PUX Explorer: An Interactive Critique and Ideation Tool for Notation Designers

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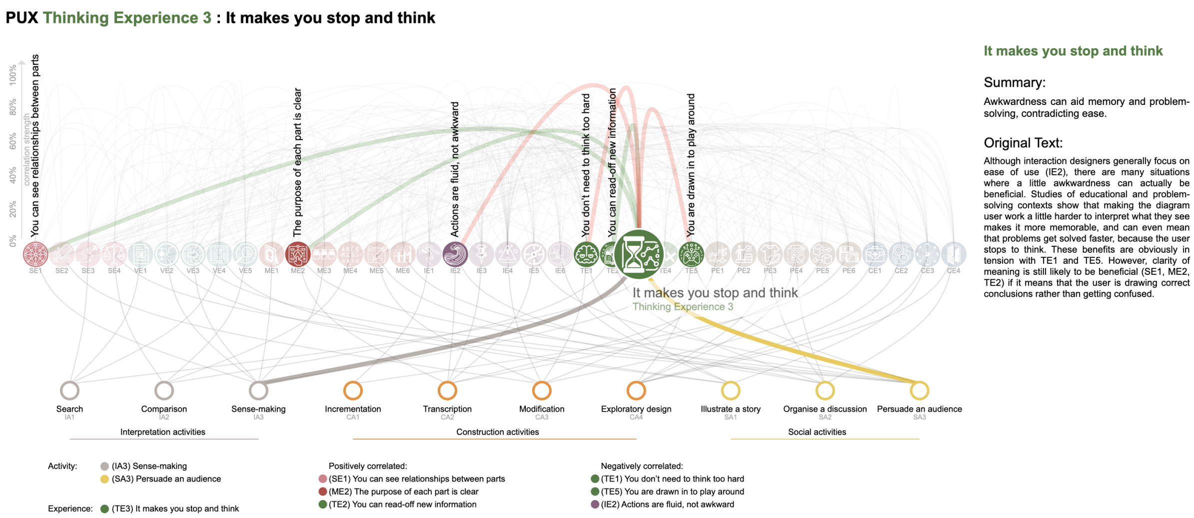

Figure 1 – Overview of the PUX Explorer, showing the main elements that will be discussed in section V and VI.

Abstract

PUX Explorer is a meta-design tool for use by designers of programming languages and other notational systems, in the tradition of Green's Cognitive Dimensions. Together with PUX Matrix and PUX Personas, these tools build on critical frameworks for notation design, informed by a general theory of design ideation. We evaluated PUX Explorer in a controlled study of meta-design, with specialist designers of new music notations. We find that these tools are effective and accessible design aids for meta-designers, not requiring specialist technical expertise.

1. Introduction

The design of novel programming languages can be informed by systematic documentation of the usability issues and tradeoffs that users experience when they need to understand or create information structures in any formal notation. However, formulating design guidance in a replicable process is challenging, especially because users with different specialist training or different task requirements will need different things from the notation.

There have been many attempts to formalise the design space of notational systems, in particular, the Cognitive Dimensions of Notations framework (CDNs) originally proposed by Thomas Green in 1989 (Green, 1989), and since extended and adapted by many researchers (Hadhrawi, Blackwell, & Church, 2017). One of those variants is the Patterns of User Experience (PUX) developed by Blackwell and Fincher (Blackwell & Fincher, 2010), which is taken as the starting point for this paper. PUX (Blackwell, 2024) describes a pattern language of notational activities (e.g. IA3 sense-making, CA4 exploratory design or SA3 persuasion), and experiences that users may have with a notation while undertaking those activities (e.g. VE2 the overall story is clear or IE3 things stay where you put them). As with CDNs, design choices in the notation and its environment make some kinds of experience more likely than others, leading to trade-offs. Also as with CDNs, these may be more or less desirable depending on what activities the notation is to be used for.

The most widely adopted process for application of the CDNs was the Cognitive Dimensions Questionnaire, which could be used in semi-structured interviews or design reviews to assess a notational system in relation to the properties described by the framework (Blackwell & Green, 2000). Although more approachable than tutorial descriptions of the method, the questionnaire did not offer direct design recommendations or quantifiable measures. Although there has been steady development and adoption of systematic vocabularies for analysis of tradeoffs in notation design since then, the field has been hampered by a lack of interactive design tools. One notable exception is Clarke's tool for use in the design of APIs, which characterised usability profiles of any API that was under development in relation to different programmer personas (Clarke & Becker, 2003).

In this paper we present an interactive tool specifically for use by notation designers, supporting the systematic investigation of notation usability properties such as those described in CDNs, in PUX, and in similar proposals such as Moody's PoNs (Van Der Linden & Hadar, 2018). The contributions of this work are as follows:

- Introduction of the PUX Explorer tool for systematic investigation of notation usability during both formative and summative phases of notation design.
- A theoretical characterisation of the notation design process, in terms of co-evolution of problem and solution spaces.
- A controlled evaluation study in which PUX Explorer is compared to an alternative interactive tool that uses a conventional feature matrix approach.

2. Co-evolution in Notation Design

The design and critique of new notation systems falls into the class of "meta-design", since the notations being created are generally intended to be used by other designers (Fischer, Giaccardi, Ye, Sutcliffe, & Mehandjiev, 2004). Earlier frameworks such as CDNs and PoNs did not include specific theories of design, relying instead on critique of the theoretical principles by which HCI guidance was formulated.

The original presentation of PUX (Blackwell & Fincher, 2010) did make explicit reference to Christopher Alexander's Pattern Languages (Alexander, 2018) as a theory of design, but made no claims regarding the meta-design process by which PUX might be applied. This was problematic since there is already conflicting evidence regarding the value of pattern languages in interaction design processes (Dearden & Finlay, 2006).

Our current work approaches the problem of meta-design in relation to Nathan Crilly's theory of ideation and critique in design processes (Crilly, 2021b, 2021a), which acknowledges the fundamental role of co-evolution, where the skilled designer does not simply translate predetermined requirements into product features, but rather constantly considers alternatives in both the problem space and the solution space, with the eventual design outcome reflecting a co-evolved alignment of the two.

We propose that co-evolution is the most appropriate theoretical framework by which to construct and assess meta-design tools such as PUX Explorer, since these are expected to offer benefits both in problem-oriented formative analysis (deciding what kind of notation to design) and in solution-oriented summative analysis (assessing whether the designed notation will be effective). As described later in this paper, we therefore used the perspective of co-evolution to design our own evaluation study.

3. PUX Explorer Functionality

PUX Explorer is a web application intended to help notation designers explore the activities and experiences described in the PUX framework [1], implemented in Javascript using the d3.js library (Bostock,

[1] PUX Explorer can be accessed at https://jb2328.github.io/PUX-Diagrams/

2024). The design process used to create PUX Explorer is described further below.

An overview of PUX Explorer can be seen in Figure 1, centred around two rows of circles that represent 36 experiences and 10 activities.

3.1. Primary operation

The primary mode of operation for PUX Explorer is for a designer to investigate the ways in which a candidate design delivers specific user experiences that will be associated with a given notational activity. The values used to prioritise and weight activities for different types of user can be established using the PUX Persona tool, which is described below.

PUX Explorer operates as an interactive diagram, allowing the user to isolate and explore the perspective of different activities. The overall structure of the visualisation is explored by mousing over the elements. Hovering on one activity shows the perspective of that specific activity, highlighting the notational experiences that are most salient.

Hovering on any one of the experiences, as shown in Figure 1, highlights the design trade-offs and synergies that exist with other experiences, and also indicates which other activities this experience might be associated with. Negative and positive associations (trade-offs and synergies) are indicated with red and green links, while stronger associations are indicated by the curve rising higher on the screen for greater prominence.

The PUX Explorer provides a targeted browsing interface guiding viewers to the documentation of the most relevant design guidance and properties among the many aspects of the framework. The tool converts the PUX framework into an interactive diagram, enabling integrated navigation of the entire framework.

3.2. Evidence Journey

Initially, the user sees two rows of distinctive circular icons, with the top row of 36 experiences organized into seven colour-coded groups, and the bottom row of 10 activities segmented into three groups. Activities are linked to experiences, and each experience is connected to others by grey arcs representing trade-offs. The arcs become highlighted and animated as the user hovers their mouse over different icons.

Whenever an experience or activity circle is hovered on, the right-hand side of the visualisation provides a description, summary and textual narrative for design guidance. This information can be captured for transfer to design documents, and a trail of the experiences identified as being relevant is maintained at the bottom of the screen.

Hovering over an *experience* icon highlights its connections to other experiences through green and red lines, indicating positive synergies and negative tradeoffs. Hovering enlarges the icon and animates lines that grow from there to the destination, illustrating directionality. Similarly, hovering over an *activity* circle emphasizes and animates the links to the experiences associated with that activity.

These animations give the Explorer tool a playful feel, including a degree of jitter that is designed to encourage users to explore the entire framework, avoiding premature design fixation and facilitating serendipitous discovery. The tool is designed such that the exploratory phase is led by animated lines. Once a user selects the appropriate experience or activity by clicking on it, the animation freezes until the unlock button is pressed.

See Appendix A for a zoomed-in view of the experiences and activities, as well as Appendix B for a deconstructed view of the PUX Explorer UI.

4. Development Process

PUX Explorer was developed through a potentially replicable process, beginning with a canonical presentation of the PUX framework (Blackwell, 2024). That textbook chapter uses conventional typographical structure (lists, section headings, and cross-reference codes) to support reference consultation for application by meta-designers. PUX Explorer make this process interactive instead of typographic. Below, we provide two examples – one for an activity and one for an experience – to illustrate how we transformed the textual descriptions of the framework into an interactive tool.

4.1. Activities profiles

In the canonical PUX description, different types of activity (Interpretation, Construction, and Social) are organised into subchapters, with individual activities being described as paragraphs in text, and related experiences listed at the end of the paragraph as follows:

Interpretation Activity 3 (IA3): Sense-making
For example: What is the best route, and time of day, to make a new journey? The user is trying to learn about a new situation, or integrate data of a kind they haven't seen before. This involves understanding the overall structure, how parts are related to each other, and which are most important. Comparing different parts and aspects of the structure will be an important aspect of sense-making, so aspects of pattern IA2 will also be relevant.
Relevant experience patterns include *VE2, VE3, SE1, ME1, ME3, TE3, TE5*

```
{
  "name": "Sense-making",
  "id": "IA3",
  "links_to": ["VE2", "VE3", "SE1",
        "ME1", "ME3", "TE3", "TE5"]
}
```

We translate this descriptive text and cross-references into data structures to define the interactive tools behaviour (JSON data structure for a sample activity (Sense-making IA3) (Listing 4.1)).

4.2. Experience profiles and Tradeoff analysis

Experiences are described in groups of unique segments, such as Visual Experience (VE) in the example below. However, unlike the descriptions of activities, tradeoff links are not explicitly defined at the end of the paragraph and must be inferred from the text itself. Here we illustrate how the JSON data structure was extracted for a sample experience (The overall story is clear VE2):

VE2: The overall story is clear
People often say they prefer diagrams to text because they get a kind of 'gestalt' view of the whole information structure – you can stand back and look at the overall configuration, and get a good idea of the whole story. Of course, it needs to be visible for this to work (patterns *VE1* and *SE1*), but sometimes it is possible to leave out some of the detail in order to improve this overall understanding (pattern *VE5*).

```
{
  "name": "The overall story is clear",
  "id": "VE2",
  "link_positive": [{"VE1": 0.9}, {"SE1": 0.8}],
  "link_negative": [{"VE5": -0.7}]
}
```

Although the description delineates a clear relationship between VE2 and the three related experiences (VE1, SE1, and VE5), it does not explicitly define a tradeoff relationship.

We used textual sentiment analysis to determine whether the relationships to other experiences were described positively or negatively, and assigned a numerical value ranging from -1 (a negative tradeoff) to 1 (a positive synergy).

For example, the textbook-style descriptions of VE1 and VE5 are introduced with a positive sentiment ("of course, it needs to be visible..."), followed by a negative sentiment ("but sometimes it is possible to omit detail..."). This analysis yields the following data structure for use in the tool's data visualisation (Listing 4.2):

The extracted structural encoding in Listings 4.1 and 4.2 encodes the entire structure of PUX framework as a graph that can be visualised either as an incrementally interactive diagram (PUX Explorer) or a holistic overview (PUX Matrix).

4.3. PUX Explorer icon design

Where the textbook description refers to activities and experiences using three-character codes that have limited visual or mnemonic value, we created unique icons for each experience, and distinct colour coding for activities, ensuring clear visual differentiation between the two (shown in Figure 1 and Appendix A).

Thirty-six icons were developed using a collaborative design process enabled by generative AI:

1. Generating design ideas. The PUX description of each experience was input into a large language model (LLM), prompted to create three different design concepts for an icon. For example, the LLM suggested that the concept "*SE4: You can compare or contrast different parts*" could be symbolised by a scale or balance icon as shown by the final row of icons in Figure 2. In some cases generic ideas were repeatedly proposed for different experiences (e.g. the magnifying glass in rows 1 and 3 of Figure 2), so the design team brainstormed alternatives to supplement the LLM output with more distinctive ideas.

2. Generating icons from the created prompts. The three design concepts for each icon were used as prompts for a Stable Diffusion (SD) model, with uniform style descriptors "*2D flat design, vector, white background, minimalist*" added to all prompts.

3. Selection process. At least three design options were created for each experience, as illustrated in Figure 2. Two raters experienced with the PUX framework independently selected the most appropriate icon from each set, making the final choice after reaching consensus.

4. Icon cleanup. The selected design was then vectorised from its original PNG format, refined in Adobe Illustrator, and saved as an SVG file for integration into the PUX Explorer tool as an icon.

Figure 2 – Icon selection process for the PUX Explorer tool. The final icon choices at the left of each row were selected from the three options to the right, as generated using Stable Diffusion.

Throughout the design process, a total of 112 icons were created, with 102 automatically generated, and 10 requiring some degree of manual intervention. In the final selection, 35 out of the 36 icons had been generated by SD, highlighting the efficiency of this LLM-enabled design process.

4.4. PUX Matrix

Our second interactive tool developed, the PUX Matrix (Figure 3), renders the same structural encoding of the PUX framework to emphasise an overview of interconnectedness among activities and experiences. PUX Matrix is inspired by the *contradiction matrix* that is a familiar element of the TRIZ process for inventive problem solving (Ilevbare, Probert, & Phaal, 2013). (The *inventive principles*, *standard solutions* and *separation process* of TRIZ can be considered as a rough analogy to the activities, experiences and trade-offs in PUX).

The PUX Matrix tool presents two rectangular grids corresponding to the two rows of icons and links in the PUX Explorer. The left grid shows links between activities and experiences as black dots in the corresponding cells. The right side uses red and green squares to indicate trade-offs and synergy between experiences.

PUX Matrix provides an overview of the whole framework, mapping regions in which experiences share similar patterns of trade-offs. The Matrix tool is more dense, but less interactive than the Explorer. As with the TRIZ contradiction matrix, detailed descriptions of each activity and experience are not included in the visual presentation, meaning that a separate text reference would need to be consulted. The tool in its entirety is shown in the appendix (Appendix C), along with a deconstructed version explaining its visual elements (Appendix D).

4.5. PUX Personas

The final tool complementing PUX Explorer and PUX Matrix is PUX Personas, inspired by Clarke's characterisation of programmer personas for API usability (Clarke & Becker, 2003). Previous usability questionnaires based on CDs and PUX have asked respondents to estimate what proportion of their time is spent in different activities. In the PUX Persona tool, different activity profiles are created for different user personas, and interactively visualised with polar area charts (also called Nightingale Rose Charts (Magnello, 2012)). The full tool is presented in Appendix E.

Utilisation of this tool involves three steps:

1) Time-allocation. Initially, users estimate the proportion of time, as a percentage, that this persona would spend on each of the 10 activity types from the PUX framework. This generates a pie chart where the angle of each slice corresponds to the proportion of time for that activity.

2) Rating experiences. Users then rate the comparative importance of each PUX experience within their notational environment using a 5-point Likert scale. Experiences are arranged vertically in the same order as in the PUX Explorer and Matrix tools, so that users can refer to descriptions and tradeoffs. As the rating of relevant experiences is adjusted, this determines the radius of the pie chart segment for the activity associated with that experience.

3) Creating a visual user representation. The final result of the activity and experience profiles is a rose diagram (Figure 4), where the polar area represents notation design priorities for a specific type of user. These visual persona representations can be used as a design aid and reference when making tradeoff decisions that will have differential benefits for different classes of users, or providing configuration capabilities relevant to a specific user class. In the depicted example, although a person spends a significant amount of time on *incrementation* activities, they rate other activities like *organising discussions* as more important, even though less time is spent on them. The full UI is shown in Appendix E.

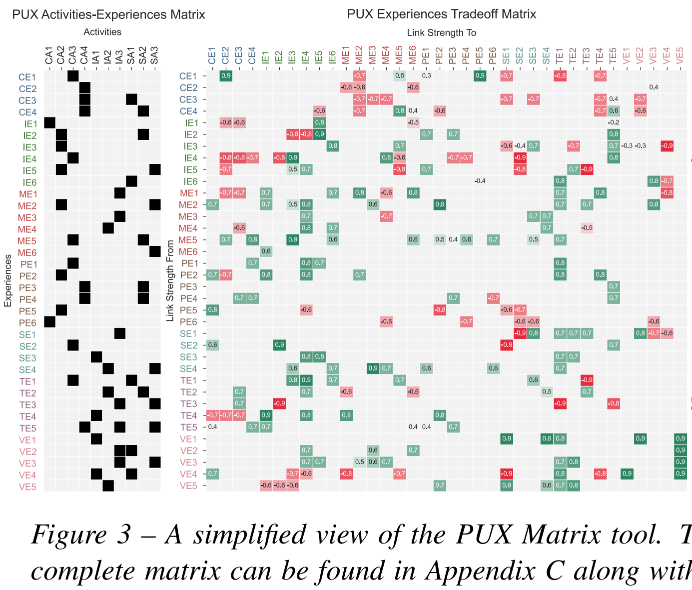

Figure 3 – A simplified view of the PUX Matrix tool. The complete matrix can be found in Appendix C along with a deconstructed version in Appendix D.

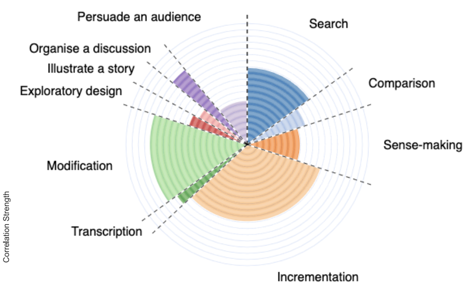

Figure 4 – Polar area chart generated by the PUX Personas tool. Slices indicate the percentage of time dedicated to specific activities (angle) and their importance (radius).

5. Evaluation

As an evaluation of the PUX Explorer tool, we chose to work with the same domain used for the initial evaluation of the Cognitive Dimensions Questionnaire (CDQ) (Blackwell & Green, 2000), which until now has been the most widely used research tool for analysis of notation usability (Hadhrawi et al., 2017). The paper introducing CDQ reported a study of music researchers who worked with and designed alternative music notations (Blackwell & Green, 2000). The advantage of the music notation domain for this type of research is that music researchers are familiar with a wide range of notation alternatives, from experimental graphic scores, to performance annotation, to formal musicological analysis. Musicians and music researchers routinely use a variety of computer-based, print, and pencil modifications. They are also accustomed to describing properties of a notation with an analytic distance from the semantic content of the music as heard or played. These factors mean that music researchers are better able, for example, than many mathematicians to consider distinctions between concrete syntax and variation in styles of perception and usage that have very different degrees of formal rigour or creative freedom.

We used music research community contacts to recruit a sample of 6 specialist music notation researchers from universities and music colleges across the UK, USA and Europe. All participants had considerable experience as researchers and practitioners designing novel notations or music visualisations, and all had a pre-existing concern (in one case, years of experimental work) with the usability properties of their systems.

All materials were made available online. Participants completed the study on their own computers, at a time of their choice, with the experimenters available for contact if needed. The study was approved by the Cambridge Computer Science Ethics Committee.

5.1. Structure of the Study

This study was designed to evaluate and compare the effectiveness of PUX Explorer and PUX Matrix during the critique and problem reformulation phase of a co-evolution design process. Two preliminary exercises introduced participants to the perspective of analysing notation systems in a preamble, and familiarised them with the overall operation of both PUX Explorer and PUX Matrix, followed by a design task in which participants used the tools to analyse design options, concerns and opportunities relevant to their own notation design project.

5.1.1. Preamble

The preamble introduced the PUX framework, explaining the concepts of activities, experiences, and trade-offs within the design process. Both PUX Explorer and PUX Matrix tools were then introduced. The presentation order of the two tools was counterbalanced across participants. To ensure every participant received the same introduction to the tool behaviour, two one-minute videos were created, demonstrating user interaction with the PUX Explorer and PUX Matrix. Participants were also provided with a deconstructed view of each tool (Appendices B and D). These views explained the operation of individual UI components and guidance on interpreting the UI.

5.1.2. Familiarisation

As an introductory exercise, participants were asked to evaluate four sample data visualisations, in relation to the activities *Illustrating a story (SA1)* and *Persuading an audience (SA3)*. As an example likely to be familiar to an international audience, we sourced visualisations of the 2020 US election results from four major news outlets: BBC(BBC News, 2020), CNN(CNN, 2020), The Economist(The Economist, 2020), and Bloomberg(Bloomberg, 2020). The data presented in these visualisations was similar across all four sources. They differed primarily in their visual language and graphic design elements, allowing for comparison of notational properties.

5.2. Design Task

In the core design task, participants were asked to evaluate music notation systems they had designed themselves or with which they were extensively familiar. They completed five tasks using both PUX Explorer and PUX Matrix. The first four tasks involved analysing their notation systems through the lens of the PUX framework, considering both design priorities and problem reformulation. The final task was a direct comparison of the Explorer and Matrix tools.

5.2.1. Pre-existing problems (Task 1/5)

In the first task, participants were asked to identify current design issues and problematic parts of their notation system. They were asked to consider how their notation might be used by diverse kinds of user, engaged in a variety of activities. Participants used either the Matrix or Explorer tool (order-balanced across participants) to identify problematic components using the PUX framework, as guided by the

	EXPERIENCES	SE1 You can see relationships between parts	SE2 You can change your mind easily	SE3 There are routes linking known to undiscovered	SE4 You can compare or contrast different parts	VE1 The information you need is visible	VE2 The overall story is clear	VE3 Important parts draw your attention	VE4 The visual layout is concise	VE5 You can see detail in context	ME1 It looks like what it describes	ME2 The purpose of each part is clear	ME3 Similar things look similar	ME4 You can tell the difference between things	ME5 You can add comments	ME6 The visual connotations are appropriate
ACTIVITIES	ID	SE1	SE2	SE3	SE4	VE1	VE2	VE3	VE4	VE5	ME1	ME2	ME3	ME4	ME5	ME6
Search	IA1			0.6		0.8			0.4	0.1						
Comparison	IA2				0.8									0.9		
Sense-making	IA3	1.0					0.7	0.7			0.7		0.6			
Incrementation	CA1															
Transcription	CA2											0.5				
Modification	CA3		1.0												0.5	
Exploratory design	CA4						0.6									
Illustrate a story	SA1								0.1							
Organise a discussion	SA2															
Persuade an audience	SA3				0.9							0.8				0.3

	EXPERIENCES	IE1 Interaction opportunities are evident	IE2 Actions are fluid, not awkward	IE3 Things stay where you put them	IE4 Accidental mistakes are unlikely	IE5 Easier actions steer what you do	IE6 It is easy to refer to specific parts	TE1 You don t need to think too hard	TE2 You can read-off new information	TE3 It makes you stop and think	TE4 Elements mean only one thing	TE5 You are drawn in to play around	PE1 The order of tasks is natural	PE2 The steps you take match your goals	PE3 You can try out a partial product	PE4 You can be non-committal	PE5 Repetition can be automated	PE6 The content can be preserved	CE1 You can extend the language	CE2 You can redefine how it is interpreted	CE3 You can see different things when you look again	CE4 Anything not forbidden is allowed
ACTIVITIES	ID	IE1	IE2	IE3	IE4	IE5	IE6	TE1	TE2	TE3	TE4	TE5	PE1	PE2	PE3	PE4	PE5	PE6	CE1	CE2	CE3	CE4
Search	IA1										0.6											
Comparison	IA2								0.6													
Sense-making	IA3									0.3		0.3										
Incrementation	CA1																					
Transcription	CA2		0.9	1.1		0.7								0.1			0.3					
Modification	CA3				0.7			0.8					0.4						0.3			
Exploratory design	CA4							0.4								0.5				0.3	0.7	0.1
Illustrate a story	SA1																					
Organise a discussion	SA2																					
Persuade an audience	SA3					0.1	1.0			0.6		0.4										

Figure 5 – Key problematic activities and experiences.

tool instructions to select potential system modifications from a list of activities. (e.g., Search (IA1))". Participants were then asked to rank the experiences related to their selected activities from most to least important.

5.2.2. Pre-existing benefits (Task 2/5)

The second task asked participants to identify particularly effective parts of the system, gather evidence of their value, and select corresponding experiences from the PUX framework to confirm their usefulness in notation system design. Participants were then asked to rate the related experiences using a 5-point Likert scale (ranging from "Strongly Disagree" to "Strongly Agree") to determine if these experiences confirmed the usefulness of the identified aspects of their designs.

5.2.3. Newly Discovered Opportunities (Task 3/5)

The third task assessed whether participants would gain insights and identify new design opportunities through using the PUX tools, by contrasting desired user experiences with a wider range of design patterns. These were captured by asking participants to propose novel insights or generate new ideas for features that could enhance their notation system or reformulate it.

5.2.4. Redefining Pre-existing Problems (Task 4/5)

The fourth task asked participants to reflect on whether they had reconsidered the design objectives originally identified in Task 1/5, after further interaction with the PUX Explorer and Matrix tools. The intention of this task was to investigate the problem reformulation process as described in literature on design co-evolution (Crilly, 2021b, 2021a).

5.2.5. Comparing PUX Explorer and PUX Matrix (Task 5/5)

The final task asked participants to directly compare the effectiveness of PUX Explorer and PUX Matrix in the previous tasks. The participants were asked to rate their agreement with statements regarding each tool's effectiveness in confirming known issues and uncovering new ones, followed by an optional opportunity to provide additional feedback on their experiences with both tools.

6. Study Results

Six specialist music notation researchers completed an 80-minute session between January to March 2024. Due to the small sample size, we report means and medians as indicators of user preference.

6.1. Identifying pre-existing problems (Task 1/5)

The most common problematic activities identified were *Modification (CA3)*, *Search (IA1)*, and *Sense-making (IA3)*, as shown in Figure 6. Concurrently, Figure 5 elaborates on these results by highlighting the experiences most frequently mentioned by participants. The experiences ranked as most important include *Being able to see relationships between parts (SE1)*, *Being able to change your mind easily*

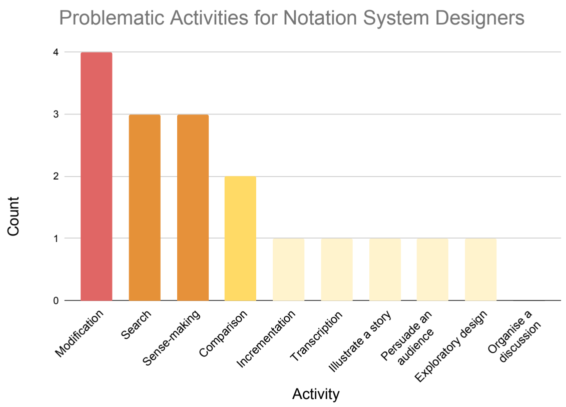

Figure 6 – Pre-existing problematic activities

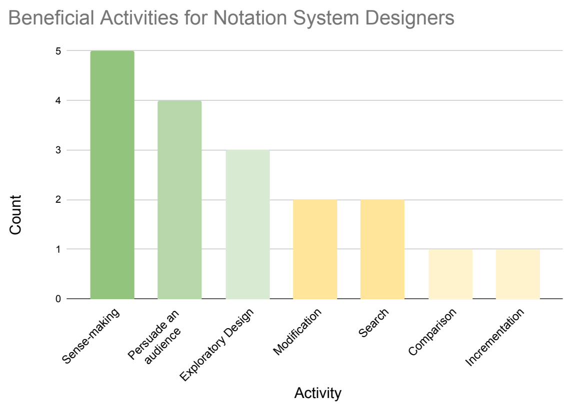

Figure 7 – Pre-existing beneficial activities

(SE2), and *Not needing to think too hard (TE1)*.

6.2. Identifying pre-existing benefits (Task 2/5)

The most commonly cited activities benefitting from the notation systems were *Sense-making (IA1)* and *Persuading an audience (SA3)*, as shown in Figure 7. Participants identified the most important experiences as *Being able to change one's mind easily (SE2)*, *Being able to compare and contrast different parts (SE4)*, and notation system elements *looking like what they describe (ME1)*.

6.3. Identifying new design opportunities (Task 3/5)

Three of the six participants provided examples of new UX patterns that they had identified. However, when asked whether the tools had helped to identify new issues, Likert scale responses were mixed (using a 5-point scale: 1. Strongly Disagree, 2. Disagree, 3. Neutral, 4. Agree, 5. Strongly Agree). The Matrix tool had a mean rating of 2.2 (median 1.5), and the Explorer tool had a mean rating of 2.8 (median 2.5), indicating a neutral to negative view on the use of these tools to identify new issues with the existing notation systems.

6.4. Redefining pre-existing problems (co-evolution) (Task 4/5)

When participants were asked if they had considered reformulating the changes they planned to make, 3 out of 6 participants agreed they were considering reformulating the changes listed in Task (1/5). Both Explorer and Matrix users indicated that they somewhat considered reformulating the changes (mean 3.2, median 4). However, when asked if the PUX framework assisted in the reformulation process, Explorer users responded more positively (mean 3.8, median 4) than Matrix users (mean 3.2, median 4).

When combining responses to tasks 3 and 4, we found that 5 out of 6 participants agreed that they had either reformulated the problem or discovered new issues. Two participants reported reformulating, two reported new discoveries, and one participant did both. We consider these reports further in the discussion section below.

6.5. Tool preference results (Task 5/5)

We found a strong preference for the Explorer tool over the Matrix, both in terms of identifying existing issues with the design, as well as uncovering new ones. For confirming existing issues, PUX Explorer had a mean of 3.8 and a median of 4, compared to the PUX Matrix's mean of 2.5 and median of 2. For uncovering new issues, PUX Explorer scored a mean of 4 with a median of 4, whereas PUX Matrix scored a mean of 2.25 and a median of 2. These results are detailed in Figure 8.

7. Discussion

Overall, Likert scale responses indicated a generally positive assessment of PUX Explorer and a neutral attitude to the PUX Matrix tool; however, the different affordances of the two tools within the design process, particularly in supporting design co-evolution, offer interesting insights.

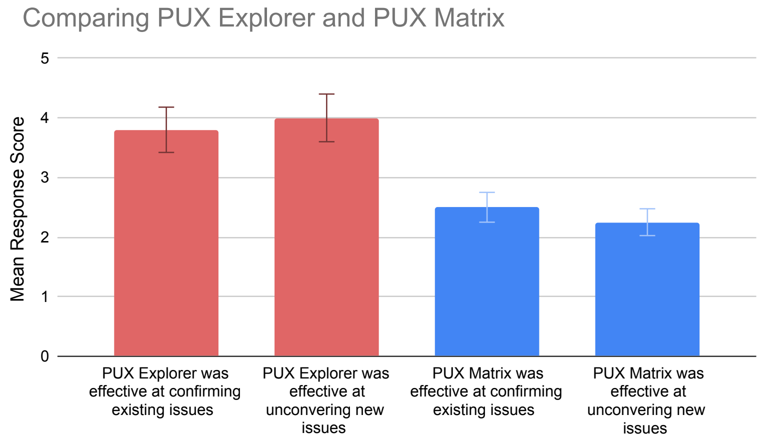

Figure 8 – The Explorer tool was preferred over the Matrix. The y-axis describes the average Likert score.

7.1. Preference for the PUX Explorer

Study data shows that both tools were effective in their use for notation designers with multiple positive comments preferring PUX Explorer.

Our initial expectation was that a more dynamic, interactive and visually engaging tool would be more appealing than a static matrix approach to visualising the PUX framework. The findings generally suggest that this was the case, as directly echoed by the study participants, e.g., P0A: *"PUX Explorer provides far more interactive exploration than PUX Matrix [and] engaged to discover more"*, and P2A: *"I think the PUX Explorer provides a more visually appealing experience"*, *"easier to navigate"* than the Matrix.

The PUX Explorer was perceived as engaging — P7B stated *"I like very much PUX Explorer, love dwelling into it"* and *"I find PUX Explorer more useful and fun and easier to use"*. P2B agreed *"the PUX Explorer provides a more visually appealing experience and one that is easier to navigate."*

In contrast, P7B reported *"[The PUX Matrix] table is too difficult for me to read, I prefer looking at the Explorer tool directly"*, and that they had *"some difficulties reading and grasping PUX Matrix"*, because it was *"difficult to read, and the need to move head, find alignments, etc."*, and additionally problematic because *"the concepts are not explained"* as in the PUX Explorer tool.

Nevertheless, beneficial aspects of the Matrix were identified — P4B stated that *"whereas the Explorer tool is more appealing and easy to navigate initially, once the Matrix has been used for a while it becomes more useful"*. This suggests that after familiarity with the PUX framework has been acquired, the Matrix can be a quick reference tool, as P4B later stated: *"when I did more detailed analyses I tended to revert to the Matrix"*.

Overall, the Explorer tool was considered superior for uncovering new issues and confirming existing design problems. We feel this is encouraging for further investigation of the PUX Personas tool, which is derived from that interaction approach.

7.2. Interaction Design of the PUX Explorer

The PUX Explorer was designed specifically to offer a dynamic experience, in which an overview map of the whole framework can be dynamically explored by mousing over different parts, with live animations drawing attention to the structural relationships. An essential interaction feature was the ability to "lock" the visualisation to zoom in and give more careful consideration to a specific pattern. This design strategy was generally effective — as P0A put it *"PUX Explorer provides far more interactive exploration than PUX Matrix, which kept me engaged to discover more."*

However, this approach was not universally liked. P1A noted that *“The icons were too small to be visually useful [...] The quick “jittery” response of the tool meant that very complex information shifted quickly before I could really process it [...] It took a while to understand the benefit of LOCK and UNLOCK in this regard!”*. P4B was concerned that *"In Explorer things disappear and this makes the Matrix more systematic"*, realising only later that they had forgotten to use the lock function.

While the dynamic exploratory animation was generally appreciated, with overall preference for the PUX Explorer, trade-offs resulting from our design decisions were apparent. P4B suggested that after a while, they started preferring the Matrix tool: *”PUX Matrix was just as good as Explorer after a while”*, even suggesting a preference over the Explorer: *”after a while Matrix becomes easier”*.

Overall, these results suggest that the exploratory aspect of the PUX Explorer tool —- characterised by its engaging, non-committal nature and the ability to reveal different insights upon reexamination -— may not be necessary for those who are more familiar with an analytic framework. The problems experienced by the participant who forgot the essential lock functionality illustrates the dangers of dynamic exploratory applications in contrast to more structured guided experiences.

7.3. Notation design insights

In addition to our evaluation of the meta-design tools PUX Explorer and PUX Matrix, this study also offers some insights into future opportunities for novel music notation design, with certain notational activities seen as being especially salient in this domain.

For instance, *Modification (CA3)* was ranked as the most problematic and the fourth most beneficial activity. Similarly, *Search (IA1)* was the second most problematic and the fifth most beneficial. Most notably, *Sense-making (IA3)* was identified as the most beneficial activity, yet also the third most problematic (Figures 6 and 7).

The way in which the PUX framework draws the attention of notation designers toward the specific priorities of their own domain, with both negative and positive implications, seems especially useful. We observed similar trends in considering specific experience patterns, for example with *You can change your mind easily (SE2)* appearing on both the problematic and beneficial lists. It is notable that this corresponds to the first-recognised Cognitive Dimension of *viscosity* (Green, 1990), and that we also observed the early tradeoff between CDs of viscosity and *hidden dependencies* (coded as SE1 in PUX).

Overall, we found that activities were highlighted in relation to a variety of usage contexts for music notation, including Interpretation, Construction, and Social activities. This showcases the versatility of the PUX framework and its ability to accommodate a diverse range of notation uses. However, we note that our emphasis on meta-design highlights the designers’ own expectations of what users of their systems need, and that this may not necessarily align with the end-users’ actual experiences. Use of PUX Explorer or PUX Matrix in a co-design setting, where notation meta-designers and notation users might collaborate to identify priorities and design opportunities, is an interesting area for future investigation.

7.4. Problem-solution reformulation

The structure of our study explicitly reflected a co-evolution perspective on the meta-design of notational systems. According to this perspective, analytic tools such as PUX Explorer can assist designers in reformulating their problems as well as finding solutions.

As reported in the results section, half of our participants identified new elements to add to their system after using the tool, and half agreed that the tools were useful in problem reformulation, but these were not the same individuals. Furthermore, some participants did correctly identify new issues yet later reported that they had not done so.

This draws attention to an important consideration in co-evolutionary design work — the phenomenon of design fixation, in which it may be hard to step away from an existing problem, especially if a potential solution has been identified (Crilly, 2015) has occurred.

The participant who was most sceptical about the value of PUX Explorer (P1A) reflected on the challenge of achieving new creative insight while focusing on the specifics of their design, being *"somewhat overwhelmed with information at a fine-grained level [...] I'm not sure how either tool, in its current form, would be directly useful at the MOMENT that I tend to develop a new notational strategy"*. P1A did explicitly recognise the potential for design fixation: *"but this may be a bias of the fact that I am a practitioner with an already firmly established notational "style" and process"*.

Overall, these observations point to the ways that meta-design problems such as the creation of new music notation systems do share the characteristics of other more routine design domains, bringing potential for innovative solutions through co-evolution of problem and solution spaces, yet also subject to well-known obstacles such as design fixation. As with the design of completely novel programming tools and other kinds of visual language, the design of completely novel music notations is undertaken only by a relatively small number of people in the world. The practices of such meta-designers can be idiosyncratic, with significant divergence between individuals, making it challenging to generalise to every member of such a small population. Nevertheless, our study has found the PUX tools to be accessible as an approach to the meta-design of notational systems, able to be applied by people having no specialist technical expertise in visual language technologies.

8. Conclusions

We have presented the PUX Explorer, complemented by the PUX Matrix and PUX Personas, all of which are meta-design tools intended for use by the designers of new visual languages and other notational systems. We have related these tools to the historical development of critical frameworks for notation design, motivated by a recent general theory of design ideation that has motivated this new approach to meta-design.

As an initial evaluation of the tools, we conducted a controlled study in meta-design. To allow comparison to previous work, we recruited the designers of new music notations, since this notation domain had previously been used to demonstrate and evaluate the original Cognitive Dimensions Questionnaire.

Our study finds that the PUX Explorer is accessible to meta-designers who do not have extensive technical expertise, and who are encountering a critical framework for notation design for the first time. Our controlled comparison between the PUX Explorer and PUX Matrix demonstrates the relative advantages of these approaches, and also provides evidence that the Explorer interaction paradigm is an effective approach to deployment of meta-design tools.

We have also introduced the PUX Persona tool, which is designed for use in longer-term practical design projects beyond controlled laboratory evaluation. PUX Persona provides a principled basis for identifying, weighting, and quantifying the consequences of alternative design decisions. In ongoing work, we are applying these meta-design tools to a wide range of programming language, software engineering, and data visualisation projects in our own organisation and elsewhere.

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A. PUX Explorer

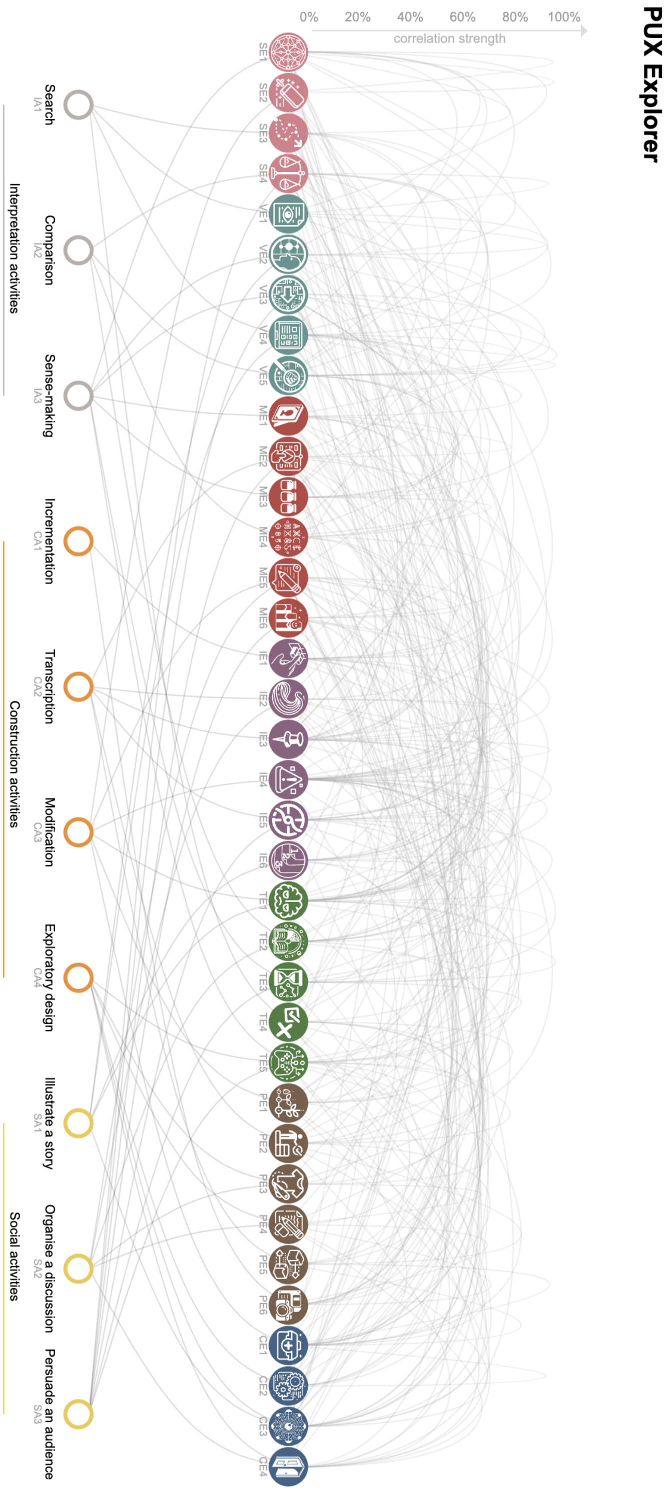
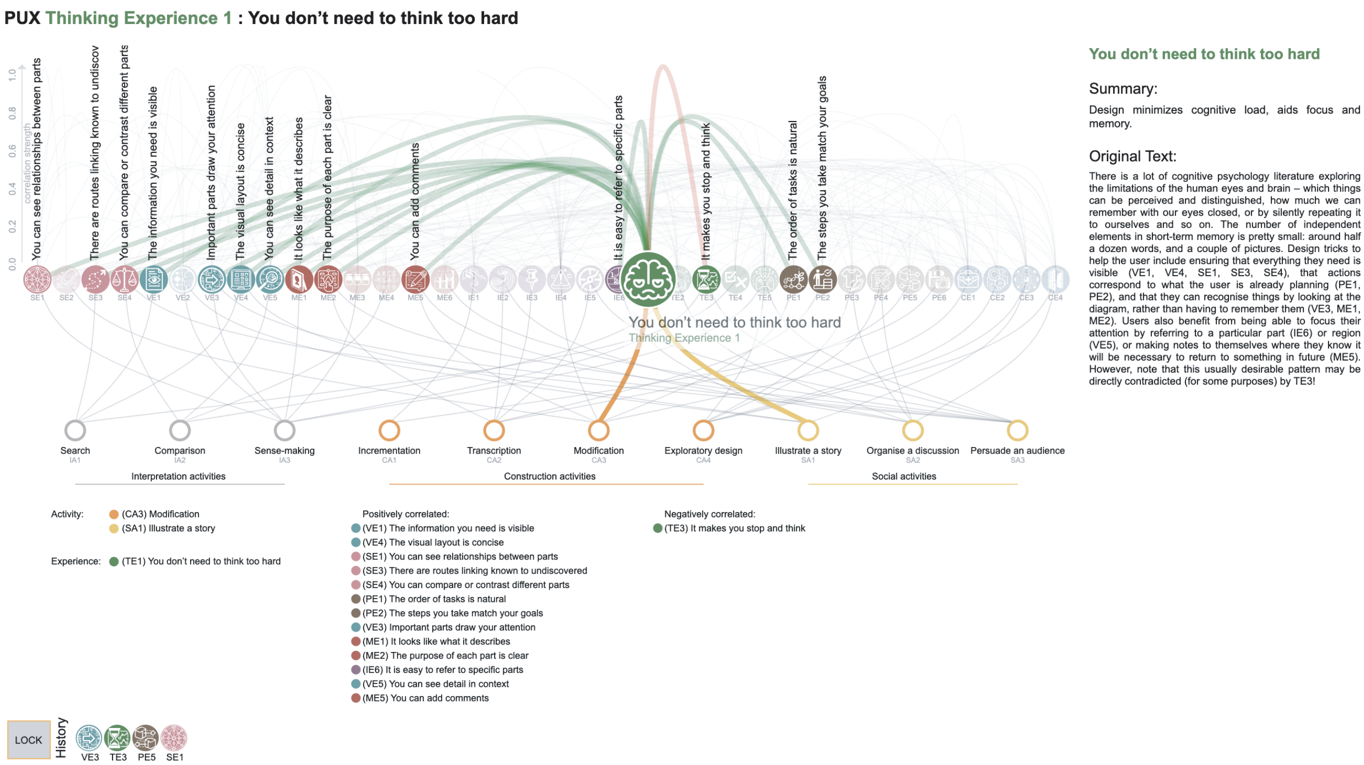
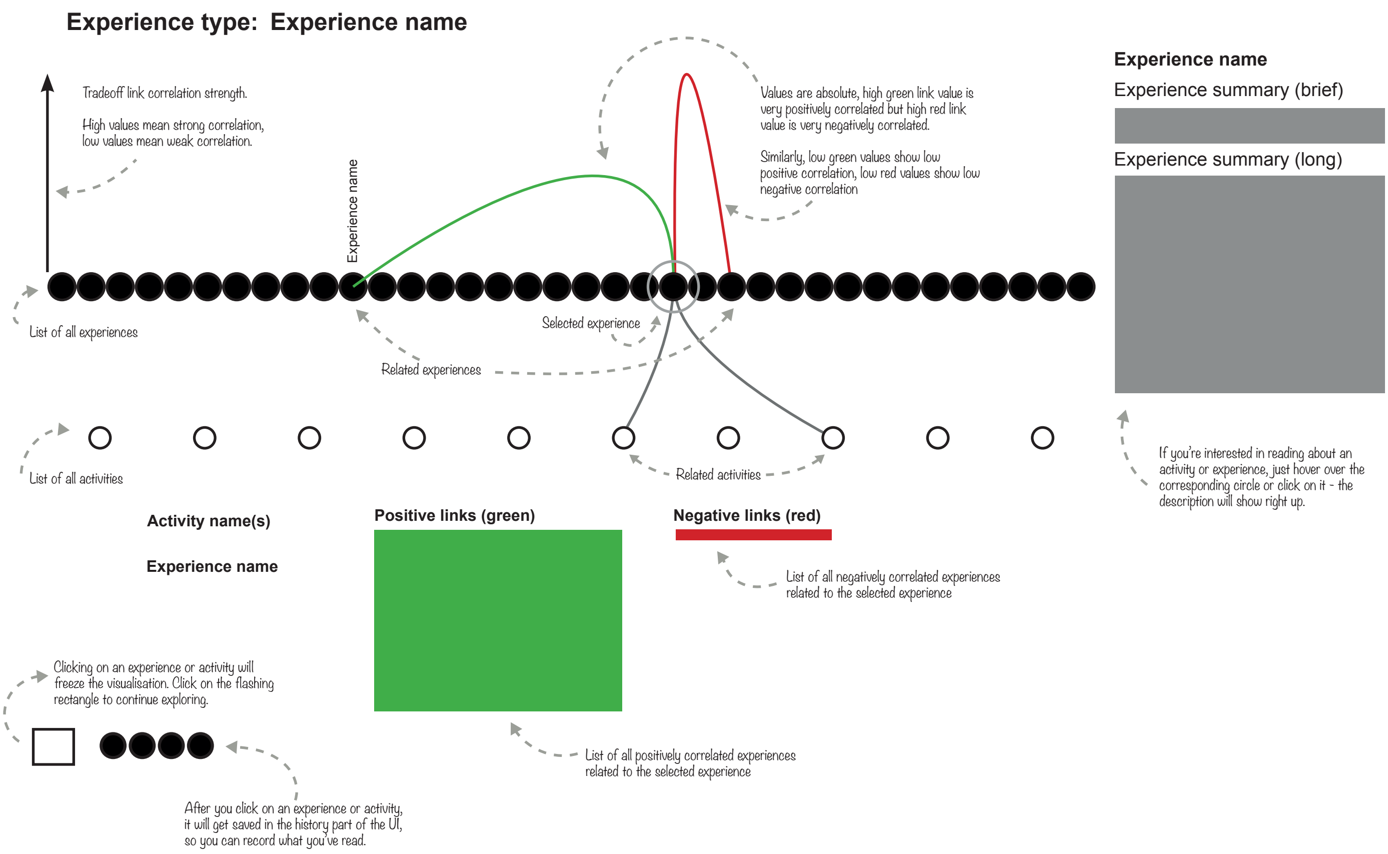


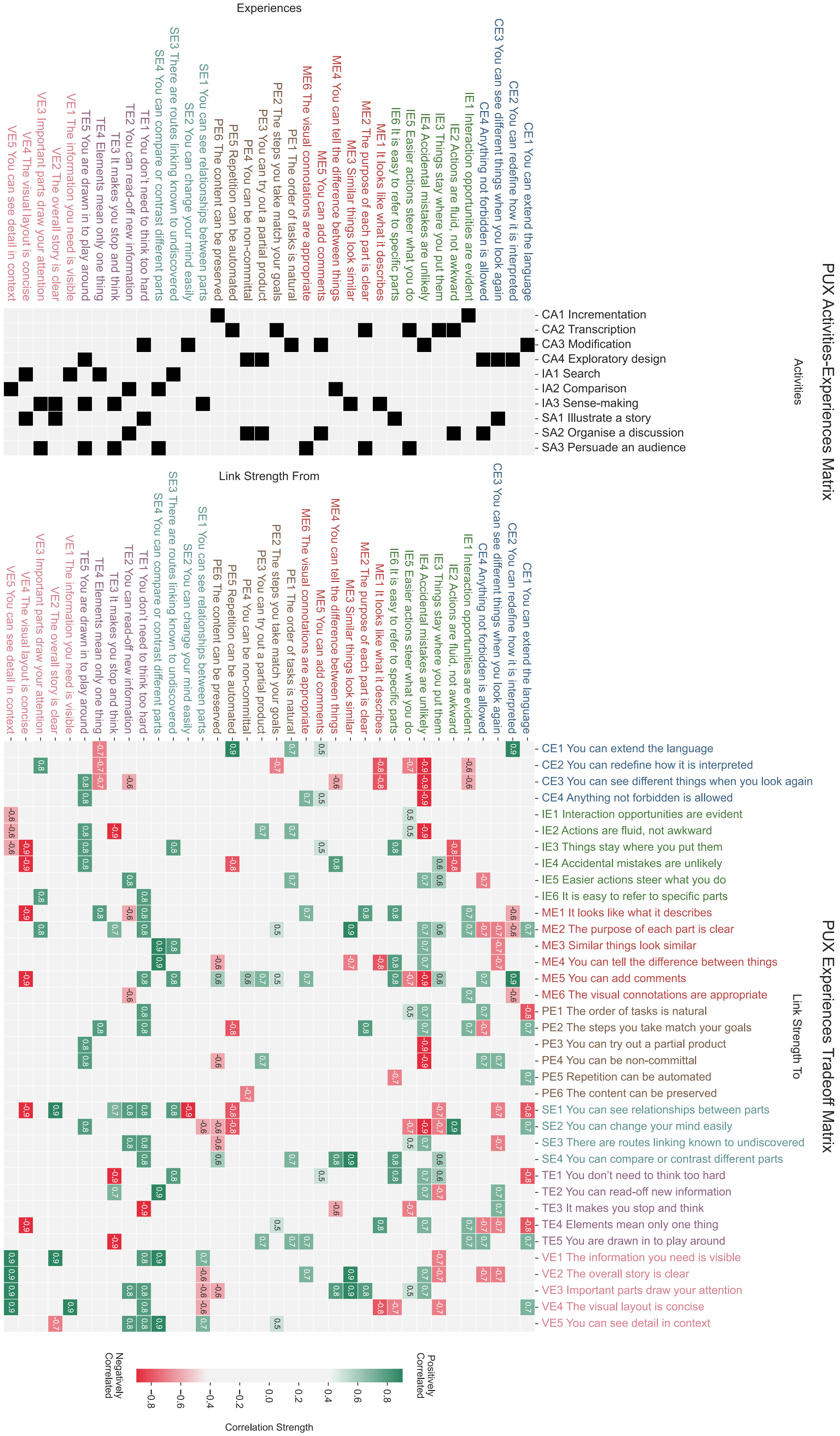
Figure 9 – PUX Explorer on startup with no experiences or activities selected. The top row of circles represents 36 unique experiences and the bottom row represents 10 unique activities described by the PUX framework.

B. PUX Explorer Deconstructed

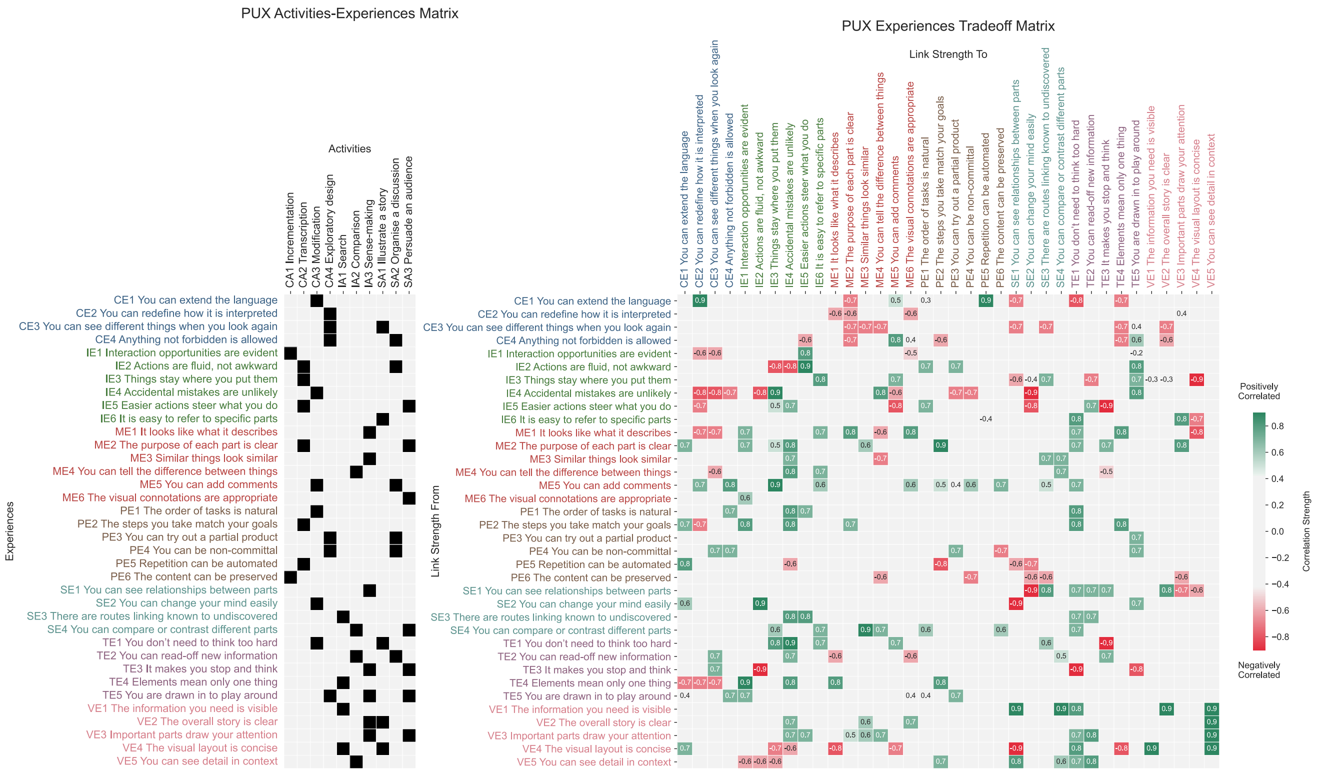


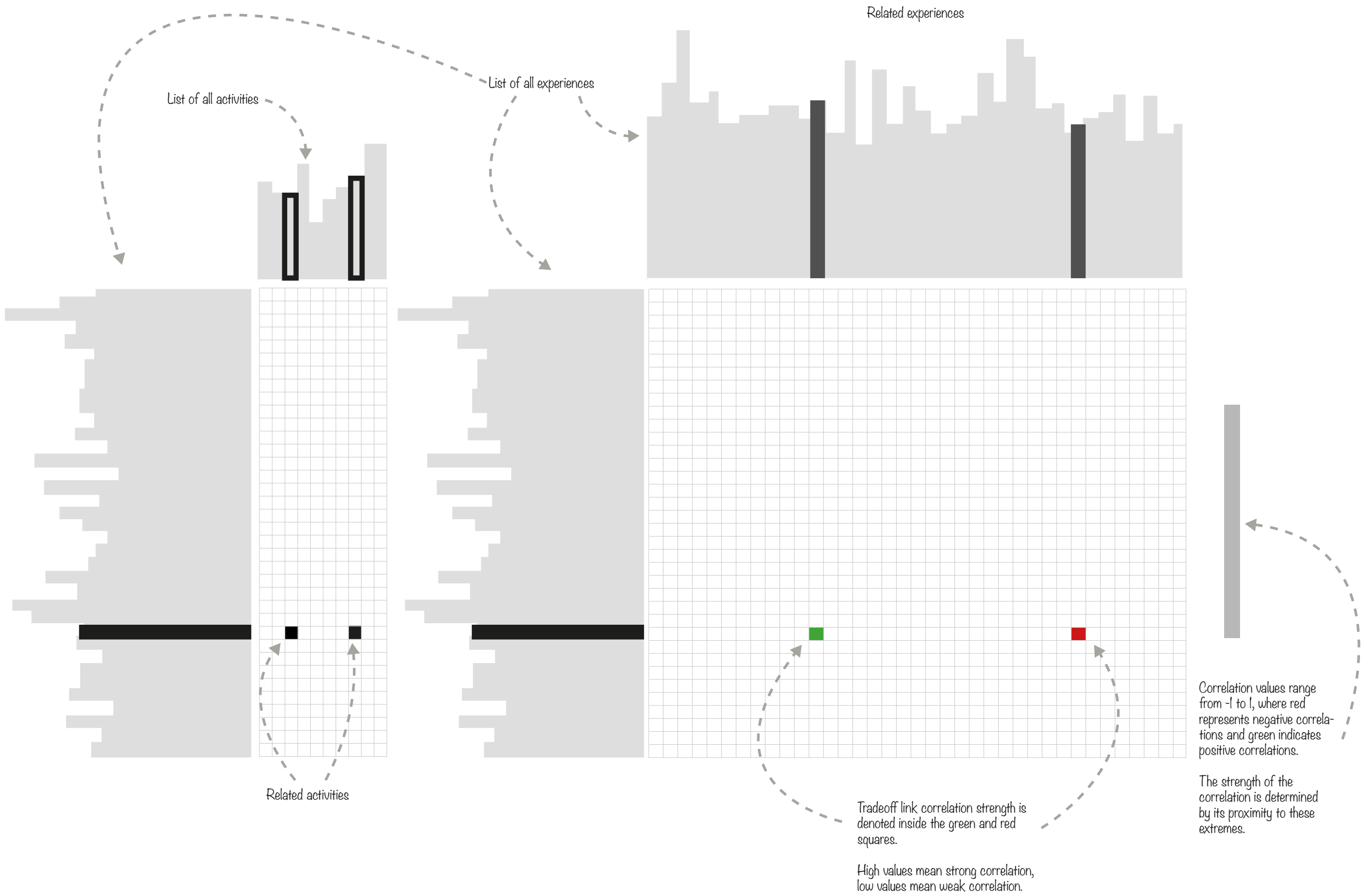


C. PUX Matrix


PUX Activities-Experiences Matrix
Experiences
Activities
CA1 Incrementation
CA2 Transcription
CA3 Modification
CA4 Exploratory design
IA1 Search
IA2 Comparison
IA3 Sense-making
SA1 Illustrate a story
SA2 Organise a discussion
SA3 Persuade an audience
PUX Experiences Tradeoff Matrix
Link Strength From
Link Strength To
CE1 You can extend the language
CE2 You can redefine how it is interpreted
CE3 You can see different things when you look again
CE4 Anything not forbidden is allowed
IE1 Interaction opportunities are evident
IE2 Actions are fluid, not awkward
IE3 Things stay where you put them
IE4 Accidental mistakes are unlikely
IE5 Easier actions steer what you do
IE6 It is easy to refer to specific parts
ME1 It looks like what it describes
ME2 The purpose of each part is clear
ME3 Similar things look similar
ME4 You can tell the difference between things
ME5 You can add comments
ME6 The visual connotations are appropriate
PE1 The order of tasks is natural
PE2 The steps you take match your goals
PE3 You can try out a partial product
PE4 You can be non-committal
PE5 Repetition can be automated
PE6 The content can be preserved
SE1 You can see relationships between parts
SE2 You can change your mind easily
SE3 There are routes linking known to undiscovered
SE4 You can compare or contrast different parts
TE1 You don't need to think too hard
TE2 You can read-off new information
TE3 It makes you stop and think
TE4 Elements mean only one thing
TE5 You are drawn in to play around
VE1 The information you need is visible
VE2 The overall story is clear
VE3 Important parts draw your attention
VE4 The visual layout is concise
VE5 You can see detail in context
Negatively Correlated
Positively Correlated
Correlation Strength
−0.8
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8

D. PUX Matrix Deconstructed





E. PUX Personas

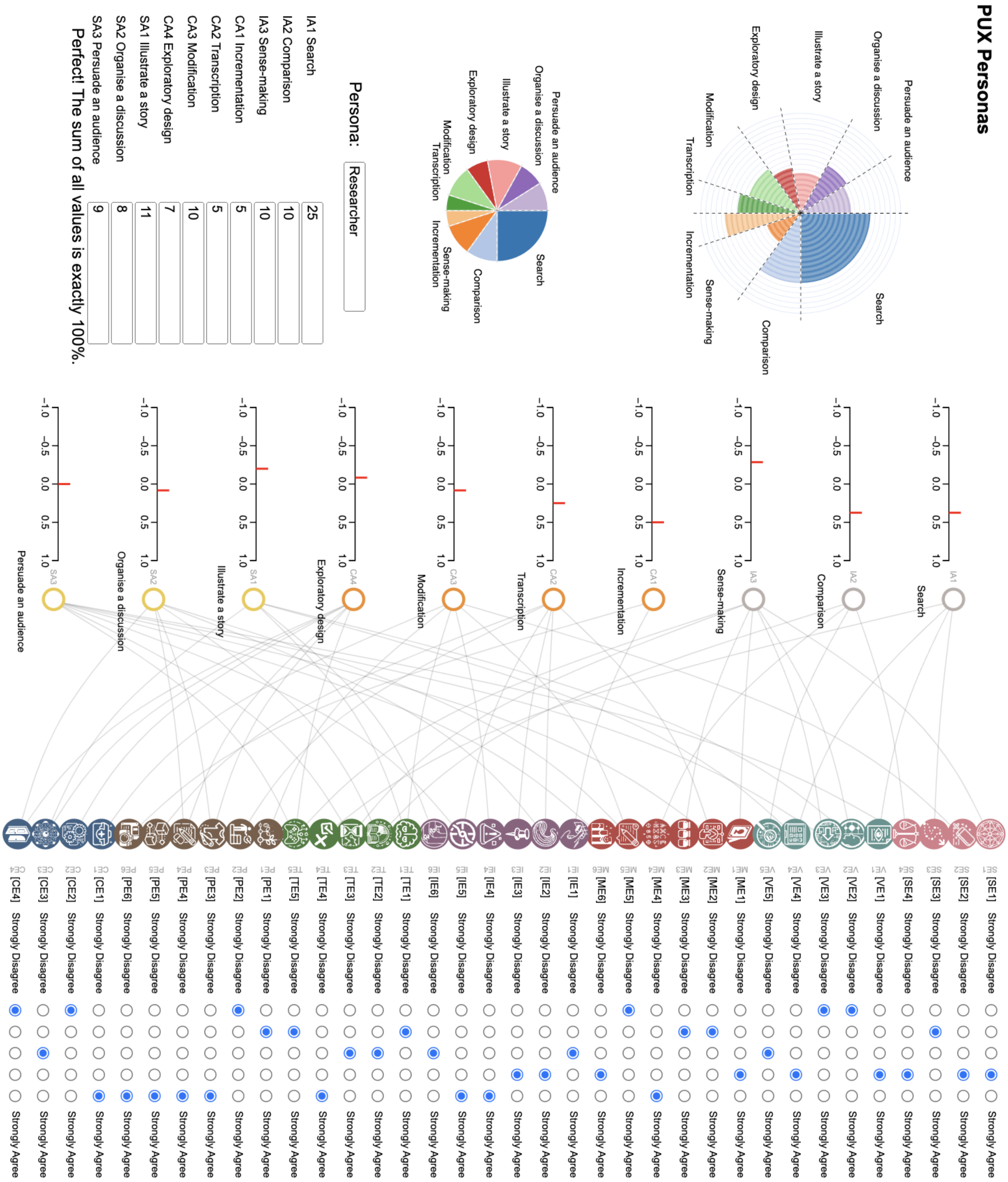


Figure 13 – PUX Personas