Learning in Parallel

Reducing Cognitive Load with Visual Emphasis on XAI

Ivan Orozco Vasquez

1. Introduction

Constraint Satisfaction Problems (CSPs) are a fundamental concept in the field of Artificial Intelligence, particularly in courses like CPSC 322 Introduction to AI. These problems require assigning values to variables while satisfying a set of constraints, a task that can be challenging for students to grasp. To address this, educational tools like the CSP Applet and its AI-enhanced version, the ACSP Applet, have been developed to provide students with interactive learning experiences.

The ACSP Applet represents a significant advancement in educational technology by incorporating Explainable AI (XAI) principles. This integration allows the applet to not only provide hints to students but also explain the reasoning behind these suggestions, offering a transparent view of the AI's decision-making process. This level of explanation transforms the applet into an XAI system, enhancing its educational value. This work adds to the field of XAI in Education as it builds upon an already established XAI applet, while also employing principles of psychology to perform these adaptations.

As a student who has firsthand experience with the applet in CPSC 322, I recognize the potential for improvement in how students interact with and learn from this tool. The primary goal of this paper is to explore methods to optimize the applet's interface and functionality, focusing on reducing cognitive load and improving the effectiveness of the Explanation Interface.

2.1 What is Cognitive Load Theory (CLT)?

Cognitive Load Theory (CLT) could provide a crucial framework for understanding how students process and retain information, particularly in complex domains like Constraint Satisfaction Problems (CSPs). CLT suggests that our working memory has limited capacity, and effective learning might occur when we optimize the use of this cognitive resource. In the context of the ACSP Applet, applying CLT principles could potentially enhance student learning experiences. By implementing strategies such as greying out less critical information, segmenting content, and using simplified displays like ratios instead of complex mathematical descriptions, we may be able to reduce extraneous cognitive load and allow students to focus on the essential aspects of CSPs

This approach could align with research suggesting that explanations in AI education should be tailored to match users' cognitive capacities, especially for those struggling with the material. Furthermore, the iterative access to explanations, as implemented in the ACSP Applet's hint system, might strike a balance between providing comprehensive information and avoiding overwhelming students

The structured presentation format, including visual cues like greying out repeated information, could potentially aid in promoting a macrostructural understanding of the content, allowing students to more effectively integrate new information with their existing knowledge. By carefully applying these CLT-informed design principles, the ACSP Applet aims to create an optimal learning environment where students might grasp complex CSP concepts without unnecessary cognitive strain. When interacting with educational applets, we want to ensure that the applet itself is helping the student rather than being another point to learn about.

2.2 ACSP Applet

The ACSP Applet was briefly mentioned earlier. It is the tool upon which the work I performed is. Applet has the main screen which displays a CSP as well as a set of options at the top left as seen in Fig. 1a below. These include Fine Step which can either perform a single step in solving the CSP, Auto Arc-Consistency which solves the problem for the student, Stop which stops the Auto Arc-Consistency, BackTrack which returns the state of the CSP to as it was previously and Reset which will return the problem to its beginning state.

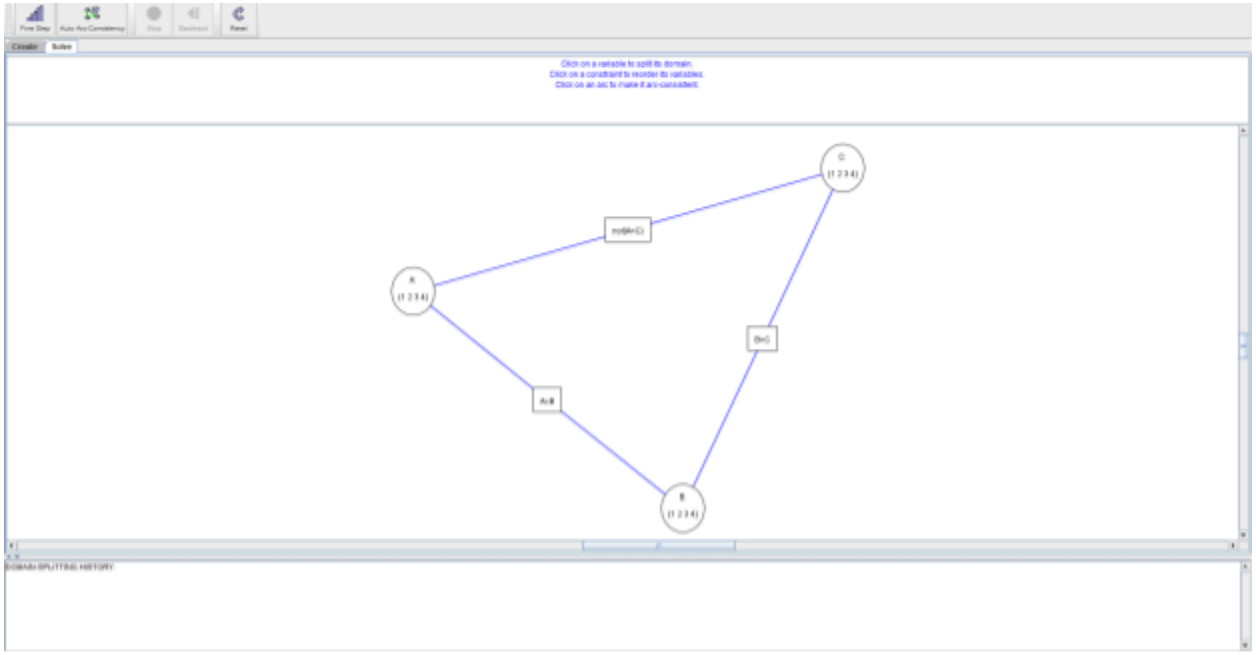

Fig 1a. ACSP Applet When First Opened

All of these tools have underlying rules related to behaviour we would like to encourage or discourage from the students. The rules are divided into 2 categories: lower learning and higher learning. Lower learning is behaviour that we are trying to discourage such as having the problem auto-solved. Higher learning is behaviour we want to promote such as pausing after performing an action so students can reflect on what they have done and what steps they could take. Once enough lower learning rules have been satisfied by the user a hint will pop up that proposes a hint accompanied by a button labelled “Why Am I Delivered this Hint” as seen in Fig 1b.

Fig 1b. ACSP Applet with Hint

Once clicking on this button the previously mentioned Explanation Interface (Fig 1c) will be displayed where students can see the following explanations:

1. Why am I delivered this hint?
2. Why am I predicted to be lower learning?
3. Why are the rules used for classification?

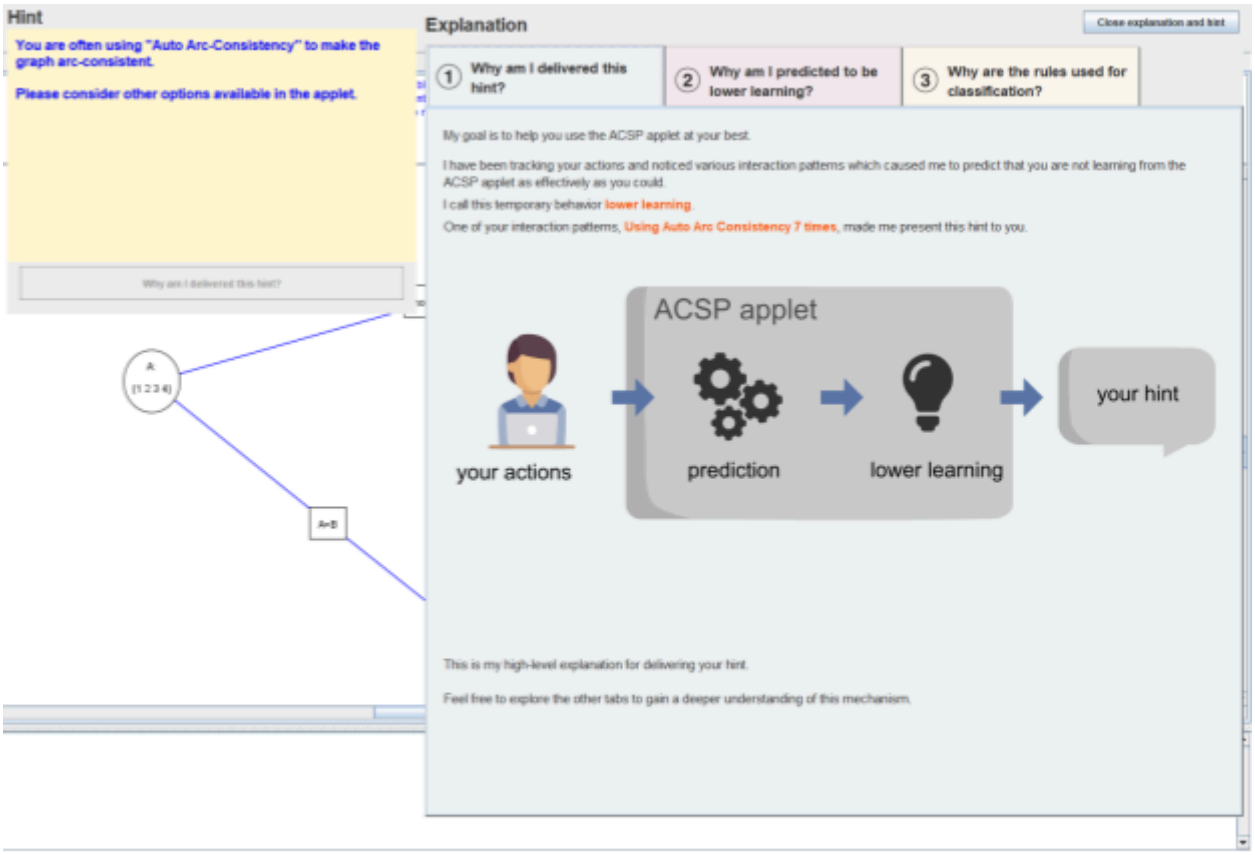

Fig 1c. ACSP Applet with Hint and Explanation Interface

During the appearance of follow-up hints, be they different hints or the same hint the text and the layout of each page of the Explanation Interface will be changed to reflect knowledge of the previous hint, making the applet seem more like a tutor and a student rather than a tool with no memory of any instance but the current one. The changes per page are labelled the number of hints, with Level 1 being the first time this hint is displayed and Level 2 being the second time this hint appears and so on in the same pattern. For example, First Level-1-Hint is the first time that this first hint has appeared, while First Level-2-Hint is the second time that this specific hint has been displayed to the user. This pattern repeats for all hints and can be visualized in Fig. 2. Where, as previously mentioned rules depend on the lower learning behaviour of users, which triggers the transition between hints. In the context of Fig. 2, LL means lower learning.

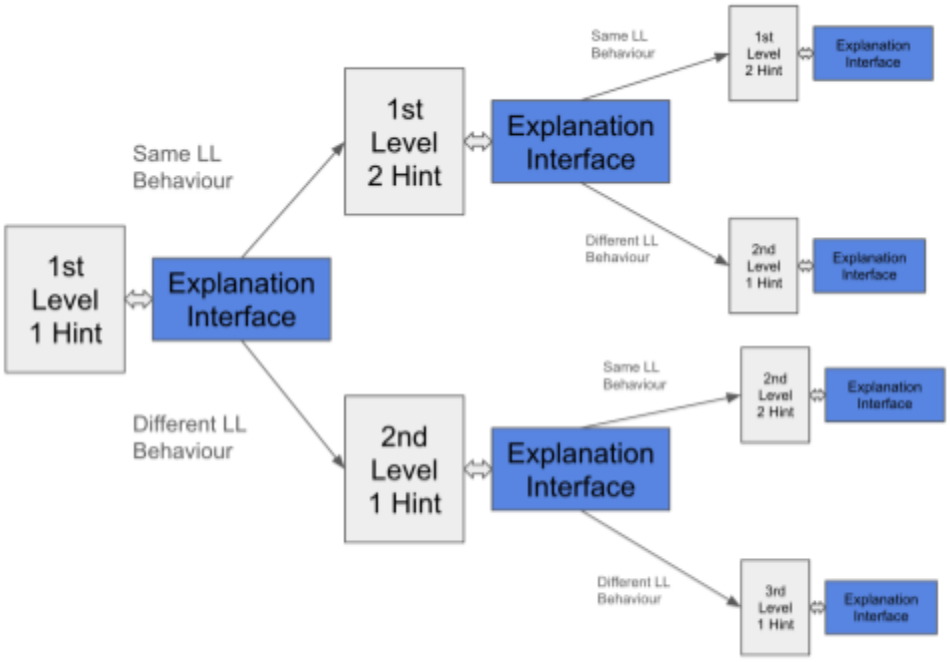

Fig 2. Visualization of Hint Transition

3. Methods

The work done is to reduce the cognitive load of the information in the Explanation Interface for students. To achieve this goal I employed 4 main guiding principles that were changes applied throughout the entirety of the Explanation Interface rather than to one single page. These include:

- Greying Out
- Segmentation
- Grouping
- Rephrasing

3.1 Greying Out

The first principle, Greying Out functions as a visual signifier to students that this information is repeated. As previously established, the text of the Explanation Interface will change depending on the hint number and hint level. To minimize cognitive load, text that hasn't changed between iterations and is simply expository is greyed out. In contrast, text that directs the user or navigational text is not greyed out even if it doesn't change since we don't know when users will want to utilize the buttons, so the text related to the figure must be also visible as they both are part of the same idea. Greying Out is to show students that this information is repeated and that if they understood it, they are free to disregard it. At its base, the purpose is to enable students to quickly identify and focus on new information, facilitating faster assimilation and understanding.

3.2 Segmentation

Our second guiding principle, Segmentation works to break down text to facilitate information comprehension. In two separate works, Liu (2024) and Lemarié et al. (2008) show that breaking text into smaller chunks enhances comprehension. This provides backing for our decision to segment chunks of text that could be difficult to understand. This principle also pairs well with our Greying Out guiding principle as it allows us to grey out entire lines of text rather than greying out portions of a paragraph, which could be more distracting and confusing. This would be counterproductive to our principles and our goal.

3.3 Grouping

The third guiding principle employed was Grouping. This principle emerged due to the Segmentation principle. Information that was previously displayed as a paragraph has now been separated. With information as a paragraph, it was easy to see what information was directly related to each other. Now we attempt to achieve the same textual interrelation by grouping text that is relevant to each other by reducing the spacing between it while increasing that of text that is unrelated. Close spatial proximity aids integration tasks, while distant proximity reduces confusion in independent tasks (Dickens & Melody, 1995). Not only this but the relationship between images or buttons and text is also tackled through grouping. Learning from mutually related text and pictures is more successful when the text is displayed near the corresponding area of the image rather than when text and pictures are placed at geographically separate positions (Bayraktar et al., 2022).

3.4 Rephrasing

Our final guiding principle is Rephrasing. This more general principle functions to edit text that in retrospect, is too lengthy, awkward or roundabout, all of which serve to increase cognitive load, thus reducing comprehension. The decision to change the length of words stems from Rayner et al. (2011) as they found that "longer words require more focus during reading, while more predictable words are read faster, indicating that word length and predictability independently affect reading patterns." Not only this, but sentence length is also reduced. This is done as shorter sentences improve comprehension in areas like informed consent forms, patient education, and clinical trials (Matthews & Folly, 2023). Readability sets the stage for comprehension, which depends on reader-text interactions.

4. Implementations

4.1 Changes to Why Page 1:

First Level-1-Hint

Building off of the version by Bahel (2024), page 1 undertook multiple changes to all iterations. All follow-up hint iterations keep the layout changes that take place in the First Level-1-Hint. In Fig 3 in the

Appendix, we can see the previous version as well as the new iteration First Level-1-Hint**.** The text was split into distinct lines to enhance information processing and reduce cognitive load as per our Segmentation guiding principle. Based on our Segmentation and Grouping principles, we segment the paragraph as well as place the sentences most relevant to each other in close proximity. These are all texts that were once paragraphs so we want to make sure that there is some communication to the student that these belong together. Aside from this, throughout the entire applet, any diagram that included the word "interaction data" was changed to "actions" for consistency with the top text “I have been tracking your actions”.

First Level-2-Hint

To get to First Level-2-Hint, students would have seen the information from First Level-1-Hint as seen in Fig. 4 in the Appendix**.** Based on our greying out principle, we can reduce visual strain on the user by de-emphasizing expository unchanging text at the bottom. There are changes to all other information so the applet demonstrates some form of knowledge of changes of iteration.

Second Level-1-Hint

Second Level-1-Hint seen in Fig. 5 in the Appendix, students would be in the same situation as First Level-2-Hint since we can’t assume that the student didn’t see the same hint twice. Based on our greying out principle, we can reduce visual strain on the user by de-emphasizing expository unchanging text at the bottom. There are changes to all other information just as in First Level-2-Hint that reference previous iterations.

Subsequent Level-1-Hint

Finally, the Subsequent Level-1-Hint seen in Fig. 6 in the Appendix will build off of the same text as the Second Level-1-Hint and considering that students have seen this previously, we can now Grey out most of the text as it is unchanging expository text.

4.2 Changes to Why Page 2:

Why Page 2 has 3 sub-pages:

- How was my score computed?
    - We will refer to this as How computed.
- How was my hint chosen?
    - We will refer to this as How chosen.
- How was my hint’s rank calculated?
    - We will refer to this as How calculated.

First Level-1-Hint

Due to the density of text on Fig. 7 in the Appendix, we are required to very carefully employ our segmentation and grouping principles. We partition every paragraph into individual lines of text and lines that were once paragraphs are placed closer together, while lines that deal with separate ideas are more

apart. We also reorganize some information into bullet points as another form of segmentation. Aside from this, moving the button located on the far right closer to the text that it is referencing as well as providing a sentence that directs the user to it follows our grouping principle, thus should reduce the overall cognitive load concerning that button.

Second Level-1-Hint & First Level-2-Hint

Since there is no text difference between iterations of Second Level-1-Hint and First Level-2-Hint we can group the changes done to these pages into one section as seen in Fig. 8 in the Appendix. The segmented layout established in the First Level-1-Hint enables cleaner visual states: when text needs to be greyed out, entire segments can be de-emphasized rather than creating confusing mixed-state paragraphs. This principle is one we employ for the greying out of all unchanging expository text on this page, rather than the changing text as well as the navigational text directing users to the button.

Subsequent Level-1-Hint

In Subsequent Level-1-Hint users will have seen all the information from the previous iterations thus we can grey out the first line as it will have now become unchanging from the previous iteration. This is visualized in Fig. 9 in the Appendix.

4.3 Changes to How Score Computed?

First Level-1-Hint

Fig. 10 in the Appendix displays some mathematical information in chunks of text. This both goes against our segmentation principle and adds another layer of difficulty. Mathematical content is already more difficult to understand than simple text, thus we want to establish the best possible visualization for it. In this case, we segment and rephrase the blocks of text into fractions similar to formulas describing how every number was calculated.

All Following Hints

In all following hints, we reduce cognitive load by removing supplementary information that users have already encountered. This streamlined display helps experienced users focus on numerical changes while maintaining a cleaner interface as seen in Fig. 11 below. Users can easily review previous equations by clicking the relevant button, providing quick access to the page displayed in First Level-1-Hint.

Fig 11. Explanation Interface How Computed-All Following Hints

4.4 Changes to How was My Hint Chosen?

First Level-1-Hint

Although Fig. 12 in the Appendix contains scarce amounts of text, we implemented selective segmentation to improve readability. The content mixes unchanging expository text and navigational text requiring clear visual separation to highlight the most relevant information. The sparse layout provides sufficient space to fully separate text segments without compromising the design, allowing us to optimize the visual organization

Second Level-1-Hint & First Level-2-Hint

The segmented layout in Fig. 13 in the Appendix enables us to grey out all expository text about processes and rationale. This keeps crucial information immediately visible: current hints and navigational text that guides users to key elements and locations

All Following Hints

The greying out principle is employed the same as in Second Level-1-Hint and First Level-2-Hint with the caveat that the first line of text of Fig 14. in the Appendix is also greyed out as there isn't any further change after these.

4.5 Changes to How was My Hint's Rank Calculated?

First Level-1-Hint

The minimal text in Fig. 15 in the Appendix allows us to apply our segmentation principle to the opening sentence, separating independent concepts that were previously combined. This reinforces our approach to improve user comprehension by keeping unrelated information distinct. Following our grouping principle, we separated the expository introduction from the navigational text that precedes the list. This creates a clear distinction between information and navigational text

Second Level-1-Hint & First Level-2-Hint

The only change between these hints in Fig. 16 in the Appendix and the First Level-1-Hint is the first line of text that changes to once again demonstrate that there is some memory of previous iterations.

All Following Hints

Since the previously changed expository text from Second Level-1-Hint & First Level-2-Hint is now unchanged we can safely grey it out as we can assume students have read it before. This can be seen in Fig. 17 in the Appendix

4.6 Changes to Why page 3:

First Level-1-Hint

In this final page of the explanation interface seen in Fig. 18 of the Appendix, we notice that there aren't many large chunks of text that would justify employing dramatic changes through our guiding principle. As the original page already followed the corresponding information break up, no changes need to be made concerning the segmentation and in that case grouping. The only guiding principle we employ for this hint is rephrasing as we change the roundabout first line from "The rules represent the most prominent interaction behaviours shown by prior users who learned well from the ACSP applet and those who did not" in Fig 19a to "The rules represent the most prominent interaction behaviours shown by prior users" in Fig. 19b Rephrasing is also employed in the diagram once more. To keep consistency throughout the whole explanation interface, we changed the diagram so that it states that the input is actions instead of interaction data.

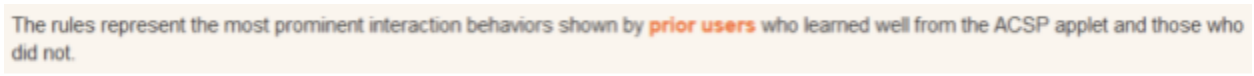

Fig 19a.

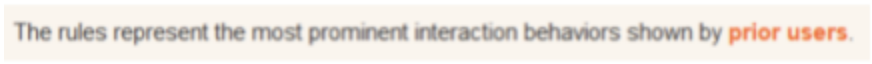

Fig 19b.

Second Level-1-Hint & First Level-2-Hint

In the case of the Second Level-1-Hint and the First Level-2-Hint, we don't make a differentiation in the text seen in Fig. 20 in the Appendix, so we can treat them as one individual page iteration. Since this text isn't dependent on which hint is present at the time it makes it solely expository information. This is especially true in this case as users getting hints multiple times have most likely viewed this page at least twice including this time. This means they are more likely to want to focus on changing and/or relevant information to their progress. Because of this, we can safely grey out almost the entirety of this page since it doesn't provide any information to the user that is relevant to tracking their improvement. The only portion not greyed out is the first line as the phrasing changed from the previous version seen in Fig. 21a to what is the first line of Fig. 21b below.

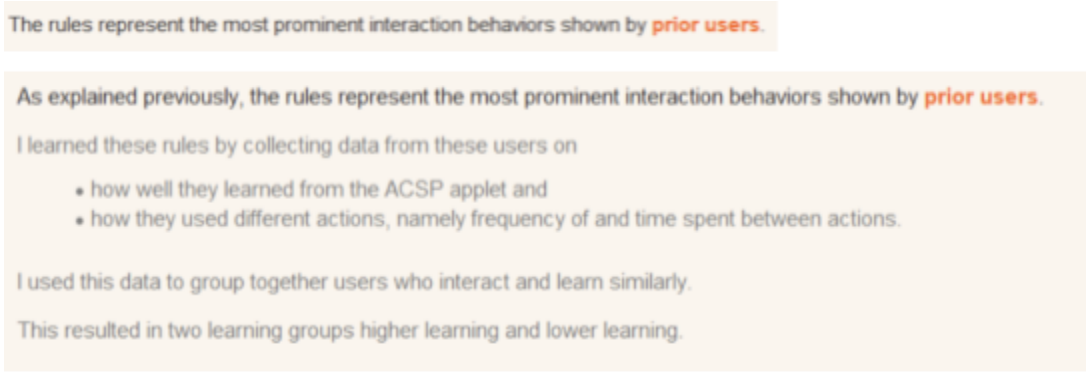

Fig. 21 a (Top) and b (Bottom)

All Following Hints

Finally, the only portion missing change would be the first line seen in the figure above. In all the following hints, we would grey out the rest of the unchanging text as exemplified in Fig. 21 in the Appendix, which would only be that line as none of the text on this page is either navigational or changed from the previous iteration.

5. Future works

The optimization of the ACSP Applet opens up paths to further grow the applet for future research and development. To verify the effectiveness of the implemented changes, user testing should be conducted on each page on a subset of the CPSC 322 as they are more likely to the be the ones exposed to this applet. The study would be focusing on the impact of greying-out techniques and the new page layouts. This will provide insights into how students interact with and perceive the new explanation interface. Further experimentation with font sizes, text length, and overall layout could lead to additional improvements in comprehension and reduction of cognitive load. Additionally, implementing tooltips in the main user interface could create visual representations of overused features, potentially guiding students toward more efficient problem-solving strategies. These tooltips could dynamically adapt based on user behaviour, offering personalized guidance and reinforcing higher learning behaviour by highlighting what is causing lower learning. By pursuing these future directions, the ACSP Applet can continue to evolve as an effective XAI educational tool, balancing cognitive load theory with an intuitive learning space.

6. Conclusion

This work has demonstrated the potential for enhancing the educational value of the ACSP Applet through the application of Cognitive Load Theory (CLT) principles and user interface optimizations. By implementing our guiding principles of greying out repetitive information, segmenting content, grouping related content, and rephrasing text, we have aimed to reduce the cognitive load on students and allow them to focus on the essential aspects of Constraint Satisfaction Problems (CSPs) rather than having them learn the applet as well.

The changes made to the Explanation Interface of the ACSP Applet represent a step towards creating a more effective and user-friendly educational tool. By carefully implementing CLT-informed decisions, we have strived to create an optimal learning environment where students can grasp CSP concepts without unnecessary cognitive strain from the applet.

This work contributes to the growing field of Explainable AI (XAI) in education by demonstrating how established AI-enhanced educational tools can be further improved through the application of psychological principles. The ACSP Applet, with its enhanced Explanation Interface, now offers a possibly more user-friendly experience, leading to improved student comprehension and engagement with CSPs.

However, this study also highlights the need for continued research and development in this field. Future work should focus on validating the effectiveness of these changes through user testing with the relevant subjects as well as testing new UI changes. These efforts will help ensure that the ACSP Applet continues to evolve as an effective educational tool, attempting to balance cognitive load management with learning.

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Appendix

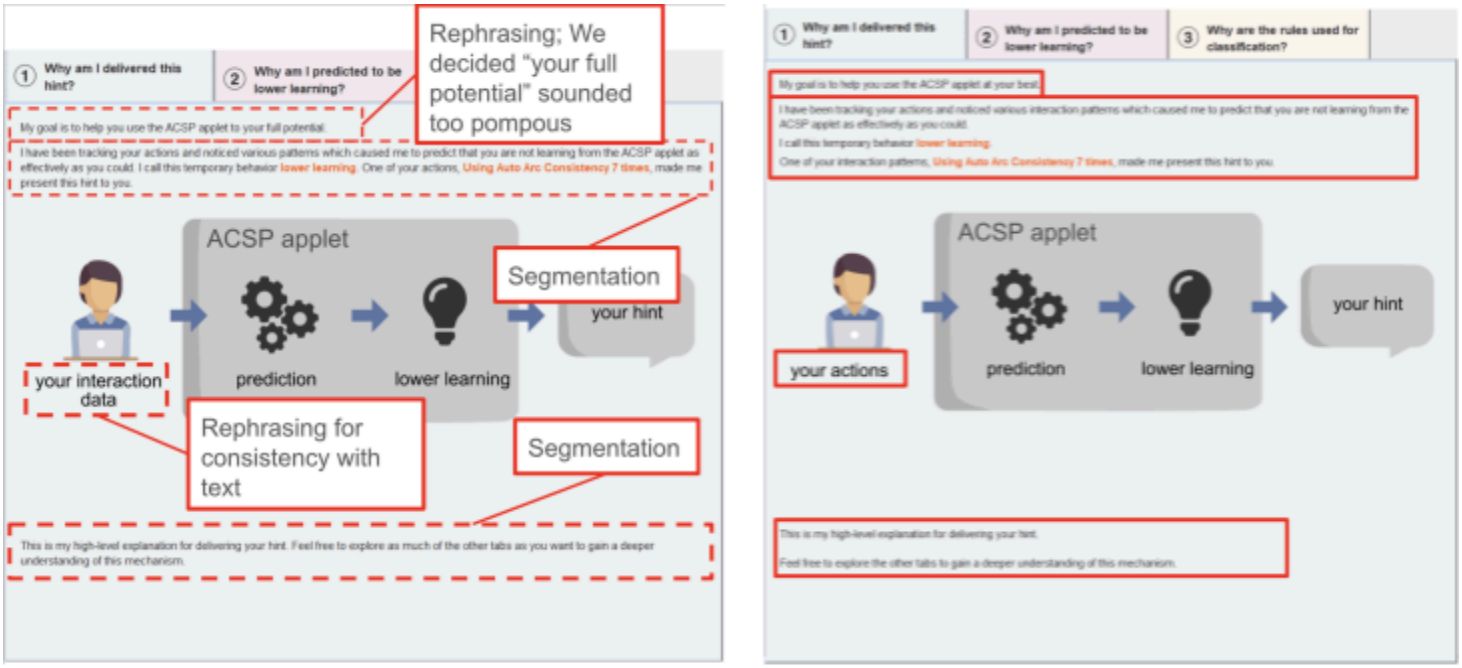


Fig 3. Explanation Interface Why-1 Original First Level-1-Hint with what will be changed and how in boxes (Left) and New First Level-1-Hint (Right)

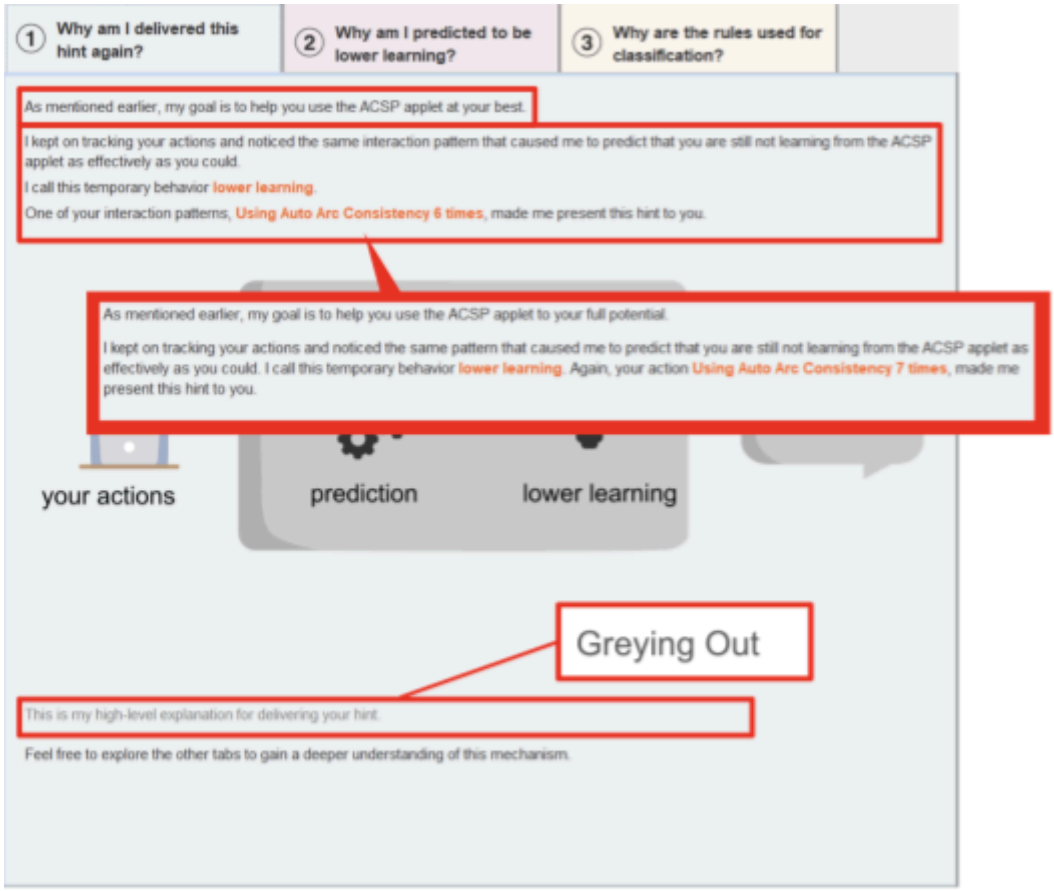


Fig 4. Explanation Interface Why-1 New First Level-2-Hint with text boxes detailing previous visuals and changes

Fig 5. Explanation Interface Why-1 New Second Level-1-Hint with text boxes detailing previous visuals and changes

Fig 6. Explanation Interface Why-1 New Subsequent Level-1-Hint with text boxes detailing previous visuals and changes

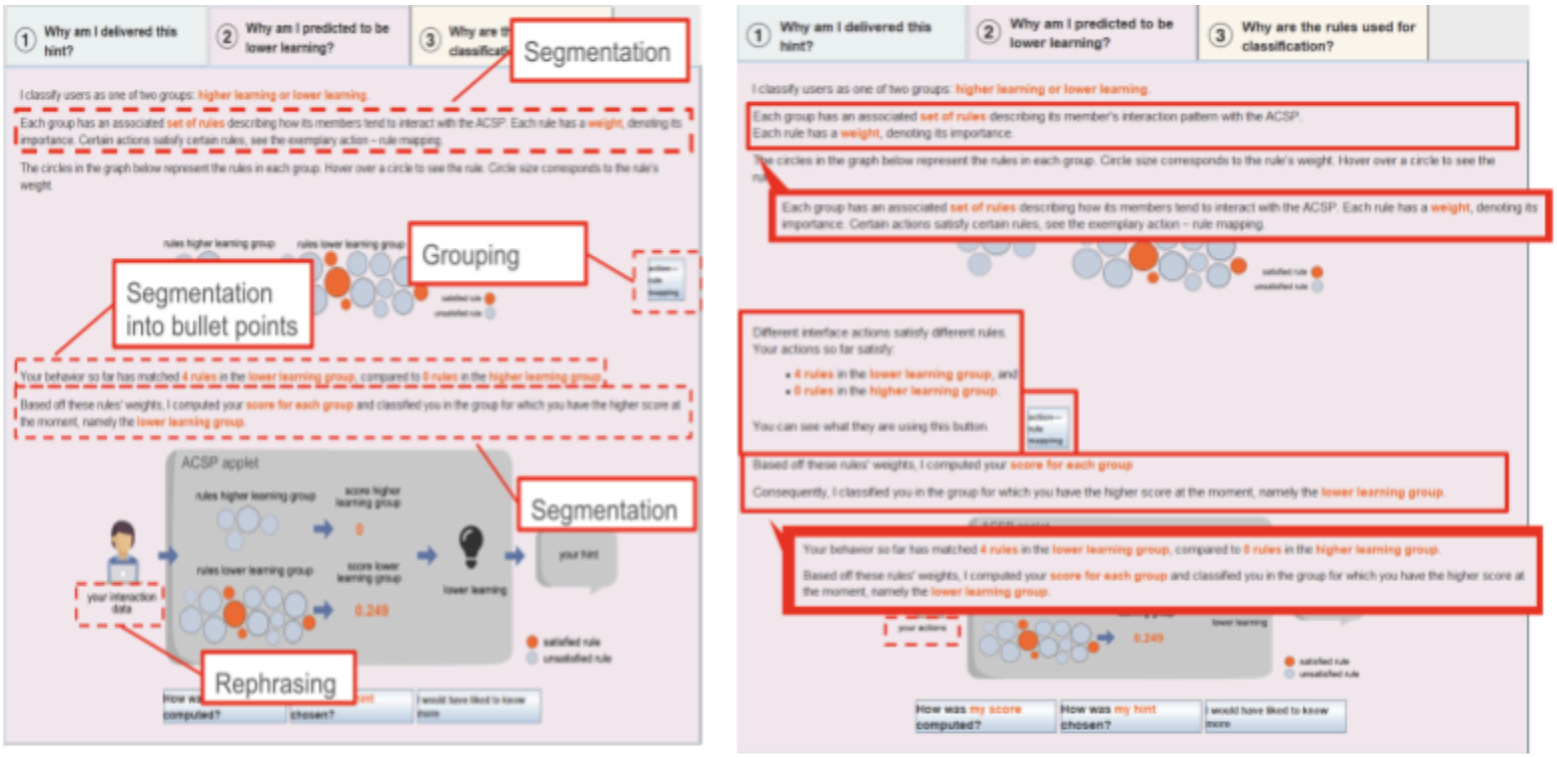
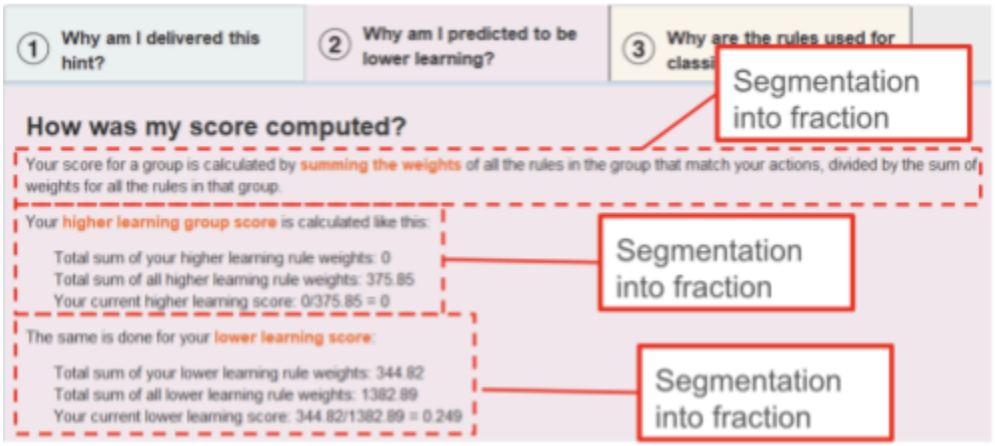


Fig 7. Explanation Interface Why-2 Original First Level-1-Hint with what will be changed and how in boxes (Left) and New First Level-1-Hint (Right)

Fig 8. Explanation Interface Why-2 New Second Level-1-Hint & New First Level-1-Hint

Fig 9. Explanation Interface Why-2 All Following Hints



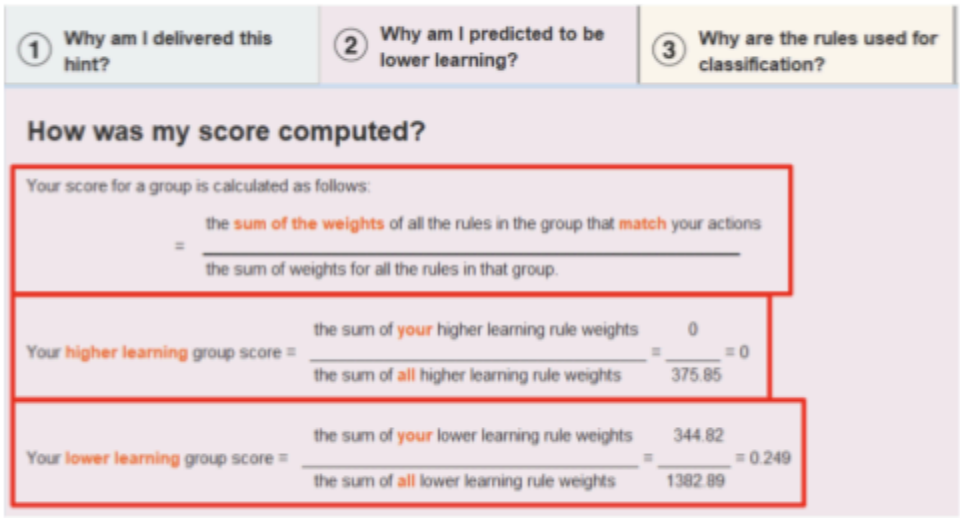


Fig 10. Explanation Interface How Computed Original First Level-1-Hint with what will be changed and how in boxes (Top) and New First Level-1-Hint (Bottom)

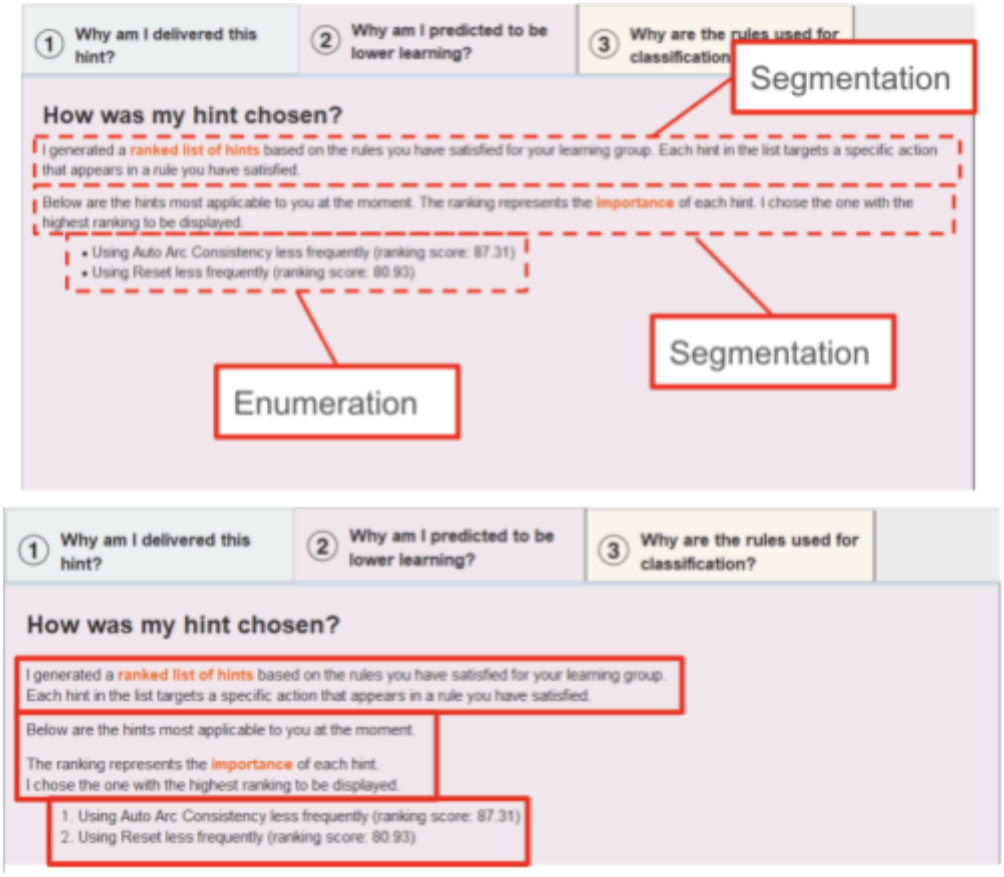


Fig 12. Explanation Interface How Chosen Original First Level-1-Hint with what will be changed and how in boxes (Top) and New First Level-1-Hint (Bottom)

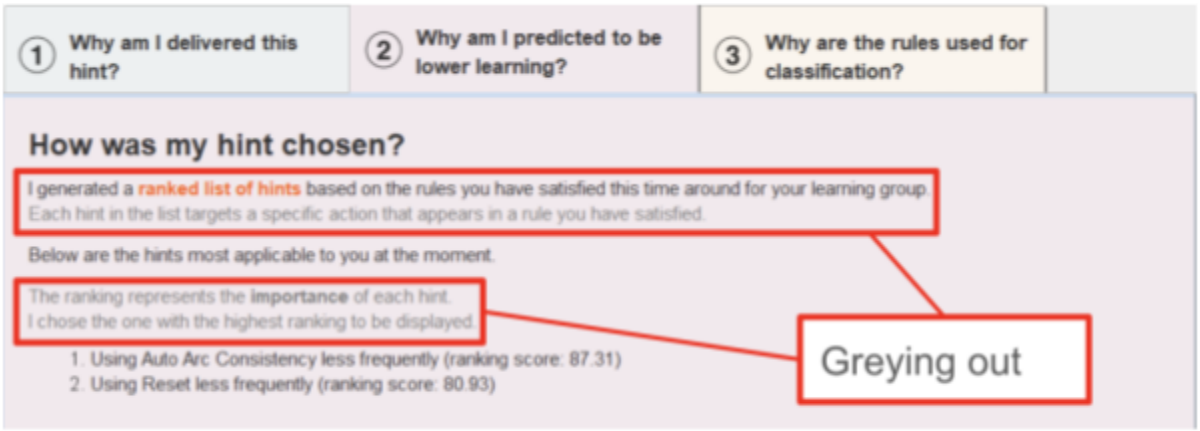


Fig 13. Explanation Interface How Chosen Original First Level-1-Hint with what will be changed and how in boxes

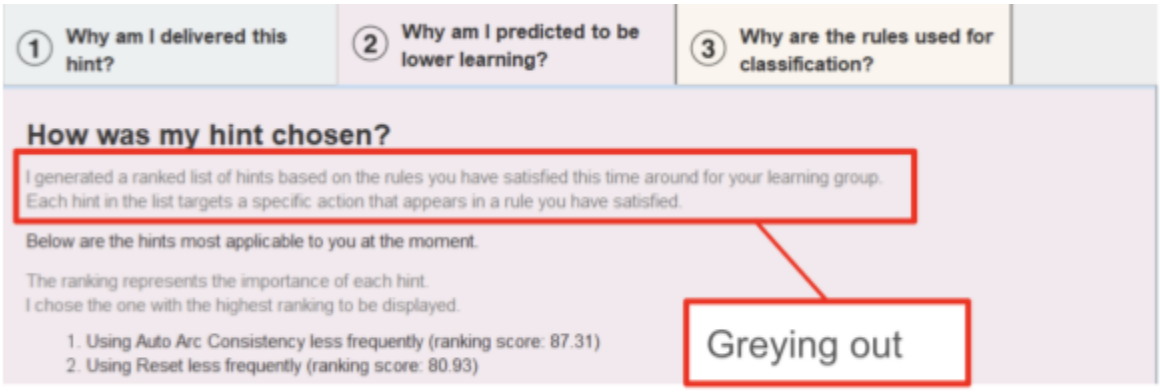


Fig 14. Explanation Interface How Chosen Original First Level-1-Hint with what will be changed and how in boxes

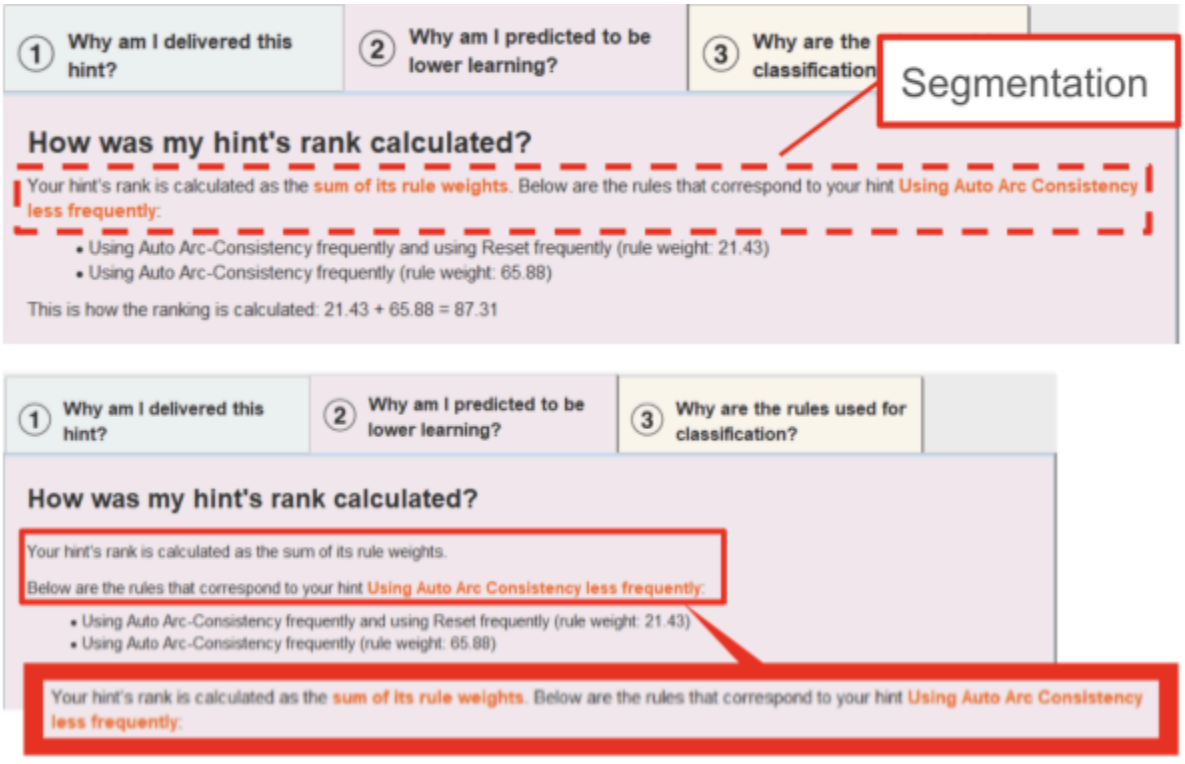


Fig 15. Explanation Interface How Calculated Original First Level-1-Hint with what will be changed and how in boxes (Top) and New First Level-1-Hint (Bottom)

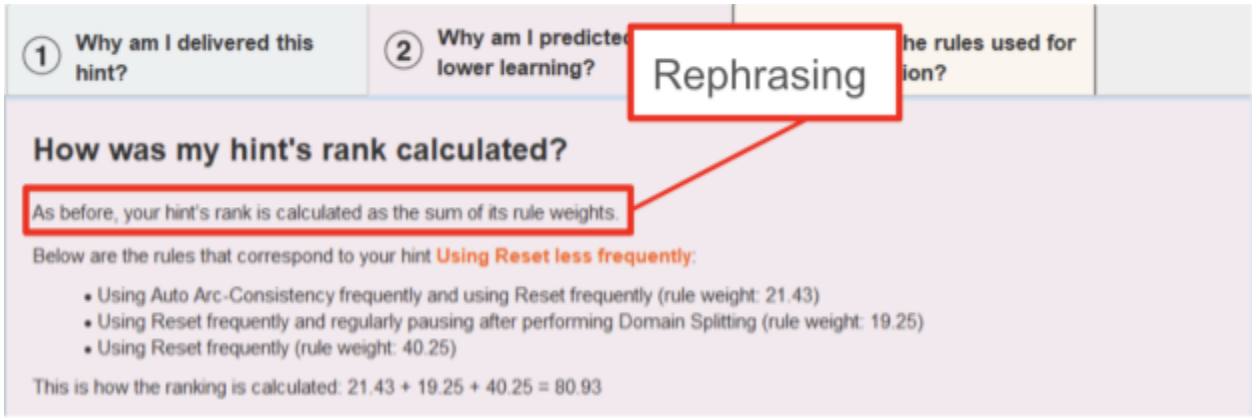


Fig 16. Explanation Interface How Calculated Second Level-1-Hint & First Level-2-Hint

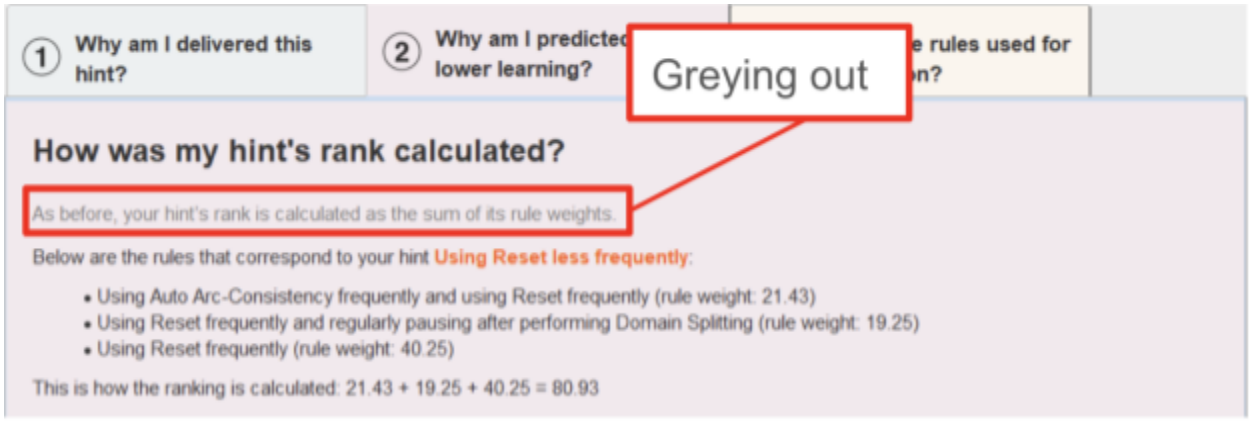


Fig 17. Explanation Interface How Calculated All Following Hints

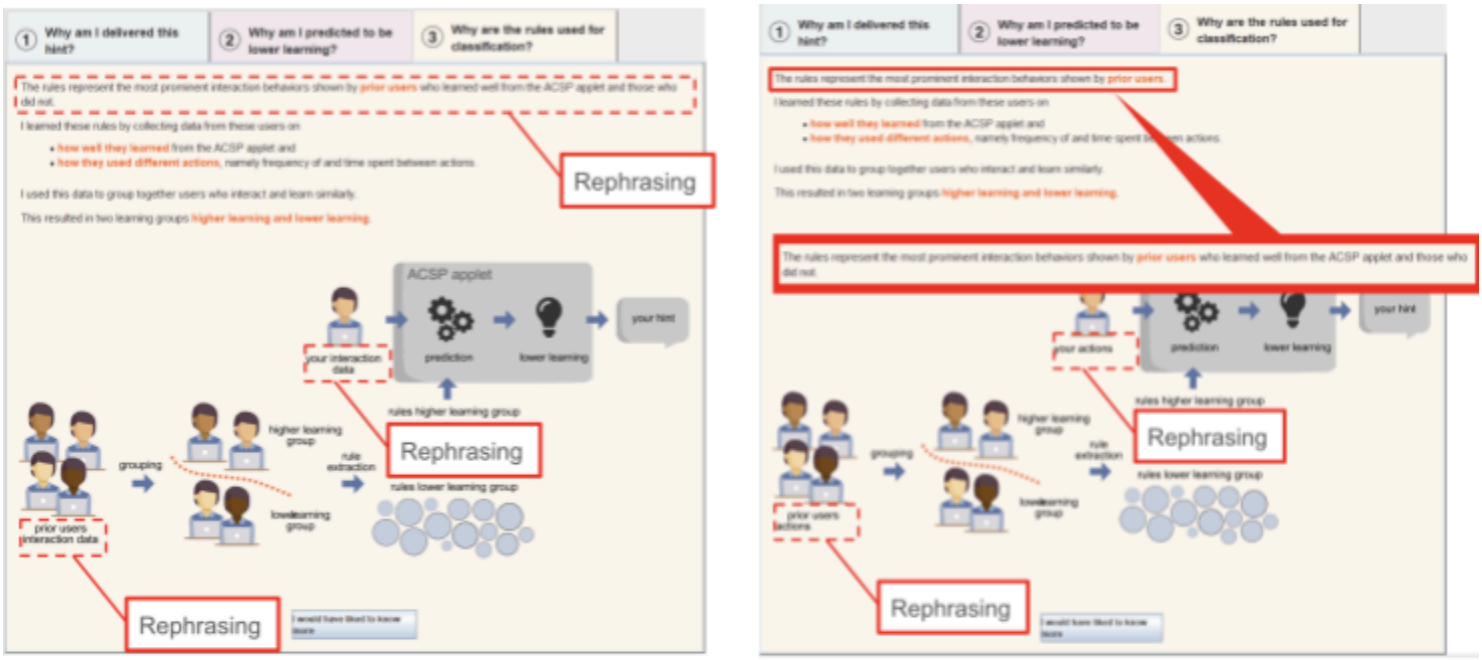


Fig 18. Explanation Interface Why-3 Original First Level-1-Hint with what will be changed and how in boxes (Left) and New First Level-1-Hint (Right)

Fig 20. Explanation Interface Why-3 Second Level-1-Hint & First Level-2-Hint

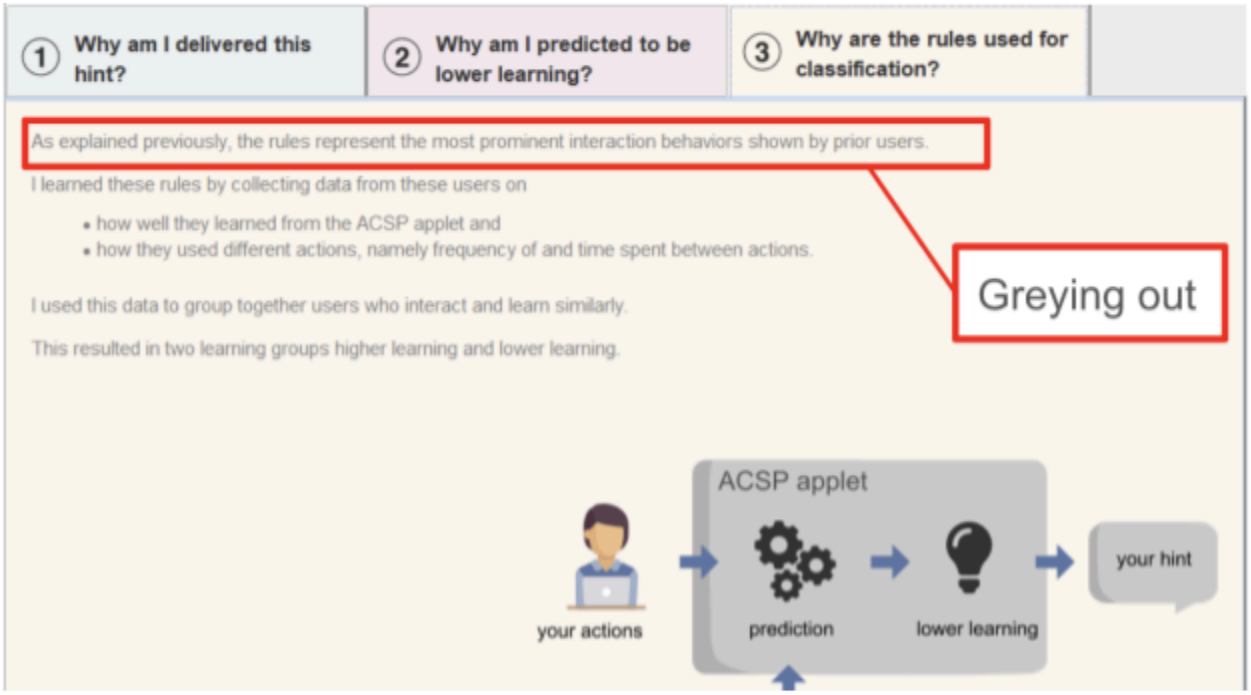


Fig 21. Explanation Interface Why-3 All Following Hints