# An Inductive Approach for Identification of Barriers to PCP Literacy

Chandana Srinivas* University of San Francisco
Elif E. Firat† Cukurova University
Robert S. Laramee‡ University of Nottingham
Alark Joshi§ University of San Francisco

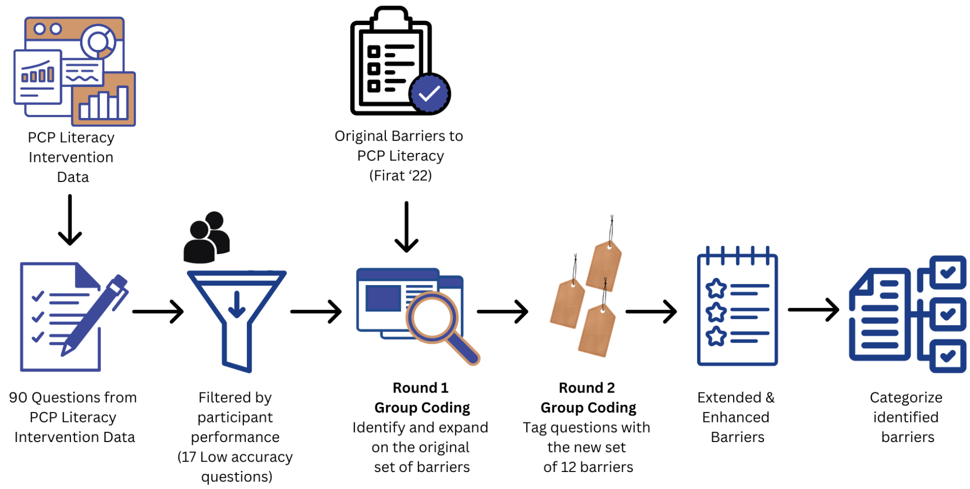


Figure 1: This figure shows the methodology used to inductively identify an enhanced list of PCP literacy barriers. We started with 90 questions from the PCP Literacy Intervention [21] and identified 17 questions where majority of the participants performed poorly on those questions. We then performed two rounds of Group Coding starting with the original set of barriers ( [9]) and extending it to include new barriers. The questions were then each tagged with the barriers and the set of barriers was updated accordingly. The final set of extended and enhanced barriers was refined and recorded. We further classified them into four categories that can be found in Table 2.

## Abstract

Parallel coordinate plots (PCPs) are gaining popularity in data exploration, statistical analysis, predictive analysis along with for data-driven storytelling. In this paper, we present the results of a post-hoc analysis of a dataset from a PCP literacy intervention to identify barriers to PCP literacy. We analyzed question responses and inductively identified barriers to PCP literacy. We performed group coding on each individual response and identified new barriers to PCP literacy. Based on our analysis, we present a extended and enhanced list of barriers to PCP literacy. Our findings have implications towards educational interventions targeting PCP literacy and can provide an approach for students to learn about PCPs through active learning.

## 1 Introduction

Learning to read, interpret, and create Parallel Coordinate Plots (PCPs) is essential due to the fact that PCPs are being used more frequently in data science (exploration and explanation), business analytics, scientific research, and more. While PCPs are familiar to researchers in the data visualization community, they are not as familiar to data analysts and others who may benefit from using PCPs for data analysis and exploration.

Identifying novel ways of teaching and assessing student understanding of data visualization techniques was identified as a challenge by Bach et al. [1]. Peng et al. [21] introduced a novel approach to teach students about Parallel Coordinate Plots using Bloom's taxonomy-based modules. They also introduced assessments to evaluate student performance on each module.

In this paper, we aim to get a better understanding of the barriers faced by new learners when they encounter PCPs. These barriers may be faced when an individual attempts to read and interpret a PCP or when a data practitioner/scientist creates a PCP for multi-dimensional data exploration and visualization. We present results from an inductive process of identifying barriers to PCP literacy based on previous investigations into PCP literacy conducted by Peng et al. [21]. We analyze the accuracy scores of students across a range of tasks from identifying, comprehending, analyzing, evaluating, as well as creating PCPs. We conducted this analysis on a total of 90 questions and identified the 17 questions where the average student accuracy was the lowest. We then examined the individual questions, the PCP for that question, and the task that the students were expected to conduct to answer the question accurately. We performed *group coding* [6, 13] of the various barriers that students may have faced when answering the question. Previous work by Firat et al. [9] implied that there may be a single barrier that may affect an individual's ability to interpret PCPs. In this paper, we posit that when interpreting a PCP, there may be *more* than one barrier that is responsible for the overall low average accuracy of the students when viewing a specific PCP.

Here are the contributions of the paper:

1. An inductive analysis of a pre-existing PCP literacy study [21]

*e-mail: csrinivas2@usfca.edu
†e-mail: elifemelfirat@gmail.com
‡e-mail: robert.laramee@nottingham.ac.uk
§e-mail: apjoshi@usfca.edu

2. An extended and enhanced list of barriers to PCP Literacy based on the inductive analysis

3. A discussion of the implications of the enhanced barriers on educational interventions related to PCP literacy

## 2 Related Work

The related work presents research in the field of visualization literacy followed by an exploration of the challenges associated with interpreting and understanding visualizations, which then goes into an in-depth examination of PCP literacy.

### 2.1 Visualization Literacy

Visualization literacy [10] has evolved over the past decades as the ability to interpret and create interactive visual charts and designs. In particular, Börner et al. [4] define it as the *"the ability to make meaning from and interpret patterns, trends, and correlations in visual representations of data"* while Lee et al. [17] refer to it as *"the ability and skill to read and interpret visually represented data in and to extract information from data visualizations"*.

In the past, many research studies have focused on visualization literacy and the creation of assessments to evaluate an individual's level of visualization literacy. Boy et al. [5] used the Item Response Theory to develop a reliable and effective test featuring line graphs, bar charts, and scatterplots to identify users with lower levels of visualization literacy. Lee et al. [17] introduced the Visualization Literacy Assessment Test (VLAT), which has since become widely recognized and established. The VLAT consists of 12 data visualizations and 53 multiple-choice questions. It is designed to evaluate an individual's ability to understand and interpret various types of visual designs. Recently, Pandey and Ottley introduced the *mini-VLAT* [20] that provides an abbreviated visualization literacy assessment test with only 12 items. Ge et al. [12] expanded previous definitions to include the ability to detect and reason about visualization misinformation. They developed the Critical Thinking Assessment for Literacy in Visualizations (CALVI), which consists of a mix of *trick items* and *normal items* to estimate a user's ability to detect visualization misinformation.

### 2.2 Barriers to Visualization Literacy

Even though visualization literacy is crucial, numerous individuals find it difficult to read and interpret charts and graphs. Nobre et al. [19] investigate the barriers faced by individuals who misinterpret visualizations, with the goal of identifying their specific cognitive gaps. They utilized the VLAT test and enhanced it to gather both quantitative and qualitative data, including student sketches and open-ended responses, to gain a deeper understanding of users' mental models. However, they did not delve into the specifics of PCP barriers. Researchers have also identified barriers in interpreting specific visualization techniques. Firat et al. [8] examine challenges in treemap literacy to improve skills among non-expert users. They utilize a treemap literacy assessment to identify barriers hindering comprehension and construction of treemaps. Similar work has been done by Firat et al. [9] in the field of PCP literacy, which is discussed in detail in Section 4.1.

### 2.3 PCP Literacy

Previously, multiple user studies on PCPs have been formulated to inform and evaluate the usability of the design. Inselberg [14] has written thoroughly on parallel coordinates and provides an extensive guide. Johansson and Forsell [15] present a detailed literature review that focuses on user-centered evaluation and analyzes the usability of parallel coordinates. Firat et al. [9] define PCP literacy as *"the ability to correctly read, interpret, and construct PCPs"*. However, PCPs have a reputation of being difficult to comprehend, especially if the implementation lacks essential features [22, 11]. Wang et al. [23] introduce cheat sheets as tools to aid in learning and using various data visualization techniques. They highlight how cheat sheets can facilitate understanding and creating Parallel Coordinates Plots by providing diagrammatic explanations. The paper also identifies three common pitfalls in PCPs as barriers: visual clutter, overplotting, and difficulty in tracing lines across multiple dimensions.

Choe et al. [7] developed a conversational LLM-based interface to help people read less familiar charts such as scatterplots, treemaps, and *parallel coordinate plots*. They found that their interface helped viewers interpret charts, but participants with less familiarity with data analysis did not engage as much with the data being represented in the charts. Recently, Joshi et al. [16] evaluated the ability of LLMs to teach novices about PCPs using Bloom's taxonomy. They found that while some LLMs provided useful directions, there were some hallucinations and the intervention would be better design in collaboration with a human expert.

Firat et al. designed the Parallel Coordinates Literacy Test (P-Lite) [9], utilizing a variety of images produced by widely-used PCP software tools. P-Lite was developed to assess users' understanding and ability to interpret complex high-dimensional visual designs such as parallel coordinates. Through the assessment, they identified 7 categories of difficulties for readers and present them as a list of barriers in understanding and interpreting PCPs. *Labels* and *Legends* were identified as two of the barriers, but they were not further investigated. This is because the absence of labels and legends indicates that the PCP design is incomplete. Their paper identifies further barriers to PCP literacy as future work. We present an updated list of barriers to PCP literacy based on our analysis.

## 3 Methodology

The goal of this paper is to identify barriers faced by individuals reading, interpreting, and, in some cases, constructing Parallel Coordinate Plots. Figure 1 shows an overview of the methodology followed to inductively identify an extended and enhanced list of barriers to PCP literacy. We started with 90 questions from the PCP intervention by Peng et al. [21] By examining the accuracy scores of questions from each module, we identified and selected 17 questions on which students scored the lowest. We then analyzed the 17 questions to identify 12 barriers for PCP literacy. There were a total of 55 undergraduate students across two different offerings of a Data Visualization course. Out of those, 54 students were in the 18-24 age group, 1 student was in the 25-44 age group, with 14 females and 41 males.

Peng et al. previously developed an assessment to evaluate users' understanding of parallel coordinate plots [21], structured according to Bloom's Taxonomy [2]. Figure 2 shows a schematic of the individual modules developed by Peng et al. [21] based on Bloom's taxonomy. They developed teaching and assessment for each cognitive module in Bloom's taxonomy to teach PCP literacy to students. In the Remember **(R)** module, students were taught to remember what a PCP looks like. In the Understand **(U)** module, students were taught how a PCP works and the various aspects that go into making a PCP from multivariate data. In the Apply **(Ap)** module, students applied their learned knowledge by drawing a PCP "by hand" on a piece of paper or using a software-based drawing tool. In the Analyze **(A)** module, students were asked to analyze PCPs and make decisions based on the charts. In the Evaluate **(E)** module, students were asked to critique and evaluate PCPs with faults in them. In the Create **(C)** module, students were instructed to generate PCPs using real-world tools and answer questions based on the chart constructed by them.

The overall literacy intervention by Peng et al. [21] consisted of 90 multiple-choice questions. We analyzed the average accuracy scores to identify questions where the students performed the worst in each module of Bloom's taxonomy. We selected 2-5 lowest per-

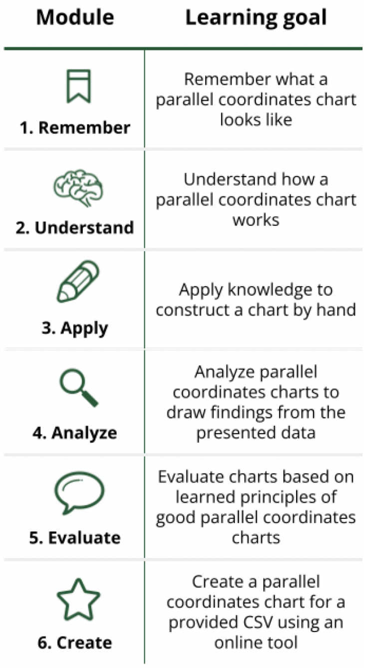


Figure 2: This figure shows an overview of the PCP literacy modules developed by Peng et al. [21] that were based on the six cognitive levels as stated in Bloom's taxonomy. Image credits: Peng et al. [21]

forming questions per module. For example, from the *Remember module* we identified two questions and labeled them as R1 and R2 in the rest of the paper. Similarly, for the rest of the questions from the other modules.

Specifically, we identified a total of 17 questions with relatively low accuracy scores, designating them as the "worst performing" questions. The question bank included a variety of question types, featuring standard multiple-choice questions as well as Yes/No/Not sure questions. All the questions per module can be found in the original data that was made available by Peng et al. [21] at `https://github.com/vis-graphics/pcp-literacy/tree/main/surveys`. [1]

During this process, we examined each PCP and analyzed the distribution of responses across different answer choices. By identifying potential reasons for incorrect answers, we observed a recurring set of factors. We identified these reasons as additional barriers that could have challenged the student's interpretation of the PCP and consolidated them with previously published barriers to create a unique, comprehensive set of barriers. The updated list is available in Section 4.2. This refined set of barriers facilitated a more thorough understanding of the reasons behind the poor performance of certain questions, thereby enhancing the overall assessment methodology.

## 4 Barriers to Interpreting Parallel Coordinate Plots

In this section, we present previous barriers [9] as well as the extended and enhanced set of barriers identified through our inductive analysis. For these enhanced set of barriers, we provide specific examples that demonstrate how that barrier may have played a role in lower accuracy numbers for those questions.

[1] One question (E3) had confusing answer choices and was hence disregarded, despite its low accuracy rate of 52%.

### 4.1 Previous Barriers

In previous work, Firat et al. [9] identified the following as barriers to PCP literacy.

1. **Space**: PCPs use a layout with repeated parallel axes (typically 2–10) instead of the two orthogonal axes in Cartesian Coordinate Plots (CCP), and this unfamiliarity can create a barrier to interpretation.
2. **Multivariate**: A challenge in understanding parallel coordinates is the need to interpret the attributes of multivariate or high-dimensional data and their relationships.
3. **Correlation**: Identifying and interpreting the correlation between data dimensions in PCPs is challenging due to the need to understand edge slopes and statistical terminology like correlation, which adds complexity.
4. **Distribution**: The uneven distribution of edges across screen space in PCPs can make it difficult to follow polylines as they cross and obstruct each other, leading to higher visual complexity and occlusion.
5. **Order**: The axis layout order in PCPs, which determines the placement of axes in screen space, can hinder understanding of relationships between non-adjacent data dimensions.
6. **Path Tracing**: Path tracing is a new task specific to PCPs that is not required in CCPs.
7. **Edges vs Points**: In a PCP, edges represent points as they do in a CCP, but this conversion can lead to cognitive challenges.

### 4.2 Extended and Enhanced Barriers

These barriers were identified by performing *group coding* [13] on each individual question. Group coding [6] of qualitative data is used due to various benefits such as increased reliability, reduced bias due to multiple perspective, enhanced quality of coding due to potential for discussion and debate, as well as for efficiency. To identify these barriers, we conducted two rounds of group coding where we first identified a first set of barriers starting from the original set of barriers from the PCP barriers by Firat et al. [9]. The set of barriers was then extended and enhanced as we examined every low-accuracy question and tagged it with all the applicable barriers. In the second round, we revisited every question as a group and tagged every question with the new barriers. The group coding was conducted synchronously using a remote collaboration platform by four researchers in the team.

1. **Edge Crossing affects path tracing**: With frequent edge crossings, it becomes hard to follow a single line from one dimension to the next because the human eye can easily lose track of the path among all the intersections. It can also lead to incorrect assumptions about relationships and correlations. Figure 3 shows an example PCP where the edge crossings make it very difficult to trace a path across the axes.

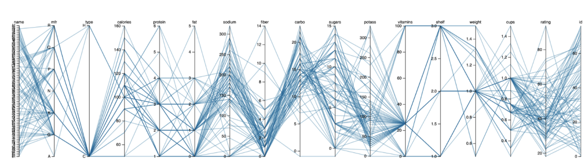

Figure 3: C1 (Accuracy = 69%) - The barriers for this PCP include the absence of color and edge crossing affecting path tracing, and a challenging domain context.

2. **Domain Context**: An obstacle to interpreting parallel coordinate plots is the necessity of having domain-specific, contextual knowledge to understand the relationships between complex variables. Figure 4 shows one such question where the domain may not be familiar to the student and may have resulted in low performance on the question.

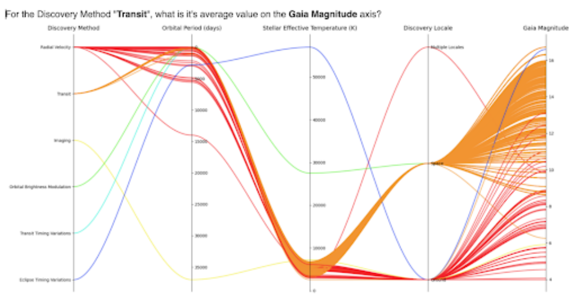


Figure 4: U1 (Accuracy = 39%) - Barriers in interpreting this PCP include edge crossing that affects path tracing, confusion with other visualization designs such as Sankey diagrams, the use of curved lines, the absence of a color legend, domain context and small font size of axis and data labels.

3. **Axis and Data Labels (Font Size)**: Small font sizes can make it challenging to read the PCP clearly and identify specific values or data points. Figure 4 and Figure 12 show an example question where the font size of the axis and data labels is too small.

4. **Missing/incorrect color legend**: A missing or incorrect color legend is a significant barrier to interpreting PCPs because users cannot accurately identify what each color represents, leading to confusion and misinterpretation of the data. Figure 5 shows an example with a problematic color legend that has multiple colors assigned to the same label. Figure 6 shows a PCP that has a missing value in the color legend. Figure 4 shows a PCP that contains color but does *not* contain a color legend.

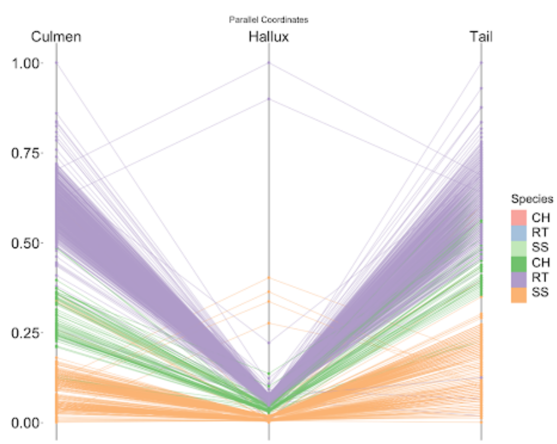


Figure 5: E8 (Accuracy = 69.7%) - The barriers for this PCP include axis labels that are inconsistent with the data, normalized data labels, and issues with color identification.

5. **Confusion with other visualization designs**: PCPs can be mistaken for other visualization techniques, such as line charts and Sankey diagrams, by new learners. The similarity between line charts and PCPs lies in their use of lines and similar axis structures to represent data points. Additionally, PCPs featuring curved lines can be confused with Sankey diagrams, as both use curved lines to depict data flow, and the parallel axes in PCPs can be misinterpreted as nodes in Sankey diagrams. Figure 4, Figure 10, and Figure 11 show examples where a student may have confused the visual design with either a Sankey diagram or a multi-series line chart.

6. **Normalized data labels**: Normalization makes it easier to compare variables directly, but it also eliminates the original scale and units, which makes it more difficult for readers to understand the actual magnitude of the data. Interpretation is further complicated by the possibility that readers will find it difficult to mentally convert normalized values to their original scales without clear explanation. Figure 6 shows an example PCP where the normalized data labels could be one of the barriers that may have affected the accurate comprehension of the PCP.

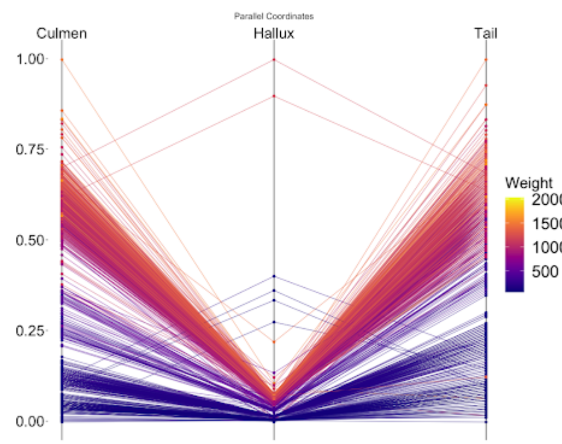


Figure 6: E1 (Accuracy = 28%) - The barriers for this PCP include axis labels that are inconsistent with the data, normalized data labels, and challenges with color identification, and edge overlapping.

7. **Lack of color can affect path tracing** : Without color, distinguishing between different data points or groups becomes more difficult, making the plot complex and difficult to interpret, especially for multivariate data attributes. All paths tend to look similar, making path tracing harder. Figure 3 and Figure 7 show examples of PCPs where the absence of color may have been one of the barriers faced by students when interpreting the PCP.

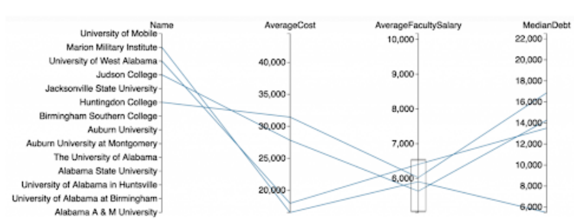


Figure 7: U3 (Accuracy = 79.5%) - The barriers for this PCP include edge crossing and the absence of color, which impacts path tracing.

8. **Color identification**: Constantly comparing the legend with polylines to match colors can be cognitively challenging, especially if the polylines are thin, colors are too light, or too similar, making differentiation difficult. Figure 8 and Figure 6 show examples where a student may have trouble matching the colors in the legend with those in the PCP.


Figure 8: E4 (Accuracy = 38.3%) - The barriers for this PCP include axis labels inconsistent with the data, normalized data labels, confusion with other visualization designs such as line charts, and a color legend where similar but not identical colors may hinder color identification.

9. **Axis labels & Data mismatch**: Incorrect axis labels can obscure the contextual understanding of variables, create confusion about what each axis represents, and make accurate comparisons between data points across different axes challenging. Figure 9 shows an example question where the axis labels for the first axis are incorrect.

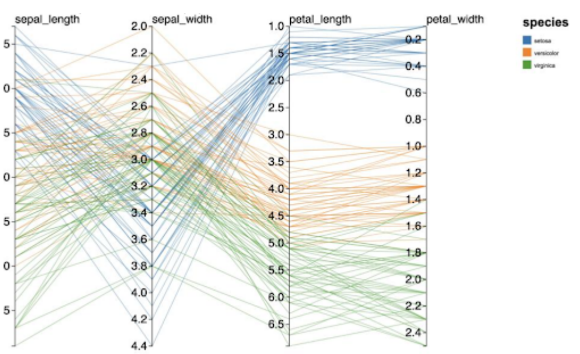


Figure 9: U2 (Accuracy = 54.3%) - The barriers for this PCP include axis labels incorrect as compared with the underlying data, challenges with domain context and normalized data labels. Specifically, the labels on the first axis (*sepal_length)* are incorrect.

10. **Curved Lines**: Curved lines pose challenges in accurately estimating values between data points and can lead to misinterpretation of trends and data values. Figure 10 shows one such question where the polylines are curved. While the overall accuracy for this question was not particularly low, it was one of the top two lowest performing questions in the *Remember* module [21]. Figure 10 and Figure 4 are examples of questions where curves were used instead of straight lines in the PCP.

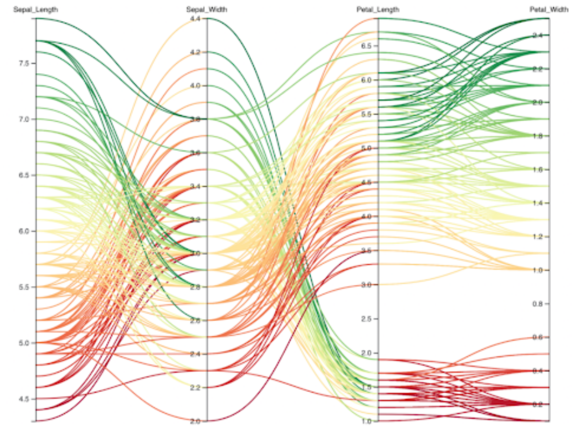


Figure 10: R1 (Accuracy = 90.7%) - The barriers identified for this question were challenges associated with not knowing the domain of the data, confusion with other visualization designs such as a Sankey diagram, the curved lines may have confused viewers, and there is no color legend for this chart.

11. **Missing consistent vertical axes**: Inconsistent vertical axes can make the plot harder to read and interpret, and can also hide any trends or patterns, making it difficult to recognize meaningful relationships. Figure 11 shows one such question where one axis is shown, but the other vertical axes are missing from the PCP.

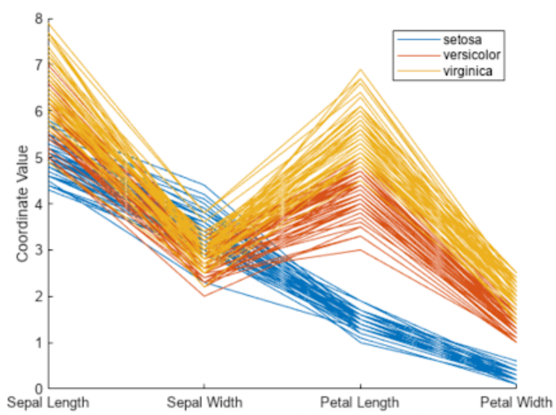


Figure 11: R2 (Accuracy = 96.7%) - The barriers for this PCP include missing consistent vertical axes causing confusion with other visualization designs, such as line charts. Additionally, the students may not have enough context knowledge about the domain of the data.

12. **Brushing can affect path tracing / legibility**: Brushing can be an extremely effective way to explore patterns in the data without losing context where the selected region is shown clearly and the rest of the data is represented in gray for context. While brushing can help the reader see patterns, it may also remove important cues needed to understand the overall distribution or relationships. Figure 12 shows one question where brushing is one of the barriers that makes it difficult to trace paths accurately.

| **Barriers** | *R1* | *R2* | *U1* | *U2* | *U3* | *Ap1* | *A1* | *A2* | *A3* | *E1* | *E2* | *E4* | *E5* | *E6* | *E7* | *E8* | *C1* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Edge Crossings affect path tracing | | | | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| Domain Context | ✓ | ✓ | ✓ | ✓ | | ✓ | | | | | | | | | ✓ | | ✓ |
| Axis and Data Labels (Font Size) | | | | ✓ | | | ✓ | ✓ | ✓ | | | ✓ | ✓ | | | | |
| Missing / incorrect color legend | ✓ | | | ✓ | | | | | | | | ✓ | ✓ | ✓ | ✓ | | |
| Confusion with other vis design | ✓ | ✓ | | ✓ | | | | | | | | ✓ | ✓ | | | | |
| Normalized Data Labels | | | ✓ | | | | | | | ✓ | | | | ✓ | ✓ | ✓ | |
| Lack of Color affects path tracing | | | | | ✓ | | ✓ | ✓ | ✓ | | | | | | | | ✓ |
| Color identification | | | | | | ✓ | | | | ✓ | ✓ | | | ✓ | | ✓ | |
| Axis Labels & Data mismatch | | | | | | | | | | ✓ | | ✓ | ✓ | | | ✓ | |
| Curved Lines | ✓ | | | ✓ | | | | | | | | | | | | | |
| Missing Consistent Vertical Axes | | ✓ | | | | | | | | | | | ✓ | | | | |
| Brushing affects path tracing | | | | | | | ✓ | | ✓ | | | | | | | | |
| *Accuracy* | 90.7 | 96.7 | 54.3 | 61 | 79.5 | 72 | 69.7 | 72 | 74 | 28 | 46.7 | 38.3 | 65 | 68.3 | 69.7 | 69.7 | 69 |

Table 1: Extended and Enhanced List of Barriers for PCP Literacy - This table shows the individual questions in columns and the various barriers that may have affected the performance of students when answering questions in the respective module. The first letter **R**, **U**, and so on corresponds to the cognitive module from Bloom's taxonomy (refer to 2) and the number after it is a question in that module. For example, **R2** is the 2nd question in the Remember module. The supplementary material contains details on every question used for the analysis. The table is sorted according to the barriers that were most frequently associated with PCP interpretation at the top (*Edge Crossing affect path tracing*) and the least frequent barriers towards the bottom.

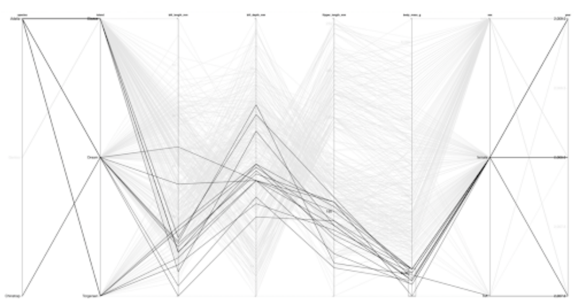

Figure 12: A1 (Accuracy = 69.7%) - The barriers for this PCP include the small font size of the axis and data labels, the absence of color affecting path tracing, brushing impacting path tracing and legibility, and edge crossing also affecting path tracing.

## 5 Discussion

The final expanded and validated set of barriers for PCP literacy can be found in Table 1. We examined the accuracy scores (shown in the last row of the table) and found that the questions where the accuracy scores were the lowest (E1, E2, E4, U1) were the ones where the most frequent barriers were encountered such as "Edge Crossings affect path tracing", "Domain Context", "Normalized Data Labels", "Missing / incorrect color legend", and "Confusion with other visualization designs."

Table 1 is also sorted in order from most frequent barrier when reading PCPs to the least frequent barriers. As can be seen from the first row, *Edge Crossings* are identified as the most common barrier when reading PCPs, as students have trouble following a polyine due to the edge crossings in the chart. Similarly, lack of familiarity with a domain can also impact the ability of an individual to read a PCP, as can be seen in the second row (Domain Context) of the table. Issues related to the axis and data labels as well as the color legend are frequent as well. Another common barrier was for some design decisions leading to potentially confused with either Sankey diagrams or multi-series line charts.

After examining the list of extended and enhanced barriers, we grouped the barriers into specific categories based on the challenges faced by students or challenges in the construction of the PCP (and it's associated color legend). Table 2 shows the various categories of the barriers. The four identified categories are: (i) path tracing (ii) Labels (iii) Color legend and (iv) Other. We found that majority of the challenges were associated with *path tracing*. Issues related to either multiple edge crossings or challenges associated with brushing or lack of color can adversely impact the ability to trace a path. Barriers related to the size and accuracy of the data and axis labels shown on a PCP were relevant too. In some cases, the data labels were normalized between 0.0-1.0 thus making it difficult for readers to accurately understand the underlying data. Another category or barriers that emerged was related to the Color Legend. Either the colors in the color legend were difficult to match with the polylines in the PCP or, in some cases, the color legend had errors or even colors that were not shown in the PCP. The last category contained barriers associated with not knowing the domain of the underlying data, confusing a PCP for new learners with other visualization designs, and, in some cases, some PCPs did not have a vertical axis for each variable in the data.

### 5.1 Implications for Educational Settings

Our findings suggest that creators of educational interventions for PCP literacy should focus on addressing these barriers when designing novel software to teach students about PCPs, or creating videos or cheat sheets [23] that introduce students about how to read and create PCPs. These pedagogical approaches (interactive software, videos, and cheat sheets) would help diverse learners learn through various modalities about PCPs keeping in mind the challenges associated with interpreting and creating them.

These barriers could also inform instructors who teach in the classroom about common stumbling blocks that their students may face when learning about PCPs for the first time. The barriers could also be addressed in a textbook teaching readers about PCP by individually addressing each barrier and showing various examples of

Table 2: This table shows the various categories that the barriers can be grouped in. We see that most of the barriers are related to path tracing, but the legibility of the labels is also an important category, along with color.

| **Barrier Category** | **Barrier** |
|---|---|
| Path Tracing | Edge Crossings affect path tracing |
| | Brushing can affect path tracing |
| | Lack of color can affect path tracing |
| | Curved Lines |
| Labels | Axis and Data Labels are not legible |
| | Axis Labels & Data mismatch |
| | Normalized data labels |
| Color Legend | Color identification |
| | Missing/incorrect color legend |
| Other | Domain Context |
| | Confusion with other vis designs |
| | Missing consistent vertical axes |

common problems.

With respect to designing new education resources, we recommend the creation of a PCP checklist that students could use to quantitatively evaluate the quality of a PCP that they encounter. The practice of evaluating various PCPs would lead to a better understanding of design considerations for creating a good PCP as well.

## 6 Conclusion and Future Work

We presented an extended and enhanced list of barriers to PCP literacy based on the analysis of a PCP intervention designed to teach students about PCPs. Of the 90 total questions used in the intervention, 17 questions were chosen and analyzed. Using group coding, we identified 12 barriers for PCP literacy (reading, understanding, and constructing). These barriers were also categorized to identify overarching themes in PCP literacy. These barriers can inform instructors and designers of PCP literacy interventions as they teach students about PCPs. In the future, we plan to explore the challenges associated with designing educational interventions for a diverse set of students and populations [3, 18].

## References


[1] B. Bach, M. Keck, F. Rajabiyazdi, T. Losev, I. Meirelles, J. Dykes, R. S. Laramee, M. AlKadi, C. Stoiber, S. Huron, C. Perin, L. Morais, W. Aigner, D. Kosminsky, M. Boucher, S. Knudsen, A. Manataki, J. Aerts, U. Hinrichs, J. C. Roberts, and S. Carpendale. Challenges and opportunities in data visualization education: A call to action. *IEEE Transactions on Visualization and Computer Graphics*, 30(1):649–660, 2024. doi: 10.1109/TVCG.2023.3327378 1

[2] B. S. Bloom et al. Taxonomy of educational objectives. vol. 1: Cognitive domain. *New York: McKay*, 20(24):1, 1956. 2

[3] R. Borgo, V. Byrd, A. Frank, K. Gaither, R. S. Laramee, R. Metoyer, and E. Yang. Diversity in visualization ieee vis 2017 panel. 7

[4] K. Börner, A. Maltese, R. N. Balliet, and J. Heimlich. Investigating aspects of data visualization literacy using 20 information visualizations and 273 science museum visitors. *Information Visualization*, 15(3):198–213, 2016. doi: 10.1177/1473871615594652 2

[5] J. Boy, R. A. Rensink, E. Bertini, and J.-D. Fekete. A principled way of assessing visualization literacy. *IEEE Transactions on Visualization and Computer Graphics*, 20(12):1963–1972, 2014. doi: 10.1109/TVCG.2014.2346984 2

[6] M. Catterall and P. Maclaran. Focus group data and qualitative analysis programs: Coding the moving picture as well as the snapshots. *Sociological research online*, 2(1):41–49, 1997. doi: 10.5153/sro.67 1, 3

[7] K. Choe, C. Lee, S. Lee, J. Song, A. Cho, N. W. Kim, and J. Seo. Enhancing data literacy on-demand: Llms as guides for novices in chart interpretation. *IEEE Transactions on Visualization and Computer Graphics*, pp. 1–17, 2024. doi: 10.1109/TVCG.2024.3413195 2

[8] E. E. Firat, A. Denisova, and R. S. Laramee. Treemap Literacy: A Classroom-Based Investigation. In M. Romero and B. Sousa Santos, eds., *Eurographics 2020 - Education Papers*. The Eurographics Association, 2020. doi: 10.2312/eged.20201032 2

[9] E. E. Firat, A. Denisova, M. L. Wilson, and R. S. Laramee. P-lite: A study of parallel coordinate plot literacy. *Visual Informatics*, 6(3):81–99, 2022. doi: 10.1016/j.visinf.2022.05.002 1, 2, 3

[10] E. E. Firat, A. Joshi, and R. S. Laramee. Interactive visualization literacy: The state-of-the-art. *Information Visualization*, 21(3):285–310, 2022. doi: 10.1177/14738716221081831 2

[11] E. E. Firat, B. Swallow, and R. S. Laramee. Pcp-ed: Parallel coordinate plots for ensemble data. *Visual Informatics*, 7(1):56–65, 2023. doi: 10.1016/j.visinf.2022.10.003 2

[12] L. W. Ge, Y. Cui, and M. Kay. Calvi: Critical thinking assessment for literacy in visualizations. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, CHI '23. Association for Computing Machinery, New York, NY, USA, 2023. doi: 10.1145/3544548.3581406 2

[13] L. Giesen and A. Roeser. Structuring a team-based approach to coding qualitative data. *International Journal of Qualitative Methods*, 19:1609406920968700, 2020. doi: 10.1177/1609406920968700 1, 3

[14] A. Inselberg and B. Dimsdale. Parallel coordinates. *Human-Machine Interactive Systems*, pp. 199–233, 2009. 2

[15] J. Johansson and C. Forsell. Evaluation of parallel coordinates: Overview, categorization and guidelines for future research. *IEEE transactions on visualization and computer graphics*, 22(1):579–588, 2015. doi: 10.1109/TVCG.2015.2466992 2

[16] A. Joshi, C. Srinivas, E. E. Firat, and R. S. Laramee. Evaluating the recommendations of llms to teach a visualization technique using bloom's taxonomy. *Electronic Imaging*, 36:360–1–360–8, 2024. doi: 10.2352/EI.2024.36.1 2

[17] S. Lee, S.-H. Kim, and B. C. Kwon. VLAT: Development of a visualization literacy assessment test. *IEEE Transactions on Visualization and Computer Graphics*, 23(1):551–560, 2016. doi: 10.1109/TVCG.2016.2598920 2

[18] R. Metoyer and K. Gaither. *Diversity in Visualization*. Springer Nature, 2022. 7

[19] C. Nobre, K. Zhu, E. Mörth, H. Pfister, and J. Beyer. Reading between the pixels: Investigating the barriers to visualization literacy. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*, pp. 1–17, 2024. doi: 10.1145/3613904.3642760 2

[20] S. Pandey and A. Ottley. Mini-vlat: A short and effective measure of visualization literacy. *Computer Graphics Forum*, 42(3):1–11, 2023. doi: 10.1111/cgf.14809 2

[21] I. Peng, E. E. Firat, R. S. Laramee, and A. Joshi. Evaluating Bloom's Taxonomy-based Learning Modules for Parallel Coordinates Literacy. In J.-J. Bourdin and E. Paquette, eds., *Eurographics 2022 - Education Papers*. The Eurographics Association, 2022. doi: 10.2312/eged.20221042 1, 2, 3, 5

[22] H. Siirtola and K.-J. Räihä. Interacting with parallel coordinates. *Interacting with Computers*, 18(6):1278–1309, 2006. doi: 10.1016/j.intcom.2006.03.006 2

[23] Z. Wang, L. Sundin, D. Murray-Rust, and B. Bach. Cheat sheets for data visualization techniques. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, CHI '20, p. 1–13. Association for Computing Machinery, New York, NY, USA, 2020. doi: 10.1145/3313831.3376271 2, 6