoid priming participants about our interest in creative outcomes.

## 4.5 Data Collection

We collected answers to pre-session questionnaires, post-trial questionnaires, demographics questionnaires and post-session questionnaires (see Appendix A). The pre-session questionnaire is designed to assess the participants’ self-reported *experience* with text editors, problem solving attitudes towards software and signs of appropriation of text editing functions using 5-point Likert-type questions. It is used to calculate a text editing experience score for each participant. The post-trial questionnaire is used in connection with the notes from the verbal protocol to assess the participant’s thinking process. It measures the self-perception of the quality of the result with a 5-point Likert-type item and contains a series of Yes/No items to characterize the thought process towards the technique. The demographic questionnaire collects the age and gender of the participants. The post-session questionnaire collects self-reported measures of *creativity* as a personality trait using the complete list of standardized 5-point Likert-type items from the *Originality/Creativity* scale of the International Personality Item Pool (IPIP) [26]. We use this questionnaire to calculate a creativity score for each participant.

We took notes of the participants’ verbal protocol and our observations of the participants’ screen via screen sharing. We recorded audio and video of the participant’s screen. We stored keystrokes and changes to the sample document to build an event log of each trial (see Table 7 in Appendix B for a full list of command types). All the data was referenced by participant number.

## 4.6 Data Analysis

Using the questionnaire responses, we calculated the participants’ text editing *EXPERIENCE* and *CREATIVITY* scores. Creativity items were valued based on the IPIP’s scoring instructions, where individual Likert-type scale values are added to calculate the general score. We used the same approach to calculate the *EXPERIENCE* score.

For each participant’s trial, we designated its *TECHNIQUE* from the considered levels Spacebar, Ruler, Tabulator, Clipboard and Color, corresponding to the technique used to complete the task during the trial. We used this value to count the number of participants that used each technique as well as gather information regarding the participants that used re-purposing techniques (Clipboard and Color).

Additionally, we measured *#SOLUTIONS* as the number of successful techniques used throughout the session. For example, if a participant succeeded performing Spacebar, Ruler, Clipboard and Color, *#SOLUTIONS* = 4 (see Appendix C for the complete results). We investigated the associations of *#SOLUTIONS* with *EXPERIENCE* and *CREATIVITY*. We then performed logistic regressions to study whether *EXPERIENCE* and *CREATIVITY* associated with any of the re-purposing levels (Clipboard and Color) of *TECHNIQUE*.

Last, we used a top-down (deductive) thematic analysis [8] of the notes and recordings of participants thinking aloud based on the audio and video recordings of the sessions, including answers to questionnaires and notes.

## 5 RESULTS: QUANTITATIVE ANALYSIS

In this section we report the quantitative analysis performed on the event logs and questionnaires (see Appendix C for a summary of the collected data). First we look at the techniques found by participants. Then, to further our analysis of participants’ performance, we look at the differences in the number of types of commands involved in each technique. Next, we analyze the relationship between the number of techniques and the participants’ self-evaluated experience and creativity scores. Last, we analyze whether experience and creativity scores predict the use of re-purposed techniques.

### 5.1 Most Participants Re-purposed Commands

We analyzed the event logs to record the first command of the session for every participant: 11 participants began with the Tab key and 5 began with a command associated with the ruler. Note that this is not necessarily the command that they used to solve the task in their first trial.

Participants performed a mean *#SOLUTIONS* = 3.31, *SD* = 1.14. All 16 participants performed Spacebar, 14 performed Ruler, 11 Clipboard, 7 Color and 5 Tabulator. All the participants who performed Color also performed Clipboard, resulting in 11 participants who re-purposed at least one command. Finally, 5 participants performed only familiar techniques: 4 performed Spacebar and Ruler, and 1 performed only Spacebar.

We calculate the median trial number for each technique and observe that participants predominantly started with Ruler, with Spacebar as second technique. Clipboard or Color occurred always at least on the third trial. This was also the case for Tabulator, although it was used more as a last resort before giving up (see Appendix C for details). Our results are in line with our expectation

that participants perform re-purposing techniques only after familiar ones, i.e. Clipboard and Color always took place after both Spacebar and Ruler. When Tabulator was deemed acceptable, it was always tried after Ruler and Spacebar and before Color.

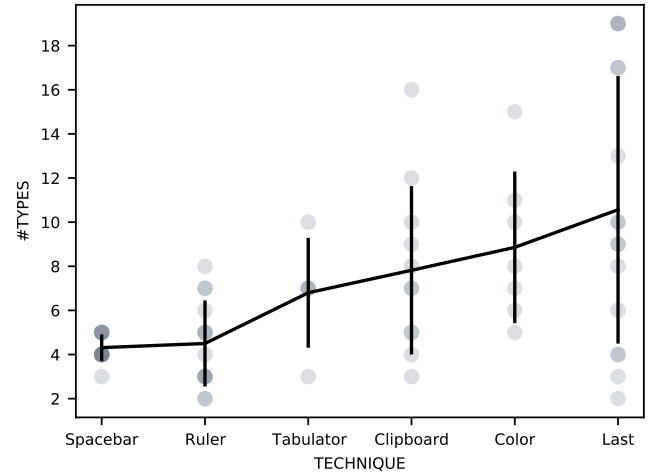
## 5.2 The Set of Used Commands Expanded with the Technique’s Difficulty

We analyze the extent to which participants explore the set of available commands before performing a technique that they consider successful. We logged the commands that participants used during each trial and classified them by type, e.g., insert space, delete characters. We measured *#TYPES* as the number of different command types used before completing a trial, where high values for a given trial indicate using or exploring a large number of different command types. We then analyze *#TYPES* by *TECHNIQUE* (Figure 2).

We use linear mixed-effects models to analyze differences in *#TYPES* between techniques, accounting for the repeated measures of the same participant as a random effect. We use two models with Spacebar and Ruler as baselines, i.e., as intercepts, respectively, because Spacebar and Ruler are the most used techniques to which we want to compare the others. Our results show that *#TYPES* for Clipboard and Color are significantly above Spacebar’s ( $p = .005$  in both cases) with no significant difference with Ruler and Tabulator ( $p > .05$ ), meaning that the set of different commands that were tried is larger for Clipboard and Color compared to Spacebar. *#TYPES* for Clipboard and Color are also significantly above *#TYPES* for Ruler as baseline values ( $p = .012$  and  $.010$  respectively) with no significant difference with Spacebar and Tabulator ( $p > .05$ ). Table 2 reports the model results, where *Diff* stands for the difference between *#TYPES* means. These suggest that Clipboard and Color are less familiar than Spacebar and Ruler, because they required a broader exploration of the available commands to be performed.

**Table 2. Results of linear mixed-effects models of *#TYPES* by *TECHNIQUE*. The top half uses the *#TYPES* of Spacebar trials while the bottom half uses the *#TYPES* of Ruler trials as intercept for each respective model. Both show significant effects of Clipboard and Color with higher *#TYPES* involved in devising these techniques.**

Technique	Diff.	Std. E.	p	95% CI
<b>Spacebar Technique as Intercept</b>				
Spacebar	<b>4.313</b>	.917	.000	[2.515, 6.110]
Ruler	.312	1.202	.795	[-8.29, -3.58]
Tabulator	3.101	1.746	.076	[-.321, 6.523]
<b>Clipboard</b>	3.670	1.299	<b>.005</b>	[1.125, 6.216]
<b>Color</b>	4.317	1.521	<b>.005</b>	[1.336, 7.297]
<b>Ruler Technique as Intercept</b>				
Spacebar	-.312	1.202	.795	[-2.669, 2.044]
Ruler	<b>4.625</b>	.976	.000	[2.711, 6.539]
Tabulator	2.788	1.763	.114	[-.667, 6.244]
<b>Clipboard</b>	3.358	1.335	<b>.012</b>	[.741, 5.975]
<b>Color</b>	4.004	1.561	<b>.010</b>	[.946, 7.063]



**Figure 2. Means of *#TYPES* for each *TECHNIQUE* across participants, including the last trial with no technique. Higher values suggest that the participants used a greater set of commands in the trial where they used the technique.**

## 5.3 Experience and Creativity Correlate with the Number of Techniques

We now analyze the impact of experience and creativity scores on participants’ performance. We study whether there exists a relationship between the number of techniques used by the participants (*#SOLUTIONS*) and their self-reported experience (*EXPERIENCE*) and creativity (*CREATIVITY*) scores. Pearson’s correlation tests show that *#SOLUTIONS* is correlated with both *EXPERIENCE* ( $r = .55, p = .03$ ) and *CREATIVITY* ( $r = .73, p = .001$ ) (Figure 3).

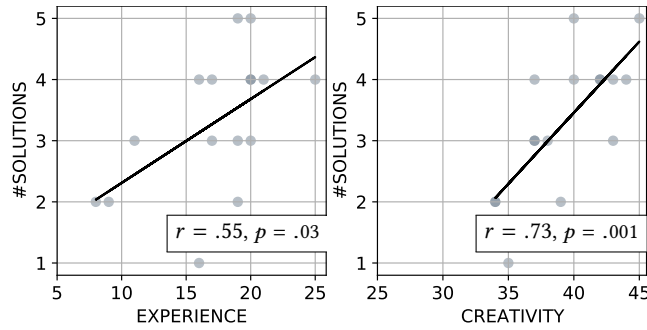
Only participants above the mean *EXPERIENCE* ( $M = 17.31, SD = 4.54$ ) performed Tabulator, and only those above the mean *CREATIVITY* ( $M = 39.38, SD = 3.56$ ) performed Color. We do not interpret that greater experience makes participants mistake a “poor” technique (Tabulator), i.e. one that does not achieve the requested goal, for a “good” one (Color), i.e., one that achieves the goal albeit in a non-standard way. In fact, none of the participants who finished a trial by performing Tabulator did it before their third trial, suggesting that it was a last resort before giving up or trying unconventional methods.

Both *EXPERIENCE* and *CREATIVITY* correlate positively with the number of alternative techniques, although *CREATIVITY* shows a stronger relationship (Pearson’s  $r = .73$  vs.  $.55$ ). Therefore, our results show that both creativity and experience are associated with finding alternative techniques to complete the task.

## 5.4 Creativity is the only Significant Predictor of Re-purposing

We now focus the analysis on the association between both creativity and experience and the two re-purposing techniques, Clipboard and Color. We use binary logistic regressions to model the likelihood of performing Clipboard and Color as functions of *EXPERIENCE* and *CREATIVITY* separately, i.e., the predictor variables. We use McFadden’s pseudo  $R^2$  as a measure of the fit of the model,





**Figure 3.** Scatter plots of #SOLUTIONS vs. EXPERIENCE and CREATIVITY scores showing positive correlations.

with values above 0.20 representing a good fit [18]. We report the odds-ratios (OR) and its 95% confidence interval to indicate the rate of change in the odds with every change by a unit in the predictor. As an example, a model predicting re-purposing with  $OR > 1$  for CREATIVITY would mean that the likelihood of re-purposing increases by OR with every 1 unit increase of CREATIVITY.

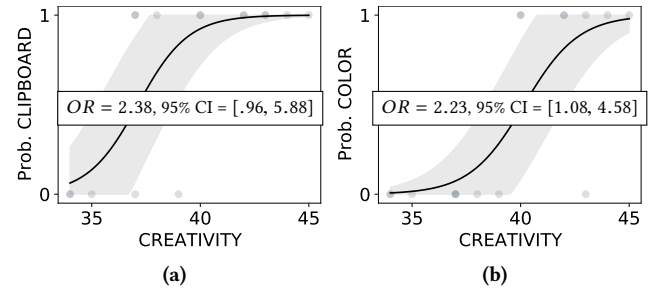
We construct four models detailed in Table 3. We find that CREATIVITY is a significant predictor of the likelihood of performing Color to solve the task ( $p = .03$ ,  $OR = 2.23$ , 95% CI = [1.08, 4.58]). Pseudo  $R^2 = .52$  indicates a good fit of the model. We also find a “borderline” effect for CREATIVITY as a predictor of Clipboard ( $p = .06$ ,  $OR = 2.38$ , 95% CI = [.96, 5.88], Pseudo  $R^2 = .52$ ). On the other hand, models using EXPERIENCE as a predictor do not produce any significant or borderline effect for either technique. We plot the predictions of Clipboard and Color as functions of CREATIVITY from our models, shown in Figure 4a and Figure 4b respectively. Our results show that CREATIVITY is a significant predictor of performing Color.

## 6 RESULTS: QUALITATIVE ANALYSIS

We present the results of our thematic analysis of the notes and recordings of the study. We analyzed the verbal protocols focusing on two categories: traces of procedural knowledge and traces of Technical Reasoning. We used codes for actions, functional fixedness, reflections about approaches, knowledge about text editing environments, transfer from past experience, and how participants found the commands that they needed. We cross-analyzed the codification to review the quotes associated with each code.

**Table 3.** Results of logistic regressions modeling the likelihood of performing Clipboard and Color as functions of EXPERIENCE and CREATIVITY separately. Rows indicate the predictor variable, p-value, odds-ratio, its 95% confidence interval, and the model’s pseudo  $R^2$ .

	TECHNIQUE							
	Clipboard				Color			
Score	p	OR	95% CI	$R^2$	p	OR	95% CI	$R^2$
EXPERIENCE	.09	1.29	[.96, 1.74]	.19	.33	1.14	[.88, 1.47]	.05
CREATIVITY	.06	2.38	[.96, 5.88]	.52	<b>.03</b>	<b>2.23</b>	<b>[1.08, 4.58]</b>	<b>.52</b>



**Figure 4.** Probability of Clipboard (a) and Color (b) as functions of CREATIVITY. Both plots include a visualization of the 95% confidence interval and an overlay of the data points used to train the models. (a) shows a curve with a borderline effect with  $p = .06$  while (b) presents a logit curve with good fit and a significant result.

We first present findings related to potential biases due to experience and procedural knowledge. Next, we present findings about cues of text-editing knowledge used to re-purpose commands that we attribute to mechanical knowledge in Technical Reasoning. Overall, we find that all participants elicited knowledge of text editing and text-based commands and most participants elicited reasoning towards re-purposing at least one command to complete the task.

### 6.1 Participants Elicited Procedural Knowledge of Familiar Techniques

All participants demonstrated pre-existing knowledge associated with the task in their first trial, manifested in the first-ever command that they used in the environment. Even if many actions would be backed by declarative knowledge due to the think-aloud protocol, we expected that trivial actions such as selecting text with the mouse or typing would be carried out backed by procedural knowledge. We found that this knowledge sometimes blocked the participants or caused them to approach the problem in ineffective ways. Furthermore, some participants who managed to re-purpose one or more commands were critical of the unorthodox nature of these approaches. We analyze how the participants’ past experience influenced exploration and decision-making.

**6.1.1 First Actions were Based on Common Practice.** All participants elicited knowledge based on usual practice in their first approach. For example, P5 had the ruler disabled in her second trial and decided to use the Tab key: “the ruler wasn’t there so I went straight for the tabulator; I didn’t even look [at the interface].” P10 illustrates a similar case coming from software IDEs. He selected a sentence and pressed the Tab key, only to see the text being replaced by a tabulator character, about which he said: “I realize I don’t know how to use the ruler on top; I try to [manipulate text] as if it was code.”<sup>3</sup>

From our quantitative analysis, all participants elicited a first approach using either Tabulator (11/16) or Ruler (5/16). Contrary to our expectation, none of the participants attempted to perform Spacebar as their first approach. We argue that these attempts to

<sup>3</sup>Although this is not standard behavior in text fields, professional word processors interpret the Tab key pressed after a text selection as an indentation command, identical to how IDEs do it.

perform Ruler and Tabulator first have their roots in priming by recognition of the environment, leading to an action associated with the task. Furthermore, our analysis suggests that participants followed a procedure, e.g., “to indent, press the Tab key,” overlooking other alternatives. This is consistent with the notion of procedural knowledge associated with the indentation task.

**6.1.2 Personal Experience Induced Biases and Blocks.** All participants justified ineffective approaches based on usual practice. For example, **P3, 5, 7, 15 and 16** finished a trial with Tabulator on the basis of it being their usual approach in text editors. Furthermore, **P13 and 16** attempted to use the smallest font size available to make characters invisible enough while still occupying space, so as to push the sentence to the right; this did not work, but they considered it valid on a “best effort” basis: “*The result was not perfect, but I used the smallest character I could find*” (**P13**).

While not necessarily ending the session, 10 participants expressed feeling blocked after standard commands became unavailable, e.g., the Spacebar: “*I don’t see other tool that would generate a blank space*” (**P1**). Similarly, **P4** felt lost at the lack of a ruler: “*[the ruler] is how I understand it is always done.*” **P4, 7, 9, 11, 12, 16 and 17** expressed frustration as they explored the interface for a replacement for either the Spacebar or the ruler: “*I’m feeling frustrated and dumb*” (**P12**); “*at this point I’d be searching on the Internet*” (**P4**).

This apparently led **P3, 5, 7, 15 and 16**—all above the median EXPERIENCE—to accept Tabulator despite its poor result. This supports the characterization of Tabulator as a last resort in our quantitative analysis, reflected in **P16**’s comment: “*[I am] leaning on leaving the tabulator and accept the [extra] space that is left. (...) My solution is resignation.*” However, attempting to use the tabulation character was a general occurrence, even among those who did not accept it as a solution. For example, **P13** rejected Tabulator yet called it “*the way to [indent].*” This suggests that the experts’ tendency to accept Tabulator was based on usual practice, i.e., the sense that it was right because it worked in other text editors.

**P4** recognized a bias from her daily practice when stating: “*I have my mind set on a design application so I try to do things that I could do with the design application.*” Similarly, **P10 and 12** realized that they had grown habituated to code editing, as they attempted to select text and press the tabulator key to indent text as in their code editing environments.

In summary, all participants demonstrated a sense of what *should* and *should not* be done in our text editor, and attempted to use familiar techniques (Spacebar, Ruler and Tabulator) before finding themselves thwarted and having to spend time exploring the environment.

**6.1.3 All Participants Elicited Knowledge of Other Text-editing Environments.** During their exploratory phase, all participants demonstrated experience with text editing commands beyond what the experimental editor offered. For example, **P7** was able to describe the way in which she uses her own text editing application to achieve the goal: “*If I were in Word (...) I’d go to [the] Paragraph [menu] and then [to the] Indentation [section] and set the indentation I want.*” **P3 and 12** extended the possibilities we had considered

for the editor by attempting to insert spaces using ASCII codes<sup>4</sup>. Similarly, **P10** showed her understanding of the system clipboard by concluding, after she performed Clipboard, that the copied text would still be stored in the operating system’s memory: “*I can paste... I have the space that I had copied before.*” However, since she had used Clipboard in the previous trial, all clipboard commands were now disabled.

This is not to say that all participants mastered the commands they knew about. For example, 7 participants expressed that they were not sure about which was the appropriate slider in the ruler to control paragraph indentation. **P7** stated: “*one control moves the line [indentation] and the other moves the paragraph [margin] but I didn’t know which one was which so I tested.*” However, even if the participants had superficial knowledge of some commands, they had a sense of whether they were pertinent to the task or not. For example, as **P1** hovered with the cursor over the toolbar, she voiced a mental checklist: “*...font face won’t do anything for me, the size neither...*” This shows that participants made associations between the task and commands, regardless of whether they were available in our experimental editor, as if trying to find the procedures that would work for the task.

**6.1.4 Some Participants Judged Techniques Based on Knowledge of Good Practice.** Some participants who managed to overcome their blocks criticized the re-purpose techniques and, to our surprise, considered Spacebar to be a bad approach. For example, **P1**, on her way to performing Spacebar to complete the task, changed her mind and switched to find if Tabulator was possible instead, stating that the latter “*is more correct.*” **P14** said of Spacebar: “*it is introducing new characters and it’s not formatting,*” and when he realized that there was no other option, added: “*I’m not satisfied by that but it does the trick.*” **P18** compared Spacebar to “*stacking books to prop a monitor up.*”

About Clipboard, **P12** felt it was against “*the rules*” of text editing, stating that in prior trials he “*was not trying to cheat but find a reasonable way*” to complete the task. **P18** characterized it as “*patching things*” and established a parallel between Color and “*using Corel DRAW or Illustrator the wrong way.*”

Nevertheless, other participants expressed satisfaction after performing Clipboard and Color. This is best exemplified with **P3** who, after performing Clipboard, recognized her action as an unorthodox use of the color command when she said: “*I feel like I am MacGyver.*”

In sum, participants were reluctant to re-purpose techniques even when they saw their effectiveness, justified by what they deemed “*good practice*”. This supports the use of procedural knowledge, because even though participants managed to break free from their block, they showed a strong reliance on a procedure-based approach.

## 6.2 Participants Elicited Technical Reasoning

All participants demonstrated a basic knowledge about the commands and interactions that apply to a text-editing environment, i.e., text properties and the mechanics of text editing. Additionally, some participants made associations between re-purposing

<sup>4</sup>In Windows, using a keyboard’s Number Pad with Number Lock on, it is possible to insert a character by typing its ASCII code with the ALT key pressed.

approaches and past experience using techniques from digital environments besides text editing, showing their ability to transfer knowledge. Some participants demonstrated knowledge of text-based commands while evaluating those that could lead to a solution vs. those that would not, consistent with the use of Technical Reasoning. Finally, participants tried commands without expecting successful results, an approach that we characterize as “poking” at the interface for inspiration.

**6.2.1 All Participants Elicited Knowledge of Text Mechanics.** All participants described how the commands’ effects would or would not produce a desired result. For example, **P1** was concise in her approach: “*All I know is that I have to put a character in front [of the sentence],*” explaining how to push existing characters to the right side of the page. **P12** explained why an initial idea he had would not work: “*I tried cutting the text and putting the cursor at the guideline, but without anything written, that’s impossible.*”

This was also reflected in steps that left participants close to a re-purposing approach without necessarily realizing it on the first try. For example, **P2** reflected: “*I can insert characters [in front] but if I delete them [the remainder] will move,*” thus understanding that characters in front of the sentence push it towards the right but missing the fact that **Color** could make them invisible. **P10** thought of another approach: “*I’m going to check if there’s a font size 0 but no. It would be complicated to align anyway*” showing an understanding that a text size 0 would imply zero-length characters.

Our observations suggest that all participants expressed some form of knowledge about the mechanics of digital text, i.e., the principles governing digital text input, which we interpret as a form of mechanical knowledge about digital text.

**6.2.2 Some Participants Elicited Knowledge of Text Properties.** 7 participants (**P1, 3, 9, 10, 12, 17 and 18**) described their need for an object to act as a blank space, referring to it in various ways. **P3** characterized it as “*a letter that is a space.*” This led her to search for “*an emoji that doesn’t work and therefore looks like a blank space,*” which she found. This was an original solution that we had not accounted for. Similarly, **P10** said: “*there are symbols that are not drawn with some fonts, [such as] accents,*” although he could not reproduce it in the experiment. Lastly, some participants were less technical in their descriptions of the object properties they sought. For example, **P18** said: “*I don’t know what to call it [...] it’s an empty character.*”

We analyze these descriptions as expressing object knowledge, i.e., object properties that are needed to complete the task. By the end of their session, 6 of these 7 participants performed **Clipboard** and 3 performed **Color**. This suggests that they had declarative knowledge about text-based properties, i.e., object-based knowledge of text.

**6.2.3 Some Participants Transferred from Past Experience.** 7 participants expressed associations with their practice using other digital environments after performing **Clipboard** and **Color**, suggesting that they transferred knowledge from other applications. **P1, 10 and 18** thought of **Color** in relation to a graphical editing trick they perform where they overlap shapes with the same fill color as the background to mask parts of the content underneath them. **P1** said: “*[In Photoshop,] I put white squares on top of everything.*”

Closer to text editing, **P13** saw in **Color** his own use of  $\LaTeX$ ’s `\phantom` macro, which draws a blank space the length of the characters passed as argument. **P12** took some time to realize that he could perform **Clipboard**, after which he reacted saying: “*I can’t believe I didn’t think of this before! I normally do that for the ‘ñ’; I [search for it on] Google and copy it from there.*” This is identical to **P10**, who explained how he performs **Clipboard** frequently to insert characters that cannot be typed with the keyboard. Additionally, **P10** crystallized his experience as a web developer when he attempted to write HTML character entities<sup>5</sup> instead of searching for conventional keyboard-based techniques.

Arguably, these participants re-purposed text-editing techniques through analogies, i.e., recognizing surface aspects of the task that matched past experience. We analyze this approach as the *transfer* of knowledge to a new task, similar to how Technical Reasoning relies on the transfer of mechanical knowledge.

**6.2.4 All Participants Consciously & Aimlessly Tried Commands in the Environment.** All participants performed one or more actions about which they were quite certain that it would not produce a result towards the solution. **P9** stated it explicitly: “*I’m gonna randomly press the Paste button (...) I’m out of ideas.*”

Despite generally good knowledge of the formatting commands, **P2, 11, 13, 14 and 18** did not know the purpose of the *Clear Format* button and decided to test it while exploring for ideas. **P3, 4, 7, 10 and 13** tested key combinations of the **Alt/Option** or **Control** key with multiple characters, hoping that they could hit a shortcut that they did not know to indent a line or insert a space. **P12** went even further: “*I know this would not work in any editor, but maybe in this one [...] if you put underscores and then you underline them, maybe you [will] cancel them.*” This demonstrates Technical Reasoning, combining the mechanical knowledge about characters having an “underlined” attribute that the “Underline” command can unset, and inaccurate object-based knowledge about the underscore character having the underlined attribute set by default.

The fact that some participants tried random actions when they were out of ideas is probably due to the design of the experiment, which could give them the impression that there was yet another solution. However, it also reveals their knowledge of text environments as some of these actions had a certain logic to them, including the fact that text editors have a lot of hidden commands and features, and the knowledge that it is possible to recover from errors with the “undo” command.

## 7 DISCUSSION

Our findings suggest that most participants engaged in Technical Reasoning to re-purpose a command in our text-editing task. The notion of “good practice” expressed by some of the participants suggests that functional fixedness was a factor in blocking or limiting uses to the culturally-assigned functions of commands. We close this section with some implications of this work for HCI.

<sup>5</sup>HTML Entities are markup to print reserved HTML characters in a document, e.g., the `&space;` entity renders a blank space character in the browser.

## 7.1 Evidence of Technical Reasoning & Functional Fixedness in Digital Tool Use

Overall, participants demonstrated text editing knowledge characterized by *principled* expectations consistent with an understanding of text mechanics. The inability of some participants to describe these principles in words despite being able to apply them, does not contradict the notion of mechanical knowledge for a digital interaction because it is defined as based on abstractions of causalities, in the same way that we understand gravity without necessarily being able to explain it.

Among the majority of participants who re-purposed at least one command, their expression of associations with past practice suggests that they found analogies with other digital environments on which to ground their approach [42]. Such transfer is also a sign of the participants exerting Technical Reasoning based on their mechanical knowledge of another environment. The association of command re-purposing cases with high creativity scores is compatible with the creative aspect behind using familiar tools in novel ways observed in creative problem-solving with physical tools [16]. Additionally, our observation of participants using commands without clear purposes resonates with fidgeting and fiddling behaviors involving physical objects around the work space, associated with creative processes [31].

The lack of significant association between re-purposing and experience seems consistent with Carroll and Rosson's [13] argument that users often focus on completing tasks rather than on exploring the interface for alternative strategies, namely, a "production" bias. Additionally, users frequently approach new tasks based on interpretations of old ones, known as an "assimilation" bias [13].

For the minority of participants who did not manage to re-purpose commands, our observations of bias and blocks show an effect akin to functional fixedness [20]. This is further supported by their justification of poor results based on usual practice, which resonates with the notion of mental set [46] in problem-solving, i.e., participants stuck using a learned pattern to complete a task when it is not possible to use it. It also echoes Cockburn et al.'s [15] discussion of "satisficing," a phenomenon evidenced notably in users learning a minimal subset of functions adapted to their needs and rarely exploring the interface for more efficient alternatives.

In sum, all participants elicited knowledge of text editing tools compatible with mechanical knowledge of physical tools. Finally, while some participants experienced functional fixedness about the use of text editing commands, most of them elicited a reasoning process towards re-purposing these commands that is compatible with the Technical Reasoning hypothesis.

## 7.2 Implications for HCI

Our findings can extend existing interaction models such as Instrumental Interaction [3], to account for Technical Reasoning. Instead of focusing on the multiplicity of domain objects with which an instrument (or tool) interacts, we could design them to operate on the *properties* of these objects instead, by taking advantage of users' ability to grasp technical principles from observing the effects of tools on these properties, and their ability to perform Technical Reasoning. For example, instead of defining the objects with which a color picker can interact, we would rather model it as a tool that

interacts with the color property of objects. Thus, any domain object with such a property, e.g., a shape, cell or text selection, would react to the color picker being used on it, and more generally to any tool that uses this property.

As a short case study inspired by our experiment, standard word processors deal with many different sizes: text size, line spacing, image size, margin size, etc. However, text size and line height are usually controlled by number input fields, e.g., in the toolbar, while images support resizing by direct manipulation, and margins require the use of a dedicated ruler. Based on the reification and polymorphism principles of Instrumental Interaction [4], we see an opportunity for redesign by creating a new tool whose mechanical principle is to alter the size of any object with a size-like property. This resize tool could be used to resize text in a selection, by dragging its corners as is done for images; line spacing, by placing the cursor between lines and dragging up and down; images, by keeping the current direct manipulation of handles; and margins, by dragging the sides of paragraphs or the page.

Technical Reasoning offers a model based on reasoning to ground the design of interfaces for appropriation [17] and creative use [16]. It capitalizes on 'real-world' cognitive abilities [29] that underlie our understanding of interactions among objects based on knowledge of their properties and the principles that govern them. Additionally, Technical Reasoning complements existing theoretical work in HCI grounded in ecological psychology and activity theory, such as technology affordances [23] and mediated action [30]. Ultimately, we believe that a reasoning-based approach to designing interactions offers a promising path to leverage instrumental genesis processes [5] in digital environments, enabling the adoption and appropriation of digital tools and overcoming the limitations imposed by current software.

## 8 CONCLUSION & FUTURE WORK

The Technical Reasoning hypothesis is a theoretical model of human tool use based on reasoning about mechanical principles and physical object properties that explains how tools can be used in unusual ways to achieve specific goals, a phenomenon we call tool re-purposing. We explored the extent to which this theory could apply to digital tool use. We designed an experimental protocol involving a text layout task that encouraged users to re-purpose digital tools to complete the task. We showed that most participants managed to re-purpose a digital tool, and we found that re-purposing techniques associate with an increased exploration of the available commands. We also found that participants with a self-reported creativity trait were more likely to use one of the re-purposed techniques. We interpreted these results as a sign of exerting technical reasoning rather than applying procedural knowledge. Our analysis of verbal protocols showed that participants elicited mechanical knowledge and object-based knowledge about text editing and text properties respectively, enabling knowledge transfer to the task at hand. These results open up the possibility of designing interactive systems that leverage users' ability to perform Technical Reasoning to enhance the power of interactive systems.

This work is but a first step towards a better understanding of human cognitive skills in digital tool use. We identify several avenues for future work. First, while we have shown evidence of transfer

of knowledge about digital object properties and mechanics, it remains unclear to what extent this transfer occurs when changing the nature of the object, e.g., from text to graphics. Second, we used an artificial task that forced participants to re-purpose tools. While similar situations can be encountered with real-world tools, e.g. when editing text in an environment that does not provide a ruler, it would be interesting to conduct studies of digital tool re-purposing in a more ecologically-valid context, including longitudinal studies focusing on the type of spontaneous re-purposing observed in previous studies [14, 27]. Finally, we highlighted positive correlations between tool re-purposing and personality traits, such as creativity and, to a lesser extent, experience. More research needs to be done to further inspect the role of such traits as well as other factors in digital tool re-purposing, for example, by using standardized measures of computer expertise.

At a higher level, Technical Reasoning relies on the users' cumulative knowledge of abstract principles or laws of digital environments and digital object properties, in the same way as we learn about the laws of naïve physics and objects through our daily experience with the world. This opens up the more fundamental question of identifying or defining the abstract technical laws of the digital world.

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## REFERENCES

- [1] John R. Anderson. 1976. *Language, Memory, and Thought*. Psychology Press, New York, NY, USA. <https://doi.org/10.4324/9780203780954>
- [2] John R. Anderson. 1983. *The Architecture of Cognition*. Psychology Press, New York, NY, USA. <https://doi.org/10.4324/9781315799438>
- [3] Michel Beaudouin-Lafon. 2000. Instrumental Interaction: An Interaction Model for Designing Post-WIMP User Interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (The Hague, The Netherlands) (CHI '00). Association for Computing Machinery, New York, NY, USA, 446–453. <https://doi.org/10.1145/332040.332473>
- [4] Michel Beaudouin-Lafon and Wendy E. Mackay. 2000. Reification, Polymorphism and Reuse: Three Principles for Designing Visual Interfaces. In *Proceedings of the Working Conference on Advanced Visual Interfaces* (Palermo, Italy) (AVI '00). Association for Computing Machinery, New York, NY, USA, 102–109. <https://doi.org/10.1145/345513.345267>
- [5] Pascal Béguin and Pierre Rabardel. 2000. Designing for Instrument-mediated Activity. *Scandinavian Journal of Information Systems* 12, 1 (2000), 1. <https://aisel.aisnet.org/sjiss/vol12/iss1/1>
- [6] François Bérard and Amélie Rochet-Capellan. 2015. The Transfer of Learning as HCI Similarity: Towards an Objective Assessment of the Sensory-Motor Basis of Naturalness. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Crossings, Seoul, Korea) (CHI '15). Association for Computing Machinery, New York, NY, USA, 1315–1324. <https://doi.org/10.1145/2702123.2702359>
- [7] Joanna Bergström, Aske Mottelson, Andreea Muresan, and Kasper Hornbæk. 2019. Tool Extension in Human-Computer Interaction. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland UK) (CHI '19). Association for Computing Machinery, New York, NY, USA, 1–11. <https://doi.org/10.1145/3290605.3300798>
- [8] Virginia Braun and Victoria Clarke. 2012. Thematic Analysis. *APA Handbook of Research Methods in Psychology* 2 (2012), 57–71. <https://doi.org/10.1037/13620-004>
- [9] Laurel J. Buxbaum and Solène Kalénine. 2010. Action Knowledge, Visuomotor Activation, and Embodiment in the Two Action Systems. *Annals of the New York Academy of Sciences* 1191, 1 (2010), 201–218. <https://doi.org/10.1111/j.1749-6632.2010.05447.x>
- [10] Susanne Bødker. 1987. Through the Interface – a Human Activity Approach to User Interface Design. *DAIMI Report Series* 16, 224 (Apr. 1987), 190. <https://doi.org/10.7146/dpb.v16i224.7586>
- [11] Susanne Bødker. 1997. Computers in Mediated Human Activity. *Mind, Culture, and Activity* 4, 3 (1997), 149–158. [https://doi.org/10.1207/s15327884mca0403\\_2](https://doi.org/10.1207/s15327884mca0403_2)
- [12] Lucilla Cardinali, Francesca Frassinetti, Claudio Brozzoli, Christian Urquizar, Alice C Roy, and Alessandro Farnè. 2009. Tool-use Induces Morphological Updating of The Body Schema. *Current biology* 19, 12 (2009), R478–R479. <https://doi.org/10.1016/j.cub.2009.05.009>
- [13] John M. Carroll and Mary Beth Rosson. 1987. *Paradox of the Active User*. MIT Press, Cambridge, MA, USA, 80–111.
- [14] Marianela Ciolfi Felice, Nolwenn Maudet, Wendy E. Mackay, and Michel Beaudouin-Lafon. 2016. Beyond Snapping: Persistent, Tweakable Alignment and Distribution with StickyLines. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology* (Tokyo, Japan) (UIST '16). Association for Computing Machinery, New York, NY, USA, 133–144. <https://doi.org/10.1145/2984511.2984577>
- [15] Andy Cockburn, Carl Gutwin, Joey Scarr, and Sylvain Malacria. 2014. Supporting Novice to Expert Transitions in User Interfaces. *ACM Comput. Surv.* 47, 2, Article 31 (11 2014), 36 pages. <https://doi.org/10.1145/2659796>
- [16] Tim Coughlan and Peter Johnson. 2009. Understanding Productive, Structural and Longitudinal Interactions in the Design of Tools for Creative Activities. In *Proceedings of the Seventh ACM Conference on Creativity and Cognition* (Berkeley, California, USA) (C&C '09). Association for Computing Machinery, New York, NY, USA, 155–164. <https://doi.org/10.1145/1640233.1640258>
- [17] Alan Dix. 2007. Designing for Appropriation. In *Proceedings of HCI 2007 The 21st British HCI Group Annual Conference University of Lancaster, UK 21*. British Computer Society, London, UK, 1–4. <https://doi.org/10.14236/ewic/HCI2007.53>
- [18] Thomas A Domencich and Daniel McFadden. 1975. *Urban Travel Demand: A Behavioral Analysis*. North-Holland Publishing Company, New York, NY, USA. <http://www.worldcat.org/oclc/915919185>
- [19] Paul Dourish. 2003. The Appropriation of Interactive Technologies: Some Lessons from Placeless Documents. *Computer Supported Cooperative Work (CSCW)* 12, 4 (2003), 465–490. <https://doi.org/10.1023/A:1026149119426>
- [20] Karl Duncker and Lynne S Lees. 1945. On Problem-solving. *Psychological Monographs* 58, 5 (1945), i. <https://doi.org/10.1037/h0093599>
- [21] K Anders Ericsson, Ralf T Krampe, and Clemens Tesch-Römer. 1993. The Role of Deliberate Practice in the Acquisition of Expert Performance. *Psychological review* 100, 3 (1993), 363–406. <https://doi.org/10.1037/0033-295X.100.3.363>
- [22] Paul M Fitts and Michael I Posner. 1967. *Human Performance*. Brooks/Cole, Michigan, USA.
- [23] William W. Gaver. 1991. Technology Affordances. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New Orleans, Louisiana, USA) (CHI '91). Association for Computing Machinery, New York, NY, USA, 79–84. <https://doi.org/10.1145/108844.108856>
- [24] William W. Gaver, Jacob Beaver, and Steve Benford. 2003. Ambiguity as a Resource for Design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Ft. Lauderdale, Florida, USA) (CHI '03). Association for Computing Machinery, New York, NY, USA, 233–240. <https://doi.org/10.1145/642611.642653>
- [25] J J Gibson. 1986. *The Ecological Approach to Visual Perception*. Psychology Press, New York, NY, USA. <https://doi.org/10.4324/9780203767764>
- [26] Lewis R. Goldberg, John A. Johnson, Herbert W. Eber, Robert Hogan, Michael C. Ashton, C. Robert Cloninger, and Harrison G. Gough. 2006. The International Personality Item Pool and the Future of Public-domain Personality Measures. *Journal of Research in Personality* 40, 1 (2006), 84–96. <https://doi.org/10.1016/j.jrp.2005.08.007> Proceedings of the 2005 Meeting of the Association of Research in Personality.
- [27] Han L. Han, Miguel A. Renom, Wendy E. Mackay, and Michel Beaudouin-Lafon. 2020. *Textlets: Supporting Constraints and Consistency in Text Documents*. Association for Computing Machinery, New York, NY, USA, 1–13. <https://doi.org/10.1145/3313831.3376804>
- [28] Robert R. Hoffman. 1989. A Survey of Methods for Eliciting the Knowledge of Experts. *SIGART Bull.* 1, 108 (April 1989), 19–27. <https://doi.org/10.1145/63266.63269>
- [29] Robert J.K. Jacob, Audrey Girouard, Leanne M. Hirshfield, Michael S. Horn, Orit Shaer, Erin Treacy Solovey, and Jamie Zigelbaum. 2008. Reality-Based Interaction: A Framework for Post-WIMP Interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Florence, Italy) (CHI '08). Association for Computing Machinery, New York, NY, USA, 201–210. <https://doi.org/10.1145/1357054.1357089>
- [30] Victor Kaptelinin and Bonnie Nardi. 2012. Affordances in HCI: Toward a Mediated Action Perspective. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Austin, Texas, USA) (CHI '12). Association for Computing Machinery, New York, NY, USA, 967–976. <https://doi.org/10.1145/2207676.2208541>
- [31] Michael Karlesky and Katherine Isbister. 2016. Understanding Fidget Widgets: Exploring the Design Space of Embodied Self-Regulation. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction* (Gothenburg, Sweden) (NordCHI '16). Association for Computing Machinery, New York, NY, USA, Article 38, 10 pages. <https://doi.org/10.1145/2971485.2971557>

- [32] Aleksei N. Leontiev. 1978. *Activity, Consciousness, and Personality*. Prentice-Hall, Englewood Cliffs, UK.
- [33] Wendy E. Mackay. 1990. *Users and Customizable Software: A Co-Adaptive Phenomenon*. Ph.D. Dissertation. Massachusetts Institute of Technology, Cambridge, MA, USA.
- [34] N.R.F. Maier. 1931. Reasoning in Humans. II. The Solution of a Problem and its Appearance in Consciousness. *Journal of Comparative Psychology* 12, 2 (1931), 181–194. <https://doi.org/10.1037/h0071361>
- [35] Joanna McGrenere. 2002. *The Design and Evaluation of Multiple Interfaces: A Solution for Complex Software*. Ph.D. Dissertation. The University of Toronto, Toronto, Ontario, Canada.
- [36] Uran Oh and Leah Findlater. 2013. *The Challenges and Potential of End-User Gesture Customization*. Association for Computing Machinery, New York, NY, USA, 1129–1138. <https://doi.org/10.1145/2470654.2466145>
- [37] Kenton P. O'Hara and Stephen J. Payne. 1999. Planning and the User Interface: The Effects of Lockout Time and Error Recovery Cost. *International Journal of Human-Computer Studies* 50, 1 (1999), 41–59. <https://doi.org/10.1006/ijhc.1998.0234>
- [38] François Osiurak. 2014. What Neuropsychology Tells us About Human Tool Use? The Four Constraints Theory (4CT): Mechanics, Space, Time, and Effort. *Neuropsychology Review* 24, 2 (2014), 88–115. <https://doi.org/10.1007/s11065-014-9260-y>
- [39] François Osiurak and Arnaud Badets. 2016. Tool Use and Affordance: Manipulation-based Versus Reasoning-based Approaches. *Psychological Review* 123, 5 (2016), 534–568. <https://doi.org/10.1037/rev0000027>
- [40] François Osiurak, Christophe Jarry, Philippe Allain, Ghislaine Aubin, Frédérique Etchary-Bouyx, Isabelle Richard, Isabelle Bernard, and Didier Le Gall. 2009. Unusual Use of Objects After Unilateral Brain Damage. The Technical Reasoning Model. *Cortex* 45, 6 (2009), 769–783. <https://doi.org/10.1016/j.cortex.2008.06.013>
- [41] François Osiurak, Christophe Jarry, and Didier Le Gall. 2010. Grasping the Affordances, Understanding The Reasoning: Toward a Dialectical Theory of Human Tool Use. *Psychological Review* 117, 2 (2010), 517. <https://doi.org/10.1037/a0019004>
- [42] John Rieman, Clayton Lewis, Richard M. Young, and Peter G. Polson. 1994. Why is a Raven like a Writing Desk? Lessons in Interface Consistency and Analogical Reasoning from Two Cognitive Architectures. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Boston, Massachusetts, USA) (CHI '94). Association for Computing Machinery, New York, NY, USA, 438–444. <https://doi.org/10.1145/191666.191816>
- [43] Mark K. Singley and John R. Anderson. 1987. A Keystroke Analysis of Learning and Transfer in Text Editing. *Human-Computer Interaction* 3, 3 (1987), 223–274. [https://doi.org/10.1207/s15327051hci0303\\_2](https://doi.org/10.1207/s15327051hci0303_2)
- [44] Robert St Amant and Thomas E. Horton. 2008. Revisiting The Definition of Animal Tool Use. *Animal Behaviour* 75, 4 (2008), 1199–1208. <https://doi.org/10.1016/j.anbehav.2007.09.028>
- [45] Marc Vass, John M. Carroll, and Clifford A. Shaffer. 2002. Supporting Creativity in Problem Solving Environments. In *Proceedings of the 4th Conference on Creativity & Cognition* (Loughborough, UK) (C&C '02). Association for Computing Machinery, New York, NY, USA, 31–37. <https://doi.org/10.1145/581710.581717>
- [46] Jennifer Wiley. 1998. Expertise as Mental Set: The Effects of Domain Knowledge in Creative Problem Solving. *Memory & Cognition* 26, 4 (1998), 716–730. <https://doi.org/10.3758/BF03211392>

## A QUESTIONNAIRES

**Table 4. Questionnaire before the session begins, assessing the experience with text editing software.**

Text	Type	Options
I edit and format text documents on the computer...	5-point Likert	<i>Very Rarely to Very Often</i>
When I get stuck using the computer I...	5-point Likert	<i>Give up right away to Try until I find the solution</i>
	5-point Likert	<i>Look up the web or ask for help right away to Try until I solve it on my own</i>
I see my knowledge about text editing with computers as...	5-point Likert	<i>Basic to Expert</i>
The number of 'hacks' or 'tricks' I know to get things done with my text editor(s) is...	5-point Likert	<i>Very Small to Very Large</i>

**Table 5. Questionnaire after every trial ends.**

Text	Type	Options
How well did you do?	5-point Likert	<i>1 to 5</i>
Have you achieved a similar result in the same way before?	Single Choice	<i>Yes or No</i>
Did you use a method that you saw somewhere else but hadn't used yourself yet?	Single Choice	<i>Yes or No</i>
Did you devise a method to use before the trial started?	Single Choice	<i>Yes or No</i>
Did you look up the interface for something that could help you solve it?	Single Choice	<i>Yes or No</i>
Did you try random things on the interface?	Single Choice	<i>Yes or No</i>

**Table 6. IPIP items for creativity assessment. Participants answer about their level of agreement with each statement. Items are keyed (+) or (-) to indicate whether they count for or against creative personalities. Items were presented in randomized order for every participant.**

Text	Type	Options
I like to solve complex problems (+)	5-point Likert	<i>1 to 5</i>
I love to read challenging material (+)	5-point Likert	<i>1 to 5</i>
I love to think up new ways of doing things (+)	5-point Likert	<i>1 to 5</i>
I have a vivid imagination (+)	5-point Likert	<i>1 to 5</i>
I know how things work (+)	5-point Likert	<i>1 to 5</i>
I am not interested in abstract ideas (-)	5-point Likert	<i>1 to 5</i>
I am not interested in theoretical discussions (-)	5-point Likert	<i>1 to 5</i>
I avoid difficult reading material (-)	5-point Likert	<i>1 to 5</i>
I try to avoid complex people (-)	5-point Likert	<i>1 to 5</i>
I do not have a good imagination (-)	5-point Likert	<i>1 to 5</i>

## B ACTION LOGS

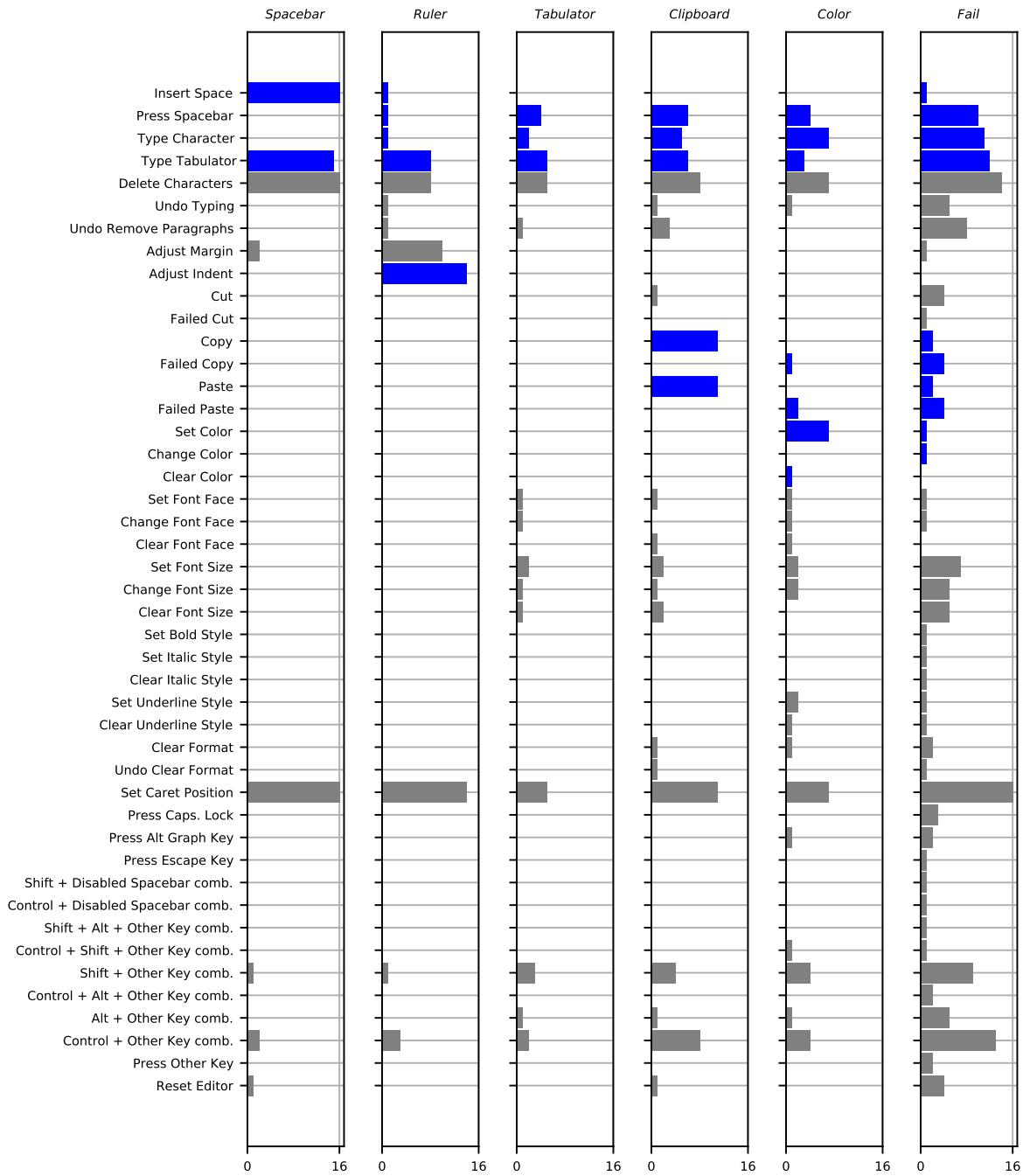


Figure 5. Number of participants registered producing the event on the left using the editor, grouped by *TECHNIQUE* and including the last trial. Includes all the command types counted in #TYPES and other key combinations and cursor updates. Primary events are highlighted to indicate their association with re-purposing techniques.



**Table 7. List of actions that were captured in the event log.**

<b>Name</b>	<b>Description</b>
Insert Space	Insert a space character using the spacebar
Press Spacebar	Press the spacebar while it is disabled
Type Character	Type any character key
Type Tabulator	Type a tabulator character
Delete Characters	Delete or backspace on characters
Undo Typing	Undo typing action
Undo Remove Paragraphs	Undo actions removing text or entire paragraphs
Adjust Margin	Adjust the ruler's paragraph margin
Adjust Indent	Adjust the ruler's paragraph indent
Cut	Cut selection from the document
Failed Cut	Attempt to cut selection while clipboard commands are disabled
Copy	Copy selection from the document
Failed Copy	Attempt to copy selection while clipboard commands are disabled
Paste	Paste text in the document
Failed Paste	Attempt to paste text in the document while clipboard commands are disabled
Set <property>	Set the selection's <property>
Change <property>	Change the selection's <property>
Clear <property>	Revert the selection's <property> value to its default
Clear Format	Clear the current selection's format properties
Undo Clear Format	Recover the format properties applied to a text before they were cleared
Set Caret Position	Put the text caret at a new position
Press <key>	Press the non-character key <key> (non-standard keys are identified as "Other")
[Shift Control Alt] + <key>	Key combination that does not produce modifications to the document as a result
Reset Editor	Resets the environment to the trial's initial state

## C STUDY RESULTS

**Table 8. Quantitative measures of our study with 16 participants. R, S, T, C and X stand for Ruler, Spacebar, Tabulator, Clipboard and Color respectively. Trial # cells indicate the trial number at which the technique was performed by the participant.**

P#	EXPERIENCE	CREATIVITY	Trial #					#SOLUTIONS
			R	S	T	C	X	
1	20	40	1	2		3	4	4
2	19	34	2	1				2
3	20	43	1	2	3	4		4
4	9	34	2	1				2
5	25	37	1	2	4	3		4
7	19	37	1	2	3			3
9	16	35		1				1
10	21	44	1	2		3	4	4
11	8	39	2	1				2
12	17	43		1		2	3	3
13	16	42	2	1		5 <sup>a</sup>	3	4
14	20	37	1	2		3		3
15	19	45	1	2	3	4	5	5
16	20	40	1	2	4	3	5	5
17	11	38	1	2		3		3
18	17	42	1	2		3	4	4

Median Trial #				
1	2	3	3	4

<sup>a</sup>Trial 4 was discarded because the participant used a small font to make characters invisible (which was not supposed to work by design) and stated that he could not see them on his screen, likely due to low resolution. We accepted the technique as valid to continue the session but did not include this trial in the analysis.