Understanding Graph Reading and Comprehension through Eye-Tracking: Evidence for the Expert/Novice Dichotomy

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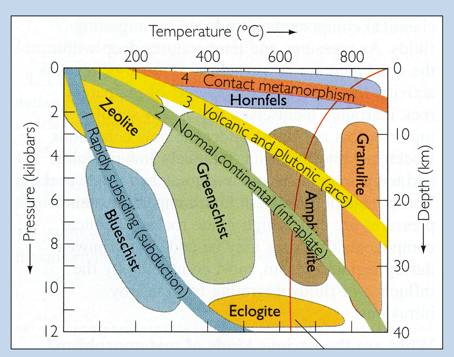
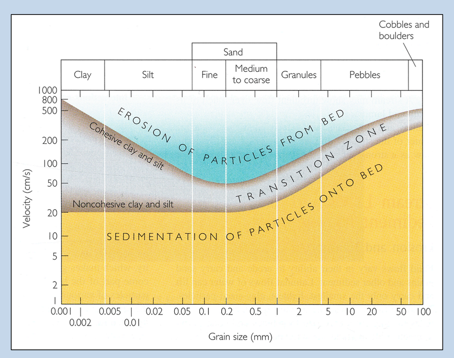
Abstract

Graphical information is used in many aspects of our lives, including vocation, media, civic processes, scientific inquiry, and education, so graph comprehension is an essential skill for informed citizenry. However, relatively little is known about how individuals perform graph-reading tasks or how these skills develop over time. Furthermore, many different forms of graphical information are used in earth science courses (e.g., "upside down" binary plots with a depth variable increasing in a downward direction; log-scales; normalized trace element diagrams; ternary plots) and can present significant thresholds for student learning. Here, we describe the results from an on-going two-year collaborative study on the skills and challenges behind graph reading and scientific literacy. Our data provides interesting insights into the differences between and within expert and novice populations that we hope will eventually illuminate new ways for improving students' graph comprehension skills.

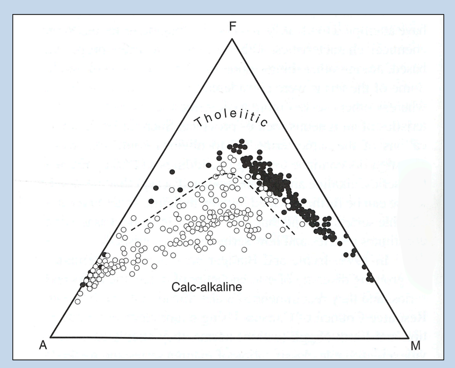
Within our expert and novice pools (distinguished by level of education), measures of the accuracy of graph interpretation show a clear dichotomy between the two groups. Experts (faculty and staff) are more accurate in interpreting graphical media. In comparison, novices (undergraduate students), regardless of their level of degree completion, exhibit significantly different approaches (based on eye-fixation dwell times, fixation order, interest-area regressions, interest-area eye dwell times) to graph reading.
Interestingly, most study participants exhibited similar eye-track metrics while examining graph after being prompted to find specific information. However, novices and experts show very different eye-track behaviors when they are asked to examine a graph without a specific prompt; the expert behavior remains largely the same as under the prompted conditions, but the novice behavior does not. Analyses of "think-alouds" during the eye-track experiments suggest that experts, with their more developed metacognitive skills, more commonly engage in self-questioning, narrative construction, monitoring, and self-assessment while examining graphs.



Press & Siever (2001)



Press & Siever (2001)



Winter (2010)

Eye-Tracking Experiment

- Experimental graphs were designed to be similar to common geoscience graph formats, but with non-disciplinary content.
- Thirty-eight novices (students from all disciplines) and twenty-five experts (faculty and staff from all disciplines) viewed graphs under unprompted conditions, then responded to questions at three different levels (description, interpretation, and prediction; after Friel et al., 2001)
- Eye-track data were recorded using an EyeLink 1000 eye-tracking device (SR Research Ltd) in the Macalester College Psychology Department iLab
- All subjects participated voluntarily; students received credit for completing the eye-track session and a reflection on graphs and graph use skills

Null Hypotheses:

Categorization Null: There is no difference between expert and novice population graph reading performance accuracy, eye movements, and fixation foci.

Novice Distribution Null: There are no differences within the novice population graph reading performance accuracy, eye movements, and fixation foci.

Expert Distribution Null: There are no differences within the expert population graph reading performance accuracy, eye movements, and fixation foci.

Table 1. Demographic information.

	Novice (n=38)		Expert (n=25)	
	Number	Percent	Number	Percent
Gender				
Male	13	34.2	18	72.0
Female	25	65.8	7	28.0
Race/Ethnicity				
African American	1	2.6	0	0.0
Asian American	1	2.6	1	4.0
Foreigner	4	10.5	3	12.0
Hispanic/Latino	1	2.6	1	4.0
Pacific Islander	1	2.6	0	0.0
White	30	78.9	20	80.0
Academic Division				
Fine Arts	2	5.3	2	8.0
Humanties	10	26.3	4	16.0
Natural Sciences	21	55.3	10	40.0
Social Sciences	5	13.2	9	36.0
Graph-Experience Class				
Science	21	55.3	10	40.0
Graphical Non-Science	5	13.2	10	40.0
Non-Graph Non-Science	12	31.6	5	20.0
Completed Semesters of Study				
0	8	21.1	n/a	n/a
1 to 2	17	44.7	n/a	n/a
3 to 4	6	15.8	n/a	n/a
5 to 6	5	13.2	n/a	n/a
7 to 8	2	5.3	n/a	n/a

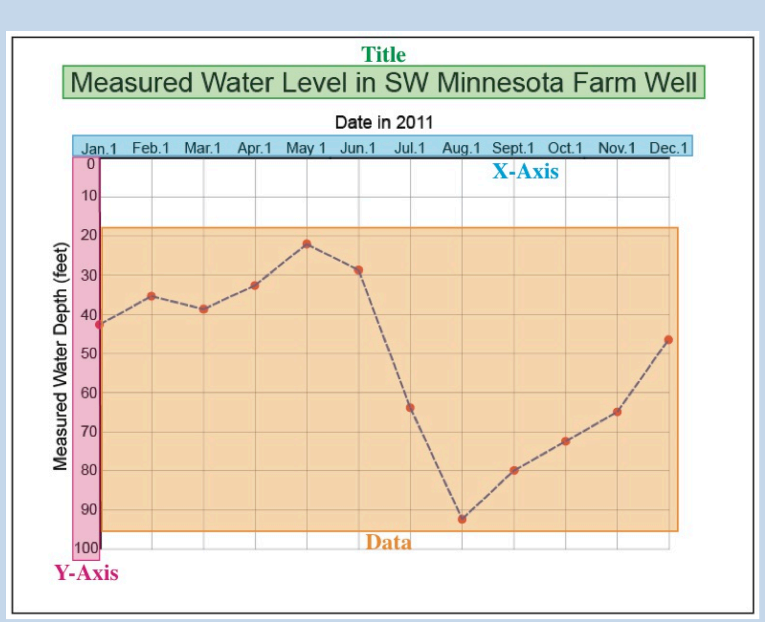


Figure 1. Inverted binary line graph showing the outline of interest areas used in the quantification of fixation parameters.

Results

Table 2. Response accuracies for novices and experts on each of four key graph formats (see Figures 2-5). Significant (p < 0.01) in bold and italic.

	Traditional Binary Line Plot		Traditional Binary Scatter Plot		Inverted Binary Plot		Ternary Plot	
	Novice	Expert	Novice	Expert	Novice	Expert	Novice	Expert
Multiple-Choice Accuracy	***0.8 ± 0.1***	***0.9 ± 0.1***	***0.8 ± 0.1***	***0.9 ± 0.1***	***0.7 ± 0.1***	***0.9 ± 0.1***	***0.7 ± 0.1***	***0.9 ± 0.1***
Intepretation Accuracy	***4.0 ± 0.8***	***4.5 ± 0.9***	**3.9 ± 0.8**	***4.5 ± 1.0***	***3.5 ± 1.1***	***4.3 ± 1.0***	*3.4 ± 1.0*	*4.1 ± 1.0*
Prediction Accuracy	***3.6 ± 1.1***	***4.4 ± 0.9***	***3.7 ± 1.2***	***4.3 ± 0.9***	***3.3 ± 0.9***	***4.2 ± 0.9***	***3.2 ± 1.2***	***4.1 ± 0.9***

Table 3. Descriptive statistics for response accuracies and quantified eye-track data for novices and experts. Significant (p < 0.05) in bold and italic.

	Category	Sub-Category	n	Multiple-Choice Accuracy	Intepretation Accuracy	Prediction Accuracy	Average Fixation Duration	Total Fixations	Total Runs
		Possible Range:		(0,1)	*(1,5)*	*(1,5)*	*(0,∞)*	*(0,∞)*	*(0,∞)*
		Novice	38	***0.7 ± 0.1***	***3.9 ± 1.3***	***3.5 ± 1.2***	255 ± 38	***400 ± 110***	***110 ± 35***
		Expert	25	***0.8 ± 0.1***	***4.5 ± 1.0***	***4.6 ± 0.9***	234 ± 48	***110 ± 18***	***30 ± 8***
Gender	Female	Novice	25	***0.7 ± 0.2***	***4.0 ± 1.3***	***3.6 ± 1.2***	257 ± 32	***400 ± 110***	***110 ± 35***
		Expert	7	***0.8 ± 0.1***	***4.2 ± 1.2***	***4.4 ± 0.9***	246 ± 42	***110 ± 15***	***30 ± 7***
	Male	Novice	13	***0.7 ± 0.1***	***3.8 ± 1.3***	***3.2 ± 1.2***	249 ± 48	***400 ± 120***	***110 ± 35***
		Expert	18	***0.8 ± 0.1***	***4.6 ± 0.8***	***4.6 ± 0.8***	230 ± 49	***110 ± 19***	***30 ± 9***
Academic Division	Fine Arts	Novice	2	***0.6 ± 0.2***	***4.1 ± 1.2***	***3.1 ± 1.1***	248 ± 35	***400 ± 94***	***100 ± 30***
		Expert	2	***0.9 ± 0.1***	***4.8 ± 0.8***	***4.6 ± 0.8***	237 ± 53	***111 ± 17***	***29 ± 8***
	Humanities	Novice	10	0.8 ± 0.1	***3.4 ± 1.2***	***3.1± 1.0***	267 ± 38	***360 ± 72***	***100 ± 29***
		Expert	4	0.8 ± 0.1	***4.4 ± 1.1***	***4.4 ± 1.0***	233 ± 42	***112 ± 17***	***28 ± 8***
	Natural Science	Novice	21	***0.8 ± 0.1***	***3.5 ± 1.2***	***3.2 ± 0.9***	263 ± 37	***340 ± 68***	***100 ± 29***
		Expert	10	***0.9 ± 0.1***	***4.6 ± 1.0***	***4.4 ± 1.0***	231 ± 39	***112 ± 17***	***33 ± 8***
	Social Science	Novice	5	***0.7 ± 0.2***	***3.5 ± 1.3***	***2.9 ± 1.2***	243 ± 41	***400 ± 130***	***130 ± 42***
		Expert	9	***0.8 ± 0.1***	***4.5 ± 1.1***	***4.6 ± 0.7***	214 ± 39	***130 ± 12***	***33 ± 8***
Graph-Expereince Class	Graphical Science	Novice	21	***0.7 ± 0.2***	***4.2 ± 1.2***	***3.8 ± 1.2***	256 ± 36	***380 ± 96***	***100 ± 30***
		Expert	10	***0.9 ± 0.1***	***4.7 ± 0.8***	***4.7 ± 0.8***	247 ± 54	***112 ± 19***	***31 ± 8***
	Graphical Non-Science	Novice	5	0.8 ± 0.1	***3.6 ± 1.2***	***3.2 ± 1.0***	264 ± 33	***350 ± 65***	***100 ± 29***
		Expert	10	0.8 ± 0.1	***4.4 ± 1.1***	***4.4 ± 1.0***	233 ± 45	***108 ± 18***	***30 ± 8***
	Non-Graph Non-Science	Novice	12	***0.6 ± 0.1***	***3.5 ± 1.3***	***2.9 ± 1.1***	249 ± 42	***400 ± 140***	***130 ± 42***
		Expert	5	***0.8 ± 0.1***	***4.4 ± 1.1***	***4.6 ± 0.8***	216 ± 33	***120 ± 13***	***30 ± 8***
Novice-Only	Number of Completed Semesters	0	8	0.7 ± 0.1	3.4 ± 1.4	2.9 ± 1.0	245 ± 44	360 ± 73	110 ± 30
		1 to 2	17	0.7 ± 0.1	3.8 ± 1.3	3.3 ± 1.2	254 ± 40	400 ± 120	110 ± 40
		3 to 4	6	0.8 ± 0.2	4.3 ± 1.1	3.9 ± 1.2	269 ± 29	370 ± 86	100 ± 27
		5 to 6	5	0.8 ± 0.1	4.0 ± 1.3	3.7 ± 1.3	264 ± 25	370 ± 82	110 ± 32
		7 to 8	2	0.9 ± 0.1	4.4 ± 0.9	4.1 ± 1.1	227 ± 26	500 ± 112	130 ± 32

Quantified Elements of Eye-Tracks

Fixation
A pause in eye movement; proxy for visual attention

Run
Eye-movement in or out of a defined interest area

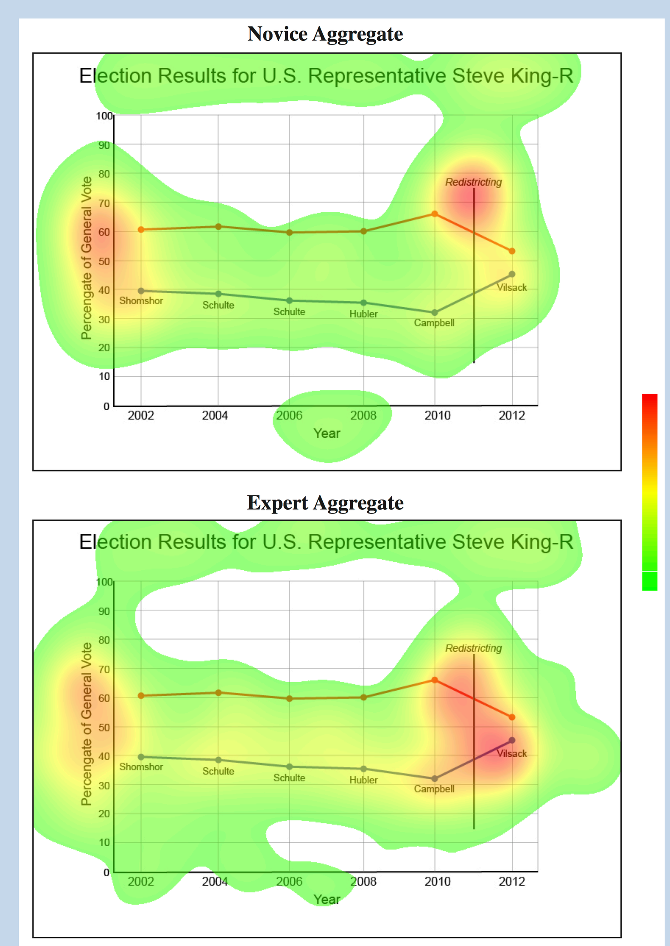


Figure 2. Novice and expert aggregated fixation density map for our traditional line graph.

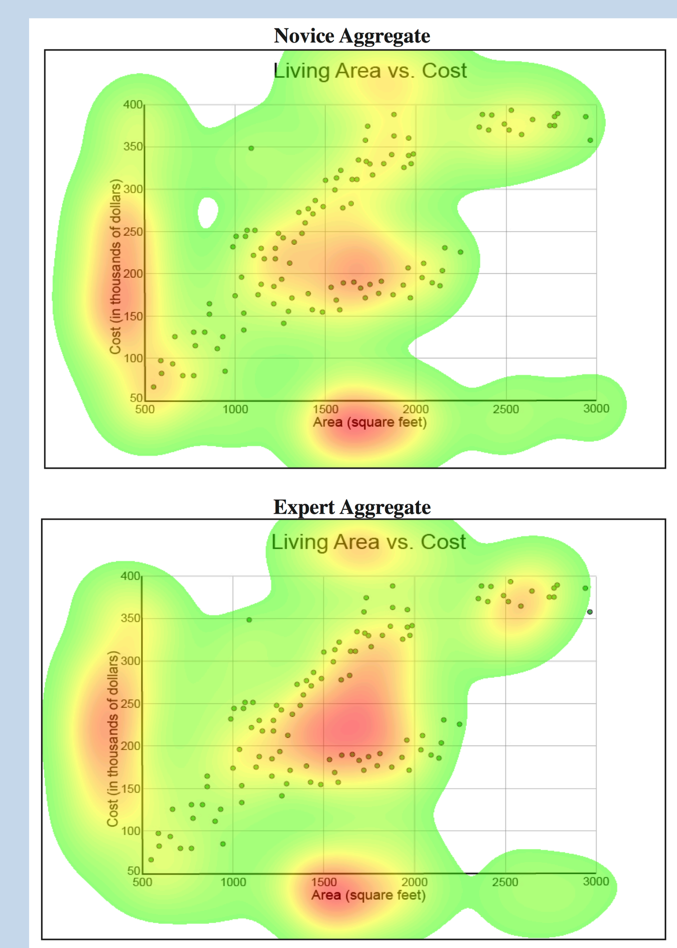


Figure 3. Novice and expert aggregated fixation density map for our traditional scatter graph.

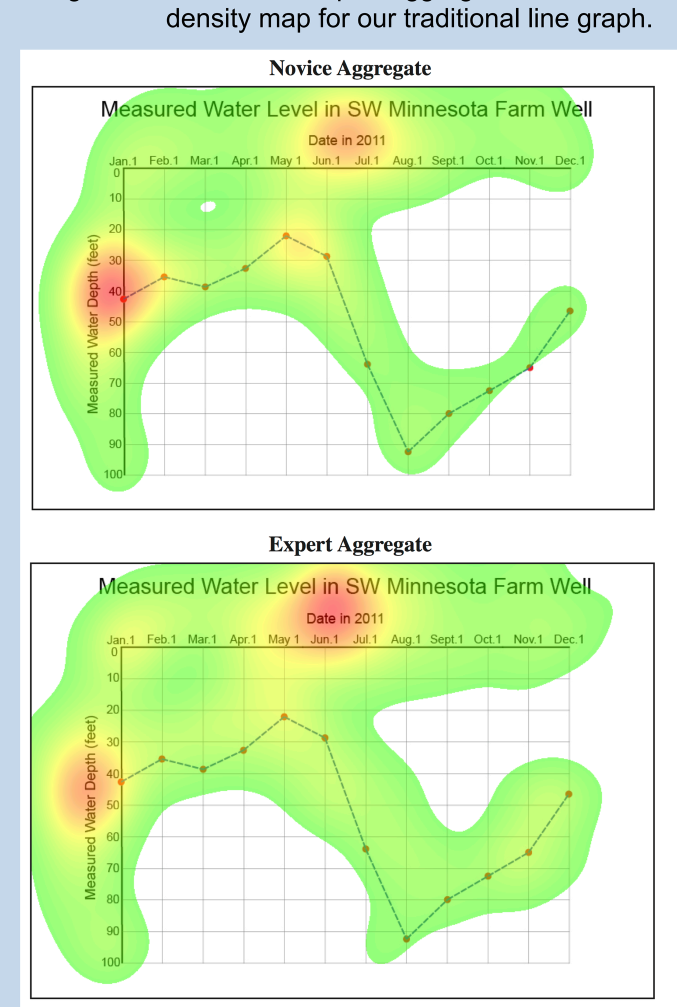


Figure 4. Novice and expert aggregated fixation density map for our inverted line graph.

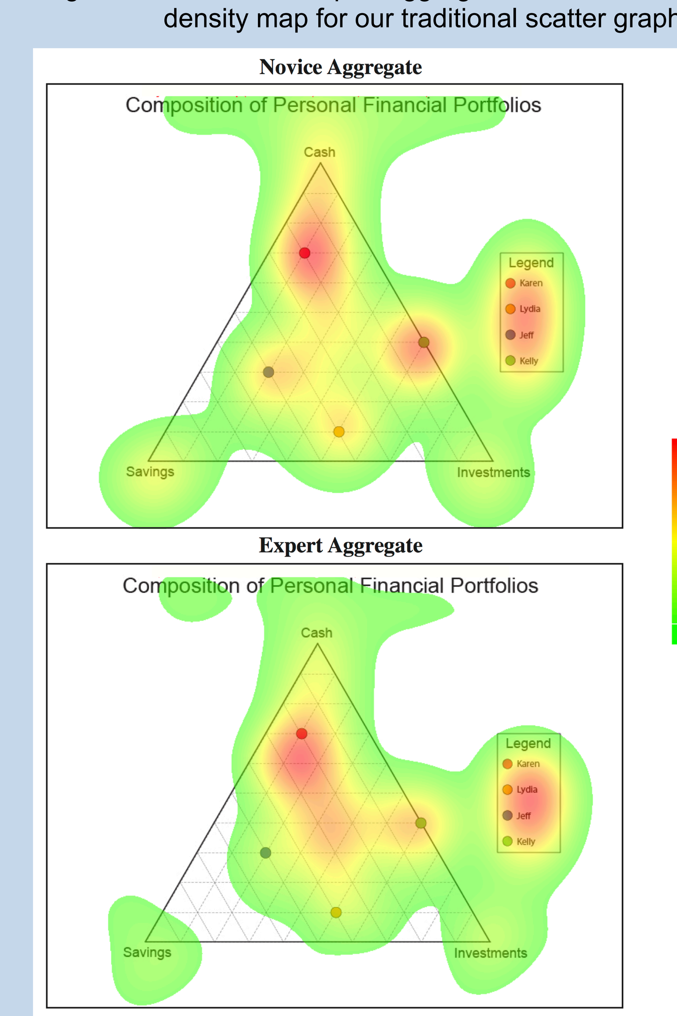


Figure 5. Novice and expert aggregated fixation density map for our ternary graph.

Discussion

- Despite having similar eye-track heat maps, experts consistently out-perform novices in terms of response accuracy. What do they do differently?
- In terms of quantified eye-track elements, experts and novices are more similar on traditional graphs than on novel graph formats (Figure 7). In general, experts also have shorter fixation durations, they look at the entire graph area, and they move about at a faster rate
- The amount of time that both groups spend fixated in the different interest areas is similar, but experts on average spend more time looking at the data and axes
- Although we can differentiate between novices and experts, and within the novice group we see a correlation based on academic division, no such difference exists within the expert group suggesting that novice-expert differences are unrelated to disciplinary expertise.

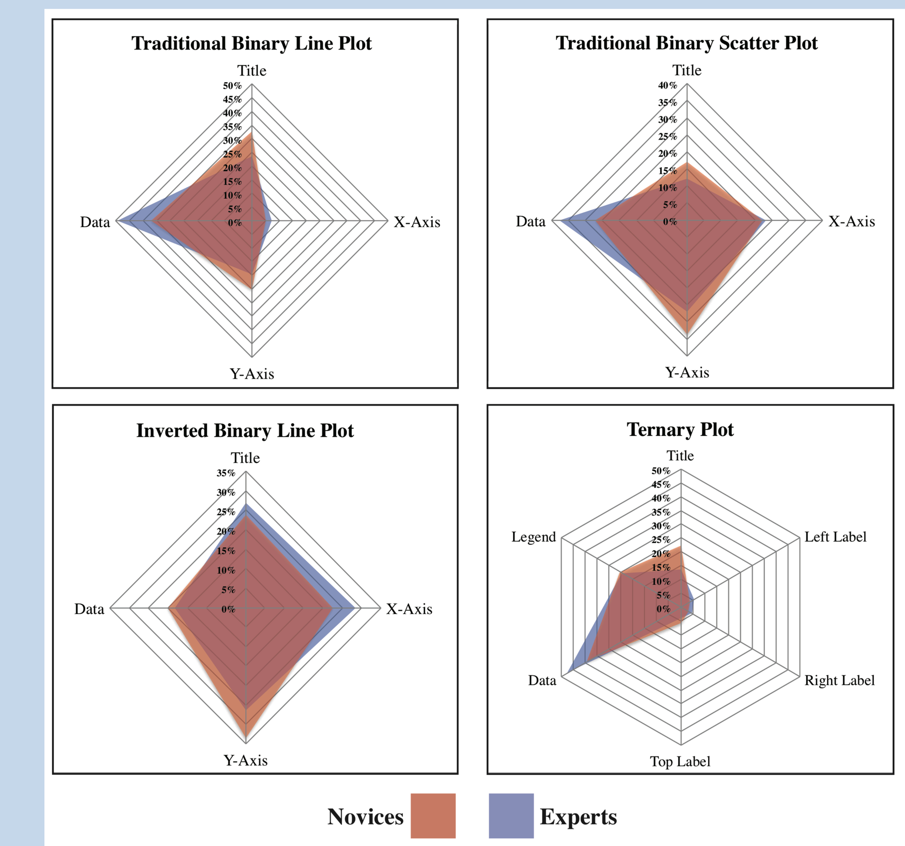


Figure 6. Radar plots of the proportions of fixations in different interest areas on all four graph types by novices and experts.

Conclusions

- The expert-novice categorization of the study population yields the highest correlation with response accuracy. (categorization null rejected)
- Within the novice population, the only demographic variables that correlate with response accuracy are the number of science and math courses completed and self-identified experience with graphs (more generally, major discipline). Correlation with the number of lab-based college science courses is not significant. (novice distribution null rejected)
- Within the expert population, there are no significant differences in accuracy or quantified eye fixation parameters, regardless of disciplinary expertise (expert distribution null not rejected)
- Novice and expert populations have distinct eye movement patterns while viewing traditional graph formats, and especially during unprompted conditions.

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Acknowledgements

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