in other task categories (Figure 3(b)). We did not find interaction effects between Condition and Question.

For duration, we found a significant main effect of Condition, $F(3, 2264) = 11.09$, $p < .001$. Post hoc analysis shows that the mean duration of the Baseline condition was significantly higher than the rest (Figure 4(a)). We also found a significant main effect of Question $F(3, 2264) = 24.08$, $p < .001$. Post hoc analysis shows that the mean duration of the Distribution & Comparison category ($M = 21.78$, $SD = 1.83$) was lower than those of Correlation & Cluster ($M = 42.70$, $SD = 1.83$) and Filter and Multicriteria evaluation ($M = 36.70$, $SD = 1.82$), respectively (Figure 4(b)). The mean duration of the Mapping category ($M = 31.65$, $SD = 1.48$) was lower than that of the Correlation & Cluster category.

We analyzed survey responses using a Kruskal-Wallis test, and found a significant association between condition and all survey responses: engagement level of the tutorial ($\chi^2(2, 90) = 12.81$, $p = .002$), the fun level of the tutorial ($\chi^2(2, 90) = 10.93$, $p = .004$), interestingness of the tutorial ($\chi^2(2, 90) = 16.04$, $p < .001$), easiness of the tutorial ($\chi^2(2, 90) = 24.68$, $p < .001$), participants' confidence of parallel coordinates ($\chi^2(2, 90) = 12.92$, $p = .002$), and their perceived understanding of parallel coordinates ($\chi^2(2, 90) = 10.07$, $p = .007$). Pair-wise Wilcoxon test shows that participants with the Video and Interactive tutorials felt more engaged and interested, had more fun, found it easier to follow the tutorial, understood better, and felt more confident with parallel coordinates than those with the Static tutorial.

## DISCUSSION AND CONCLUSION

Reflecting upon our results, we discuss implications and future direction from our study.

### Potential of Online Learning for Visualizations

Our study showed that crowdsourced non-experts could learn parallel coordinates and perform analytic tasks through 10-minute guided tutorials for learning. As the parallel coordinate is believed to be difficult for the general public to learn and understand, we are pleasantly surprised by the overall accuracy (mean score across all conditions = .77). In particular, participants with Video and Interaction conditions achieved higher scores than those with the Baseline condition, which indicate that this short tutorial can improve students' understanding of parallel coordinates.

In addition, participants generally liked the idea of the online learning tutorials for parallel coordinates regardless of their conditions. They acknowledged that learning parallel coordinates seemed difficult at first, but it turned out to be very easy and fun to follow structured guidance: "*This is how it should be taught in high school and grade school.*" (P54, Interactive); "*I took one look at the beginning and almost backed out but decided to give it a try. I am so glad I did.*" (P16, Video). However, participants of the Static condition reported difficulty in absorbing concepts. Some participants of the Static condition could not grasp the parallel coordinate visualization in the end: "*It was a bit confusing, I had trouble knowing I understood the principles*" (P36, Static).

### Interactive Tutorial vs. Video Tutorial

Though we did not find statistical differences between the Interactive and Video conditions in terms of accuracy, participants with the Interactive condition performed better than the Static and Baseline conditions while those with the Video condition performed better than the Baseline condition only. Furthermore, participants feedback generally favored the Interactive condition. Some participants of the Video condition commented that they had to watch multiple times to understand the concept. : "*Some videos I had to watch a few times to grasp the idea*" (P52, Video).

Note that participants of the Interactive condition acknowledged that the tutorials were easy to follow without reporting any difficulty: "*Loved the way it was presented. Coming into this I had no experience in the subject. I found it to be very interesting and easy to follow*" (P17, Interactive). Furthermore, they enjoyed following the tutorial activities: "*I thought the tutorial was fun and interactive. I liked that I got to apply what I learned right away to ensure that I got what it was talking about*" (P77, Interactive).

### Learning Core Concepts of Parallel Coordinates

Contrary to our expectation, participants achieved high overall accuracy even with Baseline. This might be because we used a simple and small dataset, which would not overwhelm lay people but would still be useful to teach the core concepts for the PC comprehension. On the other hand, they did poorly on correlation tasks. These results suggest that it is not very difficult to learn how data items are mapped to visual elements in PC, but it is not easy to understand the patterns for correlation and to interact with PC to find the appropriate view to identify those patterns. The real-world datasets would be much larger than the simple datasets we used in our study, and performing an exploratory analysis with real-world data to identify hidden insights would require more advanced skills than understanding the basic concepts of parallel coordinates. Further research is needed to design better activities potentially with more complex datasets, and to study interactive tutorials for advanced tasks such as complex decision-making tasks with large datasets.

### Toward Generalizing Guided, Interactive Tutorials

Our results can be generalized to other multidimensional visualizations with unfamiliar layouts such as star coordinates. We also believe that the interactive tutorial approach can be applied to other visualization types (e.g., pixel bar chart, matrix visualization) where one data item can be mapped to graphic elements such as size or color. For example, we could create a guided, interactive tutorial for a matrix-based graph visualization based on existing graph visualization task taxonomies (e.g., [8]). Rows and columns can be coupled with a list of nodes, and each cell can be connected with a list of links. Our study results also encourage the further investigation into a systematic approach to teach visualizations by leveraging the learning-by-doing approach.

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