Mixed-Initiative Collaborative Workflow Support for Online Tasks

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Abstract

We present a mixed-initiative browser extension for semi-automated support of online tasks, which is designed for joint use by a support-seeker and a workflow-encoder. The support-seeker is an individual with mild cognitive deficits who may struggle to complete infrequently repeated online tasks. The workflow-encoder is able to support them in reviewing their task requirements, and automating elements of the task using a simple domain-specific visual language. The novel contribution of this work is in extending classical mixed-initiative models of programming by example (such as Cypher's Eager, and subsequent application to CoScripter) to accommodate social situations in which end-user programming is achieved jointly by pairs of individuals having distinct needs and abilities.

1. Introduction

Almost a quarter of UK adults have "very low" digital capability (Bank, 2024), with older age the best predictor (Hall, Money, Eost-Telling, & McDermott, 2022). Adults over the age of 75 often lack foundational skills (Bank, 2024) and confidence (ITU, 2021; Ofcom, 2024) to operate online. Despite this, support services increasingly move online, with public services such as healthcare and housing benefits among the least accessible (Bank, 2024; Hall et al., 2022). Many individuals who struggle online ask friends or family for help or to use the internet on their behalf (Ofcom, 2024), with 80% of 16-38-year-olds providing support for online tasks at least monthly. However, when the person providing support lacks time and patience to teach, or takes control of the device, the individual's digital capability does not improve, and fragile self-efficacy can be harmed (Richardson, 2018). Moreover, if that support network becomes unexpectedly unavailable, an individual can be left vulnerable.

We describe a system that helps individuals with low digital capability use online services by effectively reproducing in-person support through an end-user development strategy. Digitally-skilled volunteers use the system to encode a task workflow representation that can be used to provide interactive support at a later time. To meet diverse support needs while offering learning opportunities, the system provides different levels of support. Moreover, as individuals may be too overwhelmed to consider adjusting the level of support, the system helps select the appropriate support level. Because volunteers may make mistakes when encoding task workflows, and those needing support may lack the knowledge or confidence to identify them, the system also helps report problems with the support.

We thus address two distinct groups of users: *Support Seekers* with low digital capability, and digitally-skilled *Workflow Encoders*. We focus in particular on Support Seekers with mild cognitive impairment due to ageing, who may have reduced self-efficacy (Wild et al., 2012), deficits in metacognition (Murphy, Schmitt, Caruso, & Sanders, 1987), and increased cognitive load when accessing online services (Hollender, Hofmann, Deneke, & Schmitz, 2010; Oviatt, 2006). Workflow Encoders are relatively skilled individuals who volunteer their expertise to help others access online services. However, they may have limited availability to provide direct support.

2. Background

Tools already exist that can automate task workflows (BardeenAI, n.d.; Ovadia, 2014; Zapier, n.d.) and help users perform tasks online (Adept, 2022). However, these are designed for users familiar with tasks they wish to automate, and are intended to run unattended. We extend ideas introduced by CoScripter (Leshed, Haber, Matthews, & Lau, 2008), a browser extension that allowed users to

record online actions for playback at a later time. We adopt ideas for end-user programming of scripts (Bogart, Burnett, Cypher, & Scaffidi, 2008), recording re-playable actions in a central repository, whilst introducing new features to meet the needs of individuals with low digital capability. Our system relies on Workflow Encoders creating machine-interpretable representations of how to use online services, which we consider as an end-user development task (Kelleher & Pausch, 2005). We provide a Domain-Specific Visual Programming Language (DSVPL) to capture their expert knowledge of website usage (Mernik, Heering, & Sloane, 2005), while improving accessibility through graphical syntax (Baroth & Hartsough, 1995; Maleki, Woodbury, Goldstein, Breslav, & Khan, 2015).

3. Mixed-Initiative Interaction

Given the high cognitive load Support Seekers face, they may lack the metacognitive resources to assess their support needs or identify problems with the support provided. Therefore, the system acts as an intelligent agent, assisting with these secondary tasks. However, intelligent agents that make inaccurate inferences, do not consider the costs of acting, or do not allow the user to refine or control actions, can be more frustrating than helpful (the "Clippy" effect) (Baym, Shifman, Persaud, & Wagman, 2019). Misaligned system actions could lead to confusion and errors, further damaging low self-efficacy and reducing willingness to engage with the system. Mixed-initiative systems (Horvitz, 1999) combine autonomous capabilities with direct user control, allowing either system or user to initiate interactions (Tecuci, Boicu, & Cox, 2007). When deciding what action to perform, the agent considers uncertainty about the user's goal, and estimates costs and benefits of each possible outcome.

Our system differs from previous MII work where the intelligent agent directly automates actions, instead focusing on whether the level of user support should be increased or decreased. We maintain two models, the first oriented only toward Support Seekers, estimating the level of *Metacognitive Support* they need (Figure 1).

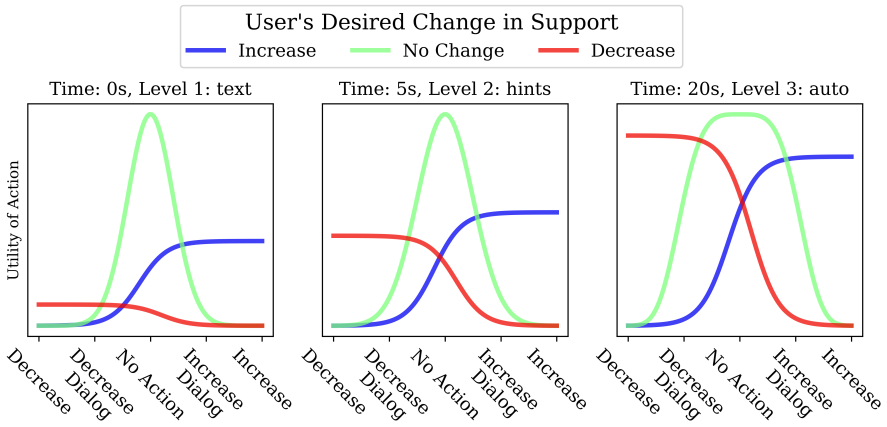


Figure 1 – The Metacognitive Support utility model

The second model is the *Consultation Trigger*, which is novel in modeling costs for two different classes of user (Figure 2). If the Consultation Trigger infers a problem in the support being given, it sends feedback to the Workflow Encoder, who can then fix or improve the workflow. This model consider costs and benefits not only for the Support Seeker, but also the Workflow Encoder and other Support Seekers. For example, it considers the cost to the Workflow Encoder of reporting a problem when there is none, and the future cost to other Support Seekers if a problem is not reported.

4. Implementation

We created a Chrome extension sidebar, providing contextual guidance to Support Seekers for any webpage. A second sidebar provides a DSVPL editor. This front-end was implemented in TypeScript using

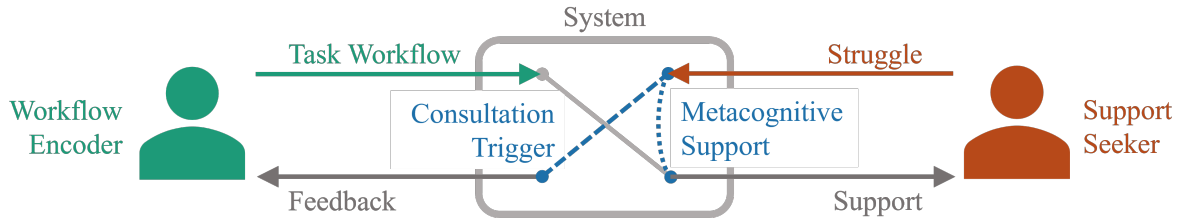
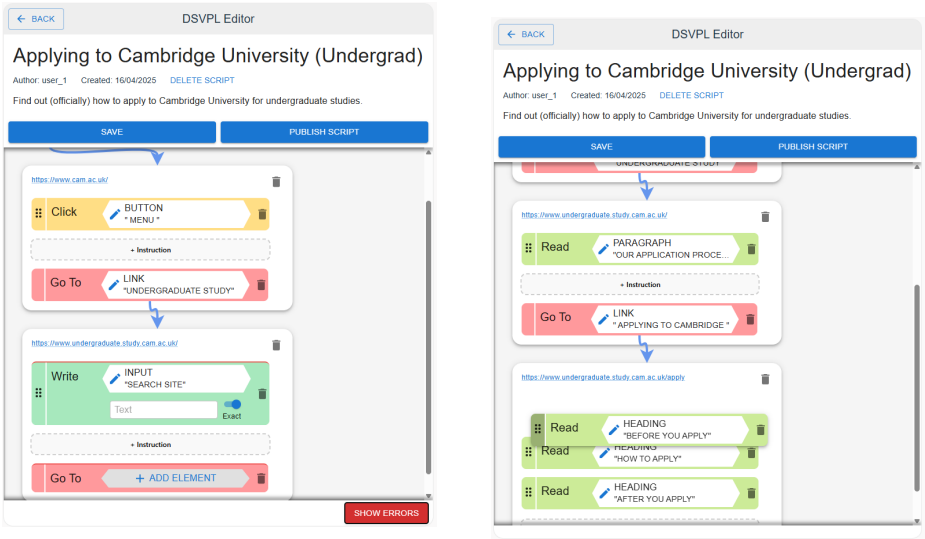


Figure 2 – The two applications of Mixed-Initiative Interaction (blue)

Vite [1], transpiled into JavaScript[2]. The back-end repository for task workflows was implemented using the SQLAlchemy Object Relational Mapper [3] and Python FastAPI framework[4], with task workflows encoded via a REST API[5].

4.1. Domain-Specific Visual Programming Language

The DSVPL serves two functions: an abstract syntax defining the workflow for support, and a concrete syntax edited by Workflow Encoders. Task steps correspond to individual webpage interactions, with sections for different pages, and subsections reflecting user decisions. The abstract syntax includes many step types to reflect the HTML elements that Support Seekers may interact with. Workflow Encoders may be unfamiliar with all HTML elements, so the concrete syntax groups these, for example the `ASTSelectNode`, `ASTCheckNode`, and `ASTRadioNode` in the abstract syntax correspond to a single `CSTSelectNode` for non-text input.



(a) Editing the task workflow

(b) Rearranging steps

Figure 3 – The DSVPL editor during task workflow creation

The Workflow Encoder adds steps to a new workflow by clicking the "add instruction" button, followed by the step type. Any step describing webpage interaction must reference the HTML element involved in the interaction. These steps have a slot for an element in the shape of an elongated hexagon (3a). This slot either shows the currently selected element or provides an add-element button. When the Workflow Encoder clicks to add or change an element, the content script activates click listeners on all the webpage elements with tags related to the step type and adds styling to highlight these elements.

[1] https://vite.dev/
[2] using the CRXJS plugin https://crxjs.dev/vite-plugin
[3] https://www.sqlalchemy.org/
[4] https://fastapi.tiangolo.com/
[5] https://fastapi.tiangolo.com/

4.2. Interactive Support

Once a Support Seeker has selected the service they wish to access, the system displays instructions in the side panel, and depending on the level of support, automates actions. The side panel tracks progress through the workflow, with each step translated into natural language based on the step type, including details relevant to that element (for example, when referencing a link, the text content from the `<a>` element is included in the instruction).

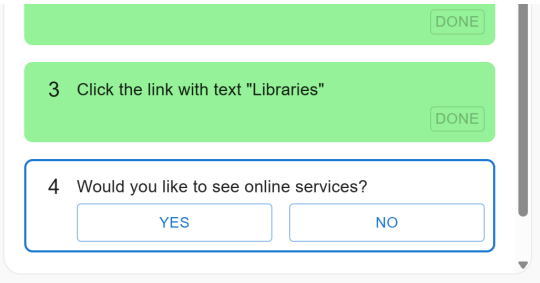


Figure 4 – Reaching the decision point in the instructions

Steps are translated sequentially until a user decision node is reached, describing the decision needed, with a yes/no choice (4), to select the next sequence of steps. When an instruction is detected as completed, a green background is added so the Support Seeker can track their progress (4). There are often alternative ways to navigate a website toward the same goal, meaning that a Support Seeker may complete an instruction in a way the extension does not expect and detect. Each instruction therefore provides a "done" button that allows the Support Seeker to report they have completed the task. Elements in the document object model (DOM) may change in ways that break the expected task workflow. For each type of HTML element, attributes are annotated based on whether they can be changed without affecting the user function.

There are three categories of instructions that the content script needs to detect: clicking on an element, scrolling to an element, and providing text input. When a webpage loads, the content script adds a click listener to all elements, so that a detection message can update the Support Seeker's progress. The second category is detected by adding a scroll listener that detects when an element moves entirely into view. The third category is detected by adding input and change event listeners to every input-related element in the DOM. This was straightforward for radio buttons, checkboxes and selections. Autocompleted text inputs require a `MutationObserver` object to detect changes to DOM elements, as do new elements such as popups being added.

The system provides three progressive levels of support:

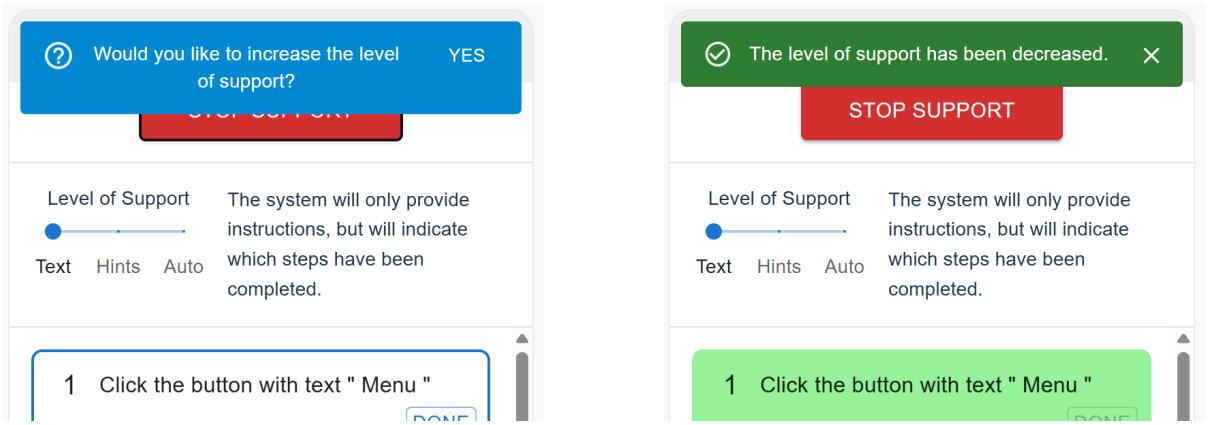
1. Text: written instructions are displayed in the extension's side panel
2. Hints: the system will automatically scroll the webpage to bring the element in the next instruction into view and outline the element with a pink box
3. Auto: the system will perform the interaction described by the next interaction for the Support Seeker, until further decision input is required

The Hints and Auto levels require the extension's content script to modify and interact with the current webpage. The Hints level of support aims to address availability or matching problems between the webpage's options and the Support Seekers' understanding of their goal (Lewis, Polson, Wharton, & Rieman, 1990). The Auto level of support provides a way for Support Seekers to keep progressing with their task, even if they do not understand how to proceed.

4.3. Mixed-Initiative Interaction model

The mixed-initiative interaction model is parameterised by user goals, system actions, observation evidence, and the utility models describing how these are related. Both the Metacognitive Support and

Consultation Trigger components build models in terms of estimated likelihood that the Support Seeker is struggling based on intervals between mouse and scroll events. The side panel tracks the number of steps completed in the last 5 seconds, and the time since the last interaction. If the system determines that the action with the highest expected utility is to change the level of support or initiate a dialog with the Support Seeker, it displays this via a notification. 5 shows the notifications displayed when the system decides to open a dialog about increasing the support and when it decreases the support, respectively. A key principle of MII is that notifications disappear after a few seconds so that the Support Seeker can elect to ignore them.



(a) Dialog to increase the level of support *(b) Notification for decreased support*

Figure 5 – Example Metacognitive Support notifications

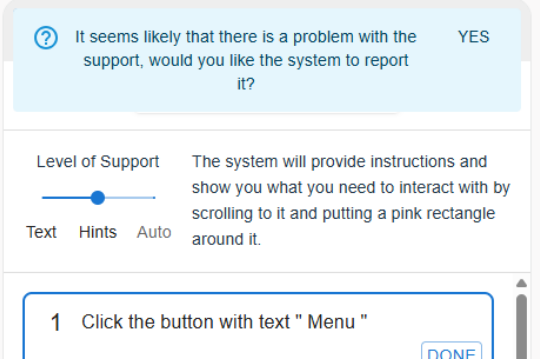


Figure 6 – Dialog to report a problem with the support

The Consultation Trigger model aims to help the Support Seeker detect problems with the support. If the system notes a likely problem, or the Support Seeker reports one, an annotation is recorded in the task workflow, to allow the Workflow Encoder to understand why it may have occurred, as shown in 7. 6 shows the dialog notification displayed to Support Seekers when the Consultation Support determines that a problem is likely and it would be beneficial to first consult the Support Seeker. Notifications for the Consultation Trigger are distinguished from those for Metacognitive Support by styling, but they otherwise behave identically.

5. Evaluation

Two user studies were conducted, one with a sample chosen to represent Support Seekers, and the other representing Workflow Encoders. The studies were approved by the ethics committee of the University of Cambridge Department of Computer Science and Technology. Because Support Seekers potentially belong to vulnerable groups, we took care in the study design to avoid potential distress.

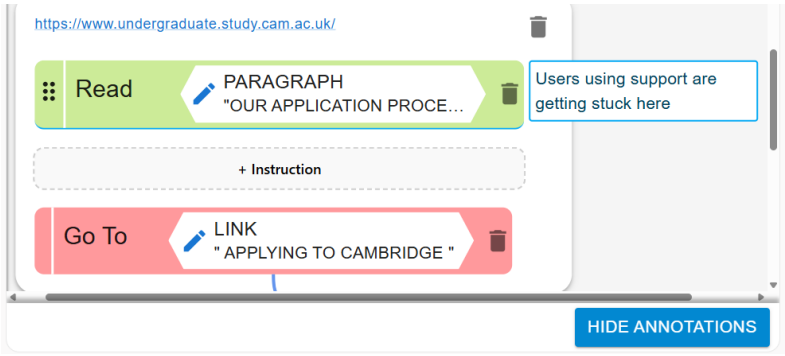


Figure 7 – An annotation on an unpublished task workflow

5.1. Participants

Each study involved six participants. Support Seekers (P1-P6) were recruited from the Marple Ramblers walking group and the Marple and District Women's Institute. Screening was based on lack of confidence using online services, and previous experience of receiving assistance. Workflow Encoders (P7-P12) were recruited from students at Cambridge University. Screening selected individuals who were confident using online platforms, had prior experience providing support to others, and were not expert programmers.

5.2. Study Protocol

The main part of the study involved completing tasks while thinking aloud. For Support Seekers, this involved completing an online task, while Workflow Encoders, created a task workflow for that task. The four tasks chosen to represent needs of Support Seekers were:

1. Starting from `www.gov.uk/`, find out the date of the next May bank holiday.
2. Starting from `www.gov.uk/`, fill out[6] the form to apply for a Blue Badge.
3. Starting from `www.ealing.gov.uk/`, either find the digital library services, or find out what opening hours and facilities Ealing Central Library has.
4. Starting from `www.nationalrail.co.uk/`, find out what fast trains are running from Cambridge to London, arriving before 10.00 am on the day of the London marathon.

All participants were walked through the system components relevant to their role. Workflow Encoder participants also completed a simple warm-up task to familiarise themselves with the DSVPL editor. Support Seekers completed two tasks with support and two without (counterbalanced). A pre-task questionnaire asked participants about their experience receiving or providing support, and level of technical expertise. Post-task questionnaires collected feedback on support or the DSVLP editor, as appropriate. Workflow Encoder participants also completed the NASA Task Load Index (NASA-TLX) questionnaire. Qualitative analysis focused on usability issues reported during think-aloud, and feedback in the post-task questionnaire. Texts were segmented and classified using a coding frame defined in advance, with supplementary categories added to analyse recurring themes.

5.3. Interactive Support Effectiveness

Most Support Seekers found the interactive support beneficial, commenting that it was "*very useful for people who haven't got many computer skills*" and that it "*needs extending to other areas* [such as] *passport renewal, and driving licence renewal*" (P4). The "hints" level of support was the most effective, helping participants to locate buttons and links that were not immediately obvious. With the "text" support, half of the participants (P1-P3) focused on completing their task, essentially ignoring the

[6] up to the point where the form redirects to the issuing authority's website

support. In particular, P3 only used the "text" level of support due to their confident attitude towards the tasks and consequently reported being "*not aware when the support assisted* [them]". P1 and P2 subsequently followed up, after having more time to reflect on the support, to say that they thought the approach was "*excellent*" as it provides "*very specific help very easily* [...] *exactly when it's needed so one can get through the procedure not only more quickly but without the stress that almost always occurs*".

When asked if they would prefer to have the interactive support available when navigating websites and whether they thought they would likely use the support in the future, supposing the system was refined for production, the participants' answers ranged from "maybe" to "yes", in line with their digital capability.

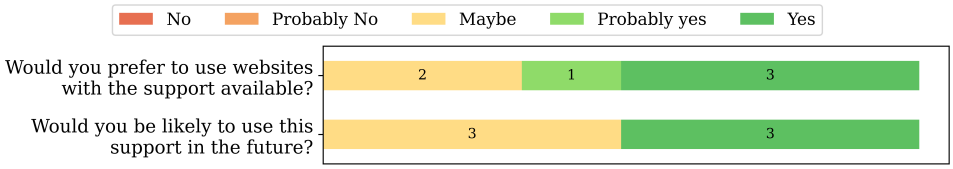


Figure 8 – Preference for using websites with the support available

5.4. Task Workflow Creation Success Rate

Each Workflow Encoder participant was asked to create five task workflows. A task workflow was deemed complete if the system could generate automatic support from it that performed the particular online task (with the necessary user input provided). Every participant successfully created five complete task workflows.

5.5. DSVPL Editor Ease of Use

The NASA-TLX measures workload using six subscales, each rated on a 0-100 scale (the Physical Demand subscale was omitted), as shown in figure 9. Overall workload score (Raw TLX (Hart, 2006)) was calculated as the mean of the subscales. Mean scores for the subscales "Mental Demand", "Effort", and "Frustration" are in the 20th percentile for NASA-TLX results (Hertzum, 2021), and the means for "Temporal Demand", "Performance", and overall TLX are in the 10th percentile. We conclude that the Workflow Encoders experienced low overall workload.

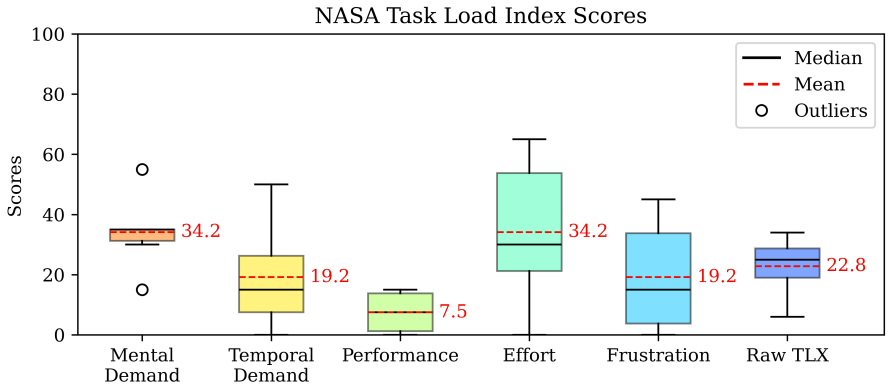


Figure 9 – NASA Task Load Index (TLX) scores

5.6. DSVPL Editor Learnability

After being shown a simple example of a task workflow, all Workflow Encoders spent less than 30 minutes creating the task workflows, without further instruction. The qualitative data collected from the moderated think-aloud protocol and the post-task questionnaire feedback was analysed to assess learnability of the editor. Participants commented that it was "*easy to understand*" (P8) and "*relatively intuitive*" (P12). Initially, participants were unsure which instructions were needed for certain inter-

actions, with all confusing "select" and "click" at least once. Due to the system highlighting relevant website elements when editing an instruction, participants could test out what type of interaction an instruction related to. This was a common strategy, and by the end of the tasks, participants were confident selecting instructions, only becoming unsure when they needed to specify a new type of interaction.

6. Design guidance

Qualitative analysis identified a number of issues that may offer guidance for developers of similar systems in future.

6.1. Support Usability

Ambiguity of 'Done' Button. P5 was confused by the purpose of this button, clicking it without having performed the action. P6 had to be prompted to click it, after navigating to the next page via a path the system did not detect. This could be addressed by hiding the button until the system has detected new actions, and animated reveal could prompt users to reflection.

Disruptive Automatic Scrolling. P4 was irritated by automatic scrolling while still reading, describing it as "*gone ballistic*". While reading time can be added programmatically in workflows, Support Seekers may benefit from (configurable) instruction reading time.

Hidden Instructions. The list of instructions did not scroll automatically as the system detected progress, so participants using smaller displays had to scroll manually to see the next instruction. This could be addressed by defaulting to show previous, current, and next instructions. A progress indicator could provide motivation.

Control Difficulties. In all support levels, participants faced basic difficulties. Many struggled with typing speed and accuracy (as addressed in a previous PPIG paper describing MII for older users (Morris & Blackwell, 2023)). Some became unsure how to proceed after mistakes. A few lacked familiarity with standard web layouts, with one struggling to find the "menu" button despite the pink outline.

6.2. DSVPL Usability

Instruction Naming. Names of some instruction types did not match expectations. The 'click' instruction was often used for 'select' or 'go-to'. Some participants failed to recognise that date input required 'write'. They suggested adding explanations for each instruction type. However, raising the abstraction level so names match terminology familiar to Workflow Encoders may address the problem.

Instruction Parts. Certain instructions require Workflow Encoders to specify extra information. Some participants found the purpose of this unclear. P8, P9 and P12 needed to be prompted to use the 'exact' toggle on 'write' instructions for interactions that could not be precisely specified. P7 and P10-P12 all initially wrote non-'yes/no' questions as prompts for the user decision. The first issue could be addressed by lowering abstraction, e.g. separating 'write' instruction into one for exact and one for inexact text.

Direct Manipulation. Participants generally decided how to complete each task before developing their workflow. Knowing which elements they wanted, some interacted with the webpage before clicking the "add element" button. To address this, the element selection mechanism could be automatically activated whenever a new instruction is added.

Website Issues. Participants faced some challenges caused by website structure. For example, to find train times on the National Rail site, a user must click a button that looks like a text input. Participants attempting to use a "write" instruction were confused when that did not work. It is not feasible to anticipate all website idiosyncrasies , but heuristics could be added to suggest solutions when these issues arise.

6.3. Study Limitations

The use of a think-aloud protocol during task completion likely affected performance (Chi, De Leeuw, Chiu, & LaVancher, 1994). This was most evident for Support Seekers, where two participants reported post-study that they may have ignored support because they were "*so busy showing [the experimenter] what I could do*". Our care to avoid possibly vulnerable participants becoming frustrated meant that

some tasks were slightly too easy, resulting in ceiling effects when Support Seekers were able to complete tasks without support.

7. Conclusion

We have presented a novel system that leverages task workflows created by digitally-skilled Workflow Encoders to provide interactive support to Support Seekers with low digital capability. This assists Support Seekers to navigate an online service, providing step-by-step instructions and interactive webpage guidance. We employ mixed-initiative interaction techniques to provide support with secondary tasks: Metacognitive Support helps Support Seekers to select the appropriate level of support, and a Consultation Trigger assists with the detection and subsequent notification to the Workflow Encoder of potential problems. A Domain-Specific Visual Programming Language (DSVPL) enables Workflow Encoders to encode their tacit knowledge of how to access online services.

This project makes several contributions. The first is a novel Domain-Specific Visual Programming Language for specifying user interactions with websites. Secondly, it contributes to mixed-initiative interaction by extending the approach to collaborative support, demonstrating new practical approaches for designing utility models.

7.1. Future Work

This system could be extended further to better meet the needs of Support Seekers and Workflow Encoders. Possible extensions could include: voice-based interaction for Support Seekers with vision impairments or using small-screen devices; increased personalisation of Metacognitive Support and Consultation Trigger models based on the Support Seekers' responses to system actions, or via manual settings; and introducing programming by demonstration (Cypher & Halbert, 1993) mechanisms so that task workflows can be encoded by interacting directly with a site.

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