

Evaluating Bloom's Taxonomy-based Learning Modules for Parallel Coordinates Literacy

Ilena Peng¹, Elif E. Firat² , Robert S. Laramée² , Alark Joshi^{†1} 

¹University of San Francisco, USA, ²University of Nottingham, UK

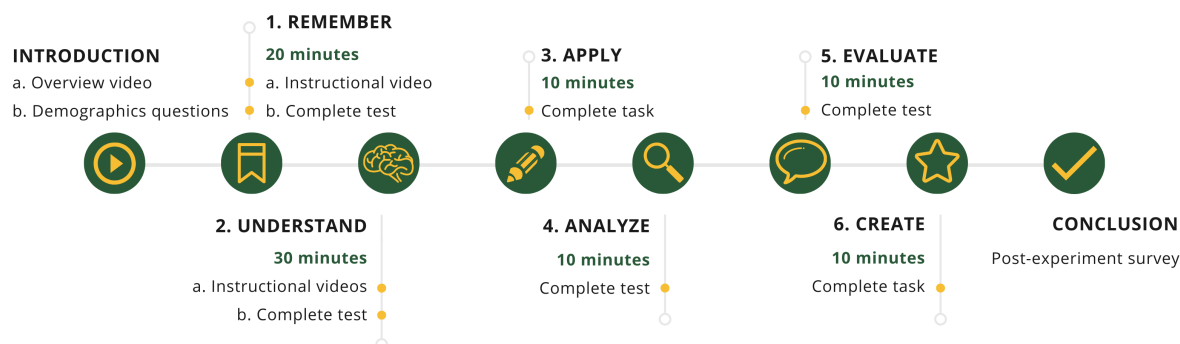


Figure 1: Our Bloom's Taxonomy-based approach to educate students on the topic of parallel coordinates.

Abstract

In this paper, we present the results of an intervention designed to introduce parallel coordinates to students. The intervention contains six new modules inspired by Bloom's taxonomy that featured a combination of videos, tests, and tasks. We studied the impact of our modules with a corrective feedback mechanism inspired by Mastery Learning. Based on analyzing the data of our students, we found that students in the Corrective Immediate Feedback (CIF) group performed better on average on all the modules as compared to the students in the No Feedback (NF) group. In the tasks where students were required to construct parallel coordinates plots, students in the Corrective Immediate Feedback group produced plots with appropriate use of color, labels, legends, etc. Overall, students in both groups grew more confident in their ability to recognize parallel coordinates plots and expressed high confidence in their ability to interpret, create, and use parallel coordinates plots for data exploration and presentation in the future.

CCS Concepts

• **Human-centered computing** → Empirical studies in visualization; Visualization techniques; Visualization design and evaluation methods;

1. Introduction

Literacy is defined as the ability to read and write, but it also encompasses an individual's competence and confidence in using that knowledge [Mon18]. Visualization literacy has been defined as the "the ability and skill to read and interpret visually represented data in and to extract information from data visualizations [LKK16]." While this definition contains the ability to read and interpret, it misses out on a key ingredient of literacy, which is the ability to apply the knowledge in a real-world setting.

Learning to read and create charts is recognized as an impor-

tant activity and is taught at an early age, frequently at the elementary school level (K–4th grade) [ARC*17]. The content is usually limited to bar charts, pie charts, line charts, and scatterplots. As newer charts gain popularity in media as well as on informational dashboards (health, personal finance, etc.), it is increasingly important for the consumers of that information to be familiar with these charts [Bor15, Cai19].

Parallel coordinates plots (PCP) [ID90] are one such chart type that has made its way into visualization libraries such as Vega [SMWH16] (and Altair [VGH*18]), Plotly [Sie20], and more. Additionally, there are multiple articles [Cat21, Kos10, Wei20] and videos [Lam21, Lar16, Kri19] instructing audiences on how to read and interpret parallel coordinates plots.

[†] Corresponding author: Alark Joshi – apjoshi@usfca.edu

Teachers have significant expertise with teaching complex concepts through various pedagogical strategies such as *Bloom's taxonomy* [B*56] that contains scaffolding to introduce new concepts. The taxonomy contains cognitive levels that start from a simple task of recognizing a new concept and contains scaffolding to eventually enable a student to apply their knowledge in the context of real-world problems. The cognitive levels introduced in Bloom's taxonomy are: Remember, Understand, Apply, Analyze, Evaluate, and Create. We used Bloom's taxonomy for PCP literacy because of its proven ability to provide a deeper understanding of a new concept in a step-by-step manner with increasing difficulty that engages various learning mechanisms (recognizing, understanding, creating, critiquing, and so on).

Mastery Learning is an instructional strategy that requires students to *master* a concept first before they can go on to more complex concepts [BB76, MOMR17]. Corrective feedback is defined as "information that is communicated to the learner to help them modify their thinking to improve their learning [Shu08]." Providing immediate feedback has been shown to lead to better learning outcomes than summative feedback at the end (where a learner may find out that they got 17 out of 20 questions right) [FRJ16].

In this project, we created learning modules based on Bloom's taxonomy and studied the impact of Corrective Immediate Feedback-based learning [Shu08] (inspired by Mastery Learning) when teaching students about the Parallel Coordinates technique. The six learning modules were based on the prescribed cognitive levels in Bloom's taxonomy that build on each other with the goal of improving their PCP literacy. We built two separate sets of the learning modules - one set contained immediate feedback on literacy test questions, while the other set did not contain any feedback.

The contributions of our work are as follows:

- The development of six parallel coordinates literacy modules based on the cognitive levels outlined in the Bloom's taxonomy [B*56].
- Creation of a test bank designed to test the PCP literacy of students
- Evaluating the impact of Corrective Immediate Feedback (CIF) on visualization literacy

2. Related Work

In this section, we discuss the research in the field of visualization literacy that is relevant to increasing the visualization literacy of various audiences, strategies and tests to evaluate the impact of the literacy intervention, and visualization research that uses concepts from Bloom's taxonomy.

Visualization Literacy: Borner [BMBH16] defined Data Visualization Literacy [BBG19] as "the ability to make meaning from and interpret patterns, trends, and correlations in visual representations of data." Stoiber et al. [SGP*19] defined visualization *onboarding* as the "process of supporting users in reading, interpreting, and extracting information from visual representations of data." Lee et al. [LKH*15] conducting an interesting study into evaluating how people interpret visual representations that are unfamiliar (including PCP) to them.

Burns et al. [BXF*20] mapped various levels of understanding of charts based on Bloom's taxonomy. They tested their framework with three case studies and found that it was better than existing methods that emphasize only quick and accurate understanding of the chart. They further applied this framework to evaluate the understanding of charts to compare the use of pictographs vs geometric areas [BXF*21]. Adar and Lee [AL20] presented work from a project that used Bloom's taxonomy to help designers identify learning objectives in order to better "define, assess, and compare communicative visualizations." They did not use it in the context of increasing the visualization literacy of students for a specific visualization technique. Our work differs from the previous work as we focus specifically on PCP literacy.

Evaluating Visualization Literacy: Boy et al. [BRBF14] introduced visualization literacy tests based on Item Response Theory. Their goal was to create "fast, effective, and reliable" visualization literacy tests that separated the difficulty of a question from the ability of an individual to answer the question. Similarly, Lee et al. [LKK16] created the Visualization Literacy Assessment Test (VLAT) to assess the visualization literacy skills of non-expert data visualization users. The VLAT consists of 12 graphic designs and 53 test items, with eight primary tasks. As far as we know, our project is the first to evaluate the construction of parallel coordinates plots.

Improving Visualization Literacy: By evaluating the effects of active learning theory, a study provided by Kwon and Lee [KL16] focuses on parallel coordinates to investigate the implications of multimedia learning environments for teaching data visualization to non-expert users. A crowdsourced experiment was conducted to investigate the efficacy of data visualization teaching. This study shares similarities with ours in one of the phases, with the concept of teaching parallel coordinates via video tutorial. Another study by Firat et al. [FDL20] introduces a pedagogical treemap tool to promote teaching treemaps and improving user's treemap literacy skills.

3. Approach

We created six modules based on the cognitive levels in Bloom's taxonomy and evaluated the impact of the modules with and without Corrective Immediate Feedback (CIF) on student learning. We closely followed the steps in the taxonomy to introduce students to the PCP technique. Figure 1 shows an overview of the design of the learning modules and the tests students took.

3.1. Bloom's Taxonomy-based Modules

We now detail the process of how each module was created and their alignment with the cognitive levels in Bloom's taxonomy for parallel coordinates literacy.

3.1.1. Remember Module

The goal for this module is for students to be able to remember/recognize a PCP. To achieve this goal, we showed students a training video introducing them to the concept and main identifiers

of a PCP. To introduce students to the technique, we showed students how the same data can be encoded using a multivariate scatterplot and a PCP. This was followed by a variety of PCPs - with and without color, vertical and horizontal layouts, and even with curved polylines.

We examined the various verbs associated with **remember** in the Bloom's taxonomy cognitive process dimension [Kra02] and selected - *recognize*, *recall*, and *locate* as the most synonymous actions associated with the remember stage. Based on these actionable verbs, we created a test to evaluate a student's ability to remember the appearance of parallel coordinates. The test bank contains questions asking students to determine if a chart is a PCP or not as well as to locate the PCP in a lineup along with other charts. Figure 2 shows a sample question from the test where a student is asked to locate the PCP from a lineup.

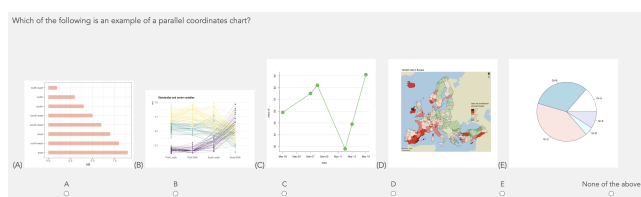


Figure 2: Remember Module - This figure shows a sample question from the test that asked students to locate the PCP in a lineup.

3.1.2. Understand Module

The goal for this module is to help students understand how to interpret a PCP correctly. To achieve this goal, we showed the students training videos introducing them to the workings of a parallel coordinates chart. We taught students to read a PCP by following a polyline across axes, to identify axis labels, to observe min/max values on each axis, to notice the use of color for categorical variables, to be mindful of flipped axes, and to identify positive and negative correlation of variables. We also demonstrated interaction techniques such as axis reordering, brushing, filtering, and highlighting a single data element.

On examining the verbs associated with **understand** in the cognitive process dimension [Kra02], we found *interpret*, *compare*, *identify*, and *represent*. Based on these associated verbs, we created a test with questions related to interpreting positive/negative correlation between variables in adjacent axes, correctly identifying which axis represented data in a specified range, identifying the minimum and maximum values for a specified axis in the chart, comparing the axes and determining if any axis was flipped in a chart (which would in turn impact the ability to interpret the correlation between variables), and so on. Figure 3 shows a sample question from the test that asks the student to identify the positive/negative correlation between two adjacent variables in the PCP.

3.1.3. Apply Module

The goal of this module is to allow students to apply their knowledge to construct a PCP given a template containing vertical axes. The tasks in this module were based on the verbs *execute*, *implement*, and *use* [Kra02]. Based on these associated verbs, we designed this task that requires students to manually construct a PCP

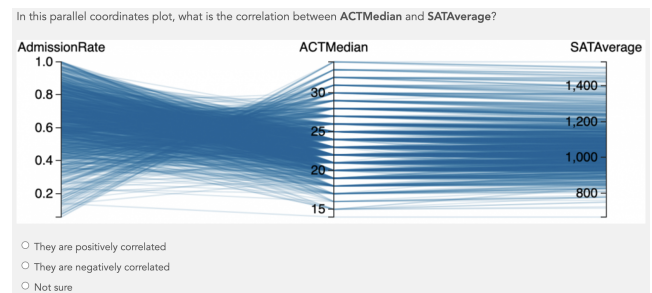


Figure 3: Understand Module - This figure shows a sample question that asked students to identify the correlation between two adjacent axes in the given PCP.

for a dataset of books containing 5 tuples with information about books. For each book, the dataset stores the following 6 dimensions — number of sentences, words, difficult words, downloads, author name, and polarity of the text. Students constructed a PCP using pen-and-paper or electronically using Google Slides.

3.1.4. Analyze Module

The goal of this module is to test the students' ability to derive observations from the presented data using parallel coordinates. Based on the verbs associated with **analyze** - *differentiate*, *select*, *arrange*, *organize*, and *examine*, [Kra02] we created a test to evaluate students' ability to analyze PCPs. Some questions required them to follow polylines along multiple axes to resolve queries, such as for a question about identifying the university that has "the lowest faculty salary and highest median debt for students." A few questions asked students to select the correct PCP for the question that was asked, given a collection of PCPs. They had to verify that all the axes required to answer the question were displayed in the chart, take into account axis adjacency, and observe flipped axes when answering these questions. Another type of question required them to arrange/sort four different charts based on a specific value (for example, the number of households in a neighborhood). We also asked open-ended questions requesting students to differentiate between a scatterplot matrix representation and a parallel coordinates representation of the same data.

Figure 4 shows a sample question from the Analyze module which asks students to trace a polyline to answer the question about which state has the lowest education levels, but highest number of households.

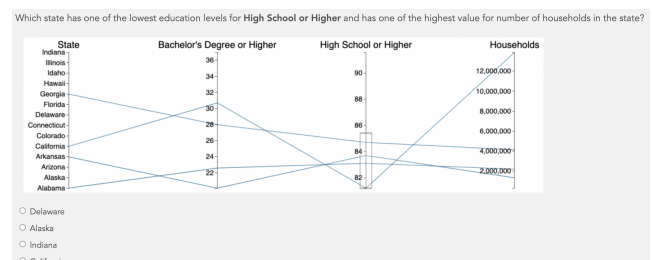


Figure 4: Analyze Module - The figure shows a sample question that requires students to follow the polyline across the axes to answer the question.

3.1.5. Evaluate Module

The goal of this module is to examine the ability of students to critically evaluate PCPs based on the knowledge they have learned so far about well-designed PCPs.

To test the students' ability to evaluate charts, we examine the verbs associated with **evaluate** in the cognitive process dimension [Kra02], and found *critique, judge, and check*. The test included a wide range of PCPs with intentionally introduced defects. The students were asked to critique the charts given multiple choice options and, in some cases, identify *all* the defects with specific charts in an open-ended text response. The PCPs that had the following defects: missing axis labels, missing data labels, disjointed polylines that did not connect, repeated axes in the same chart, missing or mismatched color legends, out of order data labels (e.g. 10, 50, 20, 30), inconsistently flipped axes, extreme overplotting, and so on. We even included a few charts with no defects in them to test the students.

Figure 5 shows a sample question that displays a chart with a color legend that does not match the colors used in the PCP. We also included charts that include more than one defect (see Table 1) and provided a free form text response for students to state all the defects that they could find.



Figure 5: Evaluate Module - The figure shows a sample question that contains a PCP with a color legend whose colors do not match the colors in the chart.

3.1.6. Create Module

The goal of this module is for students to synthesize their knowledge and create a PCP using an online tool. The tasks in this module were based on verbs such as *construct, produce, and generate* [Kra02].

Students were given two datasets in CSV format and were asked

to create a PCP using RawGraphs.io [MEC*17] and an online tool based on Kai Chang's Parallel Coordinates tool [Kai21]. The first dataset is a World Happiness Index dataset that contains 13 variables (2 categorical and 11 quantitative) and 141 countries. The second dataset is about cereals and contains 16 variables (3 categorical and 13 quantitative) with 78 rows.

We used RawGraphs.io [MEC*17] because it does not require any prior coding experience for the students. However, RawGraphs.io does not support any filtering, axis reordering, axis flipping, and the number of variables that a user can plot are limited. That led us to adapt the online demo from Kai Chang's Parallel Coordinates tool [Kai21] to make it easy for students to upload a CSV file and to perform the kind of interactions (filtering, axis reordering, and axis flipping) that they are familiar with by this time in the study.

3.2. Comparative Evaluation of Immediate Feedback

To enable the comparison between the CIF group and the No Feedback (NF) group, we showed both the groups the same set of questions, but for each module the CIF group received Correct Immediate Feedback for the first half of questions and the second half without any feedback. Figure 6 shows an outline of the study design with the learning goals for each module. The corrective feedback was implemented in such a way that the students in the CIF group were allowed to advance to the next question only after they had answered the current question correctly. To compare the students in the two groups (CIF vs NF), we only analyzed the accuracy of the questions that had no feedback, since the students in the CIF group would have 100% accuracy on the questions that featured validation (CIF).

3.2.1. Procedure

Students were provided a short text-based overview of the project and after obtaining their consent, we followed up with a color blindness check and questions about their demographics. We then asked about their overall familiarity with visualization techniques and found that none of our students had *any* prior familiarity with PCPs.

The students then watched an overview video explaining the study. Figure 1 shows an overview of the steps followed by the students. To ensure that students had completed a module (watching the training videos, completed uploading charts/screenshots, etc.), we provided students with a unique keyword per module that they had to enter before they could continue with the next module. After the students had completed the six modules, we asked them to reflect on the study in form of a short post-experiment survey.

For the evaluation, we recruited students from a programming class in our department. We had a total of 26 students (12 females and 14 males in our study). Of those students, 13 had a 4-year college degree, 11 had a graduate degree, and 2 had a high school degree/GED. The age distribution was as follows: 14 students in the 18-24 age group, 10 students in the 25-44 age group, and 2 students in the 45-64 age group. There were 14 students in the CIF group and 12 in the NF group.

Module	Learning goal	Corrective Immediate Feedback Group	No Feedback Group
1. Remember	Remember what a parallel coordinates chart looks like	Watch video → 50% test questions with feedback → 50% test questions with no feedback	Watch video → All test questions with no feedback
2. Understand	Understand how a parallel coordinates chart works	Watch videos → 50% test questions with feedback → 50% test questions with no feedback	Watch videos → All test questions with no feedback
3. Apply	Apply knowledge to construct a chart by hand	Draw a parallel coordinates chart	Draw a parallel coordinates chart
4. Analyze	Analyze parallel coordinates charts to draw findings from the presented data	50% test questions with feedback → 50% test questions with no feedback	All test questions with no feedback
5. Evaluate	Evaluate charts based on learned principles of good parallel coordinates charts	50% test questions with feedback → 50% test questions with no feedback	All test questions with no feedback
6. Create	Create a parallel coordinates chart for a provided CSV using an online tool	Use an online tool to generate a chart	Use an online tool to generate a chart

Figure 6: This figure shows an overview of each module. Students in both groups (Continuous Immediate Feedback and No Feedback) group saw the same training videos. For each test, students in the CIF group answered half the questions with corrective feedback and then answered the second half without any validation. Students in the NF group did not receive any feedback.

4. Evaluating Student Performance

Based on the study design discussed previously, we collected student responses as well as PCP images (hand-drawn and using an online tool). In this section, we describe and present the analysis of the students' performance in our study. All the training videos, student data, analysis code, and figures can be found in the **supplementary materials** repo on GitHub at <https://github.com/vis-graphics/pcp-literacy>. The significance values reported here are based on the Student's t-test.

4.1. Remember Task

For the Remember task, students were asked to recognize PCPs after watching the tutorial video. We analyzed the responses of the students in both groups (CIF and NF). We found that students in the CIF group performed significantly better ($p < 0.001, t = 6.9454, df = 15.988, \mu_{CIF} = 98.4, \mu_{NF} = 83.02, 95\% CI_{CIF} = 10.688, CI_{NF} = 20.079$) than students in the NF group. Figure 7 shows a comparison of the accuracy of the students in both the groups. The largest difference in accuracy between the CIF and the NF group was observed on Q3 and Q10. Q3 shows students a PCP with 10 polylines and Q10 is a scatterplot. On the other hand, students in both groups had lower accuracy on Q4. Q4 is a PCP, but it does not have more than one clearly visible vertical axis. Students may have misinterpreted it to be a dense line chart.

4.2. Understand Task

For the Understand task, students answered questions related to various aspects of understanding PCPs. Figure 8 shows the accuracy results of the students in both the groups (CIF and NF). Students in the CIF group performed significantly better ($p < 0.001, t = 6.547, df = 11.708, \mu_{CIF} = 94.642, \mu_{NF} = 72.5, 95\% CI_{CIF} = 14.753, CI_{NF} = 29.532$) than those in the NF group. The

Accuracy for Remember Task

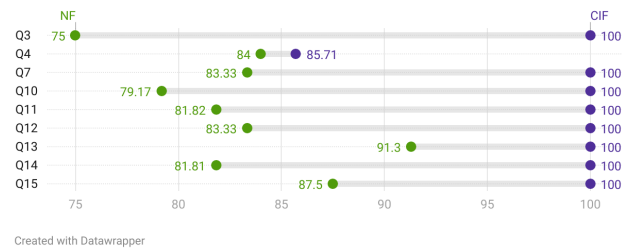


Figure 7: This chart compares the accuracy of the students for the Remember task that required them to identify a PCP (in isolation or in a line-up). The students in the CIF group performed better on all the questions as compared to the students in the NF group.

largest difference in accuracy between the CIF and the NF group was observed on Q2. In Q2, we asked students to identify the axis that has the specified minimum and maximum values. Other questions that had a fairly large difference in accuracy are Q38 and Q31. Both the questions required students to identify the correlation between two variables in the PCP. Students in the CIF group seemed to have a better grasp on the various features as well as correlation between variables in the PCP.

4.3. Apply Task

For the Apply task, PCPs drawn by the students were evaluated. Some of them chose to use color, while others did not. Students were provided a dataset and general instructions to construct a PCP. We used the following rubrics to evaluate the chart:

- Does the chart contain axis labels?
- Does the chart show min/max labels for each axis? If yes, then does the chart show correct min/max values for each axis?

Accuracy for Understand Task

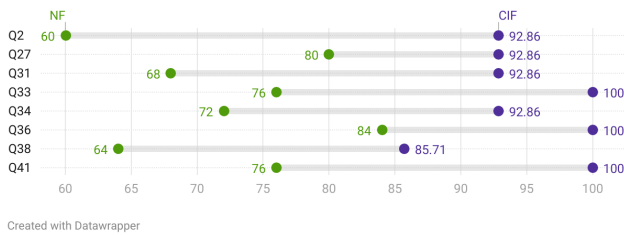


Figure 8: This chart compares the accuracy of the students for the Understand task that required them to correctly interpret a PCP. Students in the CIF group performed better on all the questions as compared to students in the NF group.

- Does the chart show data labels?
- Is the X-axis labeled with a categorical value for each book?
- Did the students plot all the data in the dataset?
- Do the polylines connect correctly across the axes?
- Does the chart use color? If yes, then does the chart contain a color legend?
- Does the chart include any annotations?
- Is the chart accurate (1 – not accurate, 2 – mostly accurate, 3 – completely accurate with no errors)

Based on the rubric above, we graded their charts and found that the students in both the groups made good charts and avoided errors such as missing axis labels or min/max values on an axis. Students in the CIF group had *slightly* higher scores on average (9.1666) than those in the NF group (8.4375).

On analyzing the accuracy of the answers for the Apply task, we found that students in the CIF group had higher accuracy for all the questions in this task. Figure 9 shows the accuracy of the students in being able to answer 5 questions based on their PCP. Students in the NF group scored much lower on the 5th question (E) that required students to follow multiple polylines to correctly answer the question. The average accuracy for the CIF group is 94 whereas the average accuracy for the NF group is 90.91 (with $p = 0.2717$).

Accuracy for Apply Task

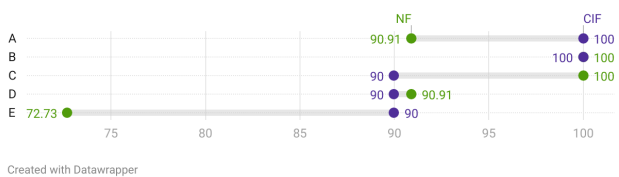


Figure 9: This chart shows the results of evaluating the ability of students to accurately answer questions based on the PCP that they drew in the Apply task.

4.4. Analyze Task

For the Analyze task, the goal was to learn whether students were able to accurately read and draw specific findings from a chart. Figure 10 shows the accuracy of students in both the groups. Students in the CIF group performed significantly better ($p = 0.04, t =$

$2.176, df = 13.341, \mu_{CIF} = 86.61, \mu_{NF} = 75.625, 95\% CI_{CIF} = 0.106, CI_{NF} = 21.858$) in all but one question (Q14_2), where the accuracy of the students in the CIF group was slightly lower. This question required students to arrange multiple PCPs in a sorted order. For Q13 that asked students to determine the correlation between two non-adjacent variables, the accuracy of the students in the NF group was much lower than those in the CIF group. Students in both the groups scored low on Q15, where they were asked to pick the scatterplot that best matched the data being represented in the PCP. It shows that not only was the question difficult, but the students (in both groups) may not yet understand how the same data can be represented in a scatterplot as well as a PCP.

Accuracy for Analyze Task

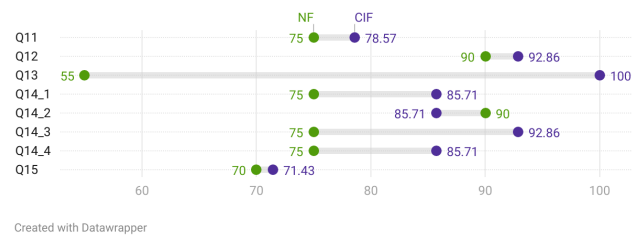


Figure 10: This chart compares the accuracy of the students for the Analyze task in the CIF group as compared to the NF group. Students performed better on all but one of the questions in the CIF group.

4.5. Evaluate Task

For the Evaluate task, students were asked to find the defect in intentionally flawed PCPs. As can be seen from Figure 11 students in the CIF group performed significantly better ($p < 0.001, t = 4.2893, df = 21.166, \mu_{CIF} = 81.632, \mu_{NF} = 53.722, 95\% CI_{CIF} = 14.384, CI_{NF} = 41.435$) at finding the defects as compared to the students in the NF group. Q31 in particular was one where the NF group performed particularly poorly as compared to students in the CIF group. In this question, the axis marks were out of order (for e.g., 10, 50, 20, 30) along one of the dimensions and students were asked to identify the defect in the chart. While students in both the groups performed poorly, almost all the students in the NF group got that question wrong. There was a fairly big difference in the accuracy of the students for Q13, Q17, and Q27. Those questions asked students to notice incorrect color legend, multiple color legends, or large number of axes and data causing clutter in the chart. Students were also shown PCPs with *multiple* defects, and they were asked to record all the defects/errors that they noticed. We analyzed their observations using Qualitative Analysis and the results are presented in Section 4.8.

4.6. Create Task

For the Create task, we analyze the accuracy of the questions they answered based on their charts. Figure 12 shows the accuracy results of the students based on the charts that they created. Students answered questions more accurately in the CIF group as compared to the NF group. The questions increased in difficulty from the first question to the last question. The largest difference in accuracy was

Accuracy for Evaluate Task

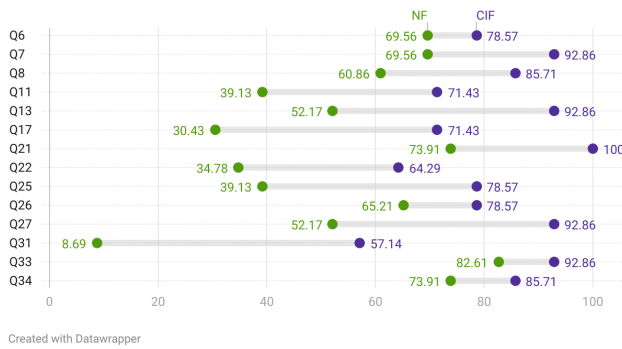


Figure 11: This chart compares the accuracy of the students on the Evaluate task. Students in the CIF group had higher accuracy on all the questions in this module and score 52% higher on average.

noted for the third question (C), which required students to use filtering. Similarly, for Questions D and E, students had to use multiple filters to answer the question correctly. Students in the CIF group demonstrated better understanding of filtering in PCPs. The average accuracy for the CIF group is 79.1 whereas the average accuracy for the NF group is 56.6 (with $p = .00058$).

Accuracy for Create Task

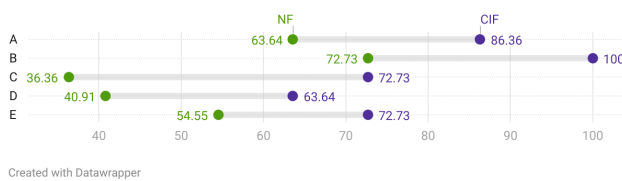


Figure 12: For the Create task, students created a PCP for a specified CSV file using an online tool. This chart shows the accuracy of the answers of the students in both the groups. Students in the CIF group performed significantly better than those in the NF group.

4.7. Post-Experiment Survey - Confidence Analysis

We also asked the students to specify their confidence in being able to recognize, interpret, and create PCPs on their own. Figure 13 shows an overview of the results of the post-experiment survey for both the groups. The students in the CIF group have a higher median and are more confident in their ability to recognize, interpret, and create a PCP. Students in the CIF group also expressed more confidence in using parallel coordinates plots in the future for data exploration.

4.8. Qualitative Analysis

The authors jointly conducted the qualitative analysis to examine the free form text responses of students from both the CIF and NF groups. Students provided these responses to the open-ended questions about parallel coordinates in the Analyze, Evaluate, and Create Module and the post-experiment survey. We coded each response to questions asked in different experiment stages according to the types of questions. The themes were established based on the

Confidence with Parallel Coordinates after Completion

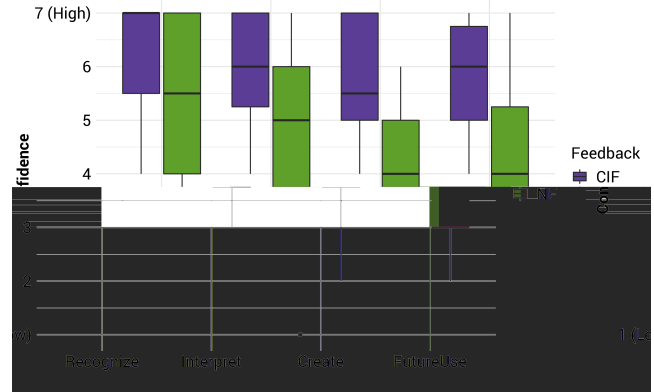


Figure 13: Post-Experiment Survey Results demonstrating student confidence. The students in the CIF group were more confident about recognizing, interpreting, creating charts, and even expressed higher likelihood of using the charts in the future.

Example	Problems	CIF	NF
	Too many colors	85%	42%
	Too many axes	57%	17%
	Too much data	57%	42%
	Small Labels	50%	17%

Table 1: Table shows the problems identified for one of the parallel coordinates examples and the percentage of students who identified the problems in the CIF & NF groups in the Evaluate module. Students in the CIF group spotted more errors than those in the NF group.

parallel coordinates features, making the design difficult or easy to comprehend. As a result of this process, different themes emerged for each module.

Analyze Module: We showed students a 3x3 scatterplot matrix and a PCP to visualize the same data and asked them to specify one advantage and one disadvantage of each technique. For the scatterplot matrix, some students stated that while it is easy to read the chart and see the trend between two data variables (64% CIF and 45% NF), comparing multiple variables and examining the relationship between them is challenging (36% CIF and 19% NF). Regarding the scatterplot matrix, students in CIF and NF groups said “[I] can more clearly see relationships between variables and have to look at multiple plots to gather the full picture” (P1-CIF) and “Scatterplot [matrix] is hard to compare all three categories of data at once” (P7-NF). They also said that the design contains too many graphs (29% CIF and 45% NF).

Regarding parallel coordinate plots, students in both groups mentioned that it is easy to compare data variables (36% CIF and 27% NF), but that it was difficult to read data because of cluster/overplotting (43% CIF and 27% NF). Students also reported that identifying the relationship between all data variables was challenging due to some axes not being adjacent to each other (43% CIF and 9% NF). One student said “Parallel coordinates provide a

quick summary of the data however, a relationship between Horsepower [1st axis] and Miles per Gallon [3rd axis] can't be established." (P6-CIF). Two students from the CIF group pointed out that it is possible to explore the relationship between other data variables by swapping non-adjacent axes: "You may have to rearrange the axes to be able to find the interesting relationships" (P3-CIF). The fact that students in the CIF group mentioned *axis reordering* is very encouraging.

Evaluate Module: We provided two PCPs and asked students to describe all the problems in each plot. We found that more students in the CIF group described the existing problems in the given example PCPs such as too much data, missing color legend etc. 10 students (71%) in the CIF group indicated that there was too much data displayed in the PCP that they saw, while 8 students (67%) in the NF group identified the same problem. A student from the CIF group stated: "No color legend to determine what colors in the chart mean. The data is cluttered." (P4-CIF) and another student from the NF group reported: "Way too much data." (P9-NF).

Similarly, in the second parallel coordinate example, students in the CIF group were more successful in finding more problems. Table 1 shows an example PCP where more students in the CIF group described the existing problems in the given plot such as too many colors, too many axes etc. While 12 students (85%) in the CIF group stated that they used too much color in the sample, only 5 students (42%) in the NF group stated this.

A student from the CIF reported: "There are way too many axes displayed. There are also way too many colors used. The axes labels are too small and difficult to read. There is also too much data." (P2-CIF) while another student from the NF group reported: "Too many axes, the legend has too many Email: apjoshi@usfca.educolors" (P6-NF).

Post-Experiment Survey: We asked students to evaluate their learning experience by reporting which module was the easiest and the most difficult. The Remember module was the *easiest* module (50% CIF and 75% NF), while Apply module was the *most difficult* module (57% CIF and 42% NF) for both groups. A student stated: "I found Module 1 [Remember] to be the easiest since the characteristics of parallel coordinates is very distinct and learning to recognize them was really easy. Module 3 [Apply] was the most difficult since data labels and figuring out the correct part of the axis for a line to pass through was more difficult." (P7-CIF). The students said that there are too many modules, and they would prefer a shorter study since those in the CIF group required 118 minutes on average, whereas those in the NF group required 103 minutes on average.

5. Discussion

Figure 14 shows a summary of the findings from the modules. The students in the CIF group were more accurate in all the six modules as compared to those in the NF group and performed significantly better in 5 out of the 6 modules. The findings indicate that CIF helps students gain proficiency of the underlying concepts in the remember, understand, analyze, and evaluate modules. Based on the qualitative analysis of the free form text that the students used to answer some questions on the Analyze, Evaluate, and Create modules, we found that students in the CIF group were able to

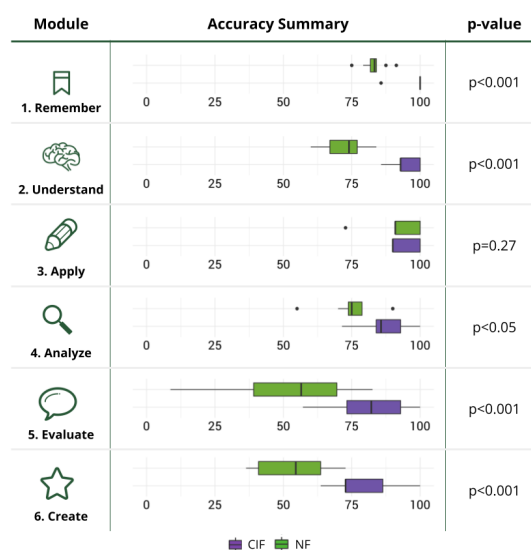


Figure 14: This figure shows a summary of the accuracy findings from the six modules with and without CIF. Students in the CIF group performed significantly better in all the modules, except the Apply module. The spread of the accuracy scores for the students in the NF group is much bigger for the Apply, Evaluate, and Create module than the CIF group.

make astute observations such as when they mentioned the need to rearrange axes (to bring them next to each other) to better understand the relationship between two variables in the chart. Students in the CIF group also observed missing color legends or missing axes labels more often than students in the NF group.

We believe that the Bloom's taxonomy based approach to literacy provides a deeper understanding of a visualization technique.

5.1. Limitations

One of the limitations of our approach is that we only used the video modality for instruction. We could experiment with an interactive tool as the training technique instead [KL16]. All our students were undergraduate students, and we need to conduct a follow up study with general audiences to evaluate the modules and tests. Many of the students informed us that the intervention was too long (especially with CIF) and may have caused fatigue to set in towards the end.

6. Conclusion and Future Work

We developed six new parallel coordinates literacy modules aligned with the cognitive levels in the Bloom's taxonomy. Based on our study, we found that students who took the modules using a Continuous Immediate Feedback approach were more accurate and had a better understanding of the components and workings of a parallel coordinates chart. Students in both the groups showed an increased understanding of parallel coordinates and expressed higher confidence as the study progressed. In the future, it would be interesting to examine whether general audiences can study PCPs using our modules and tests.

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