

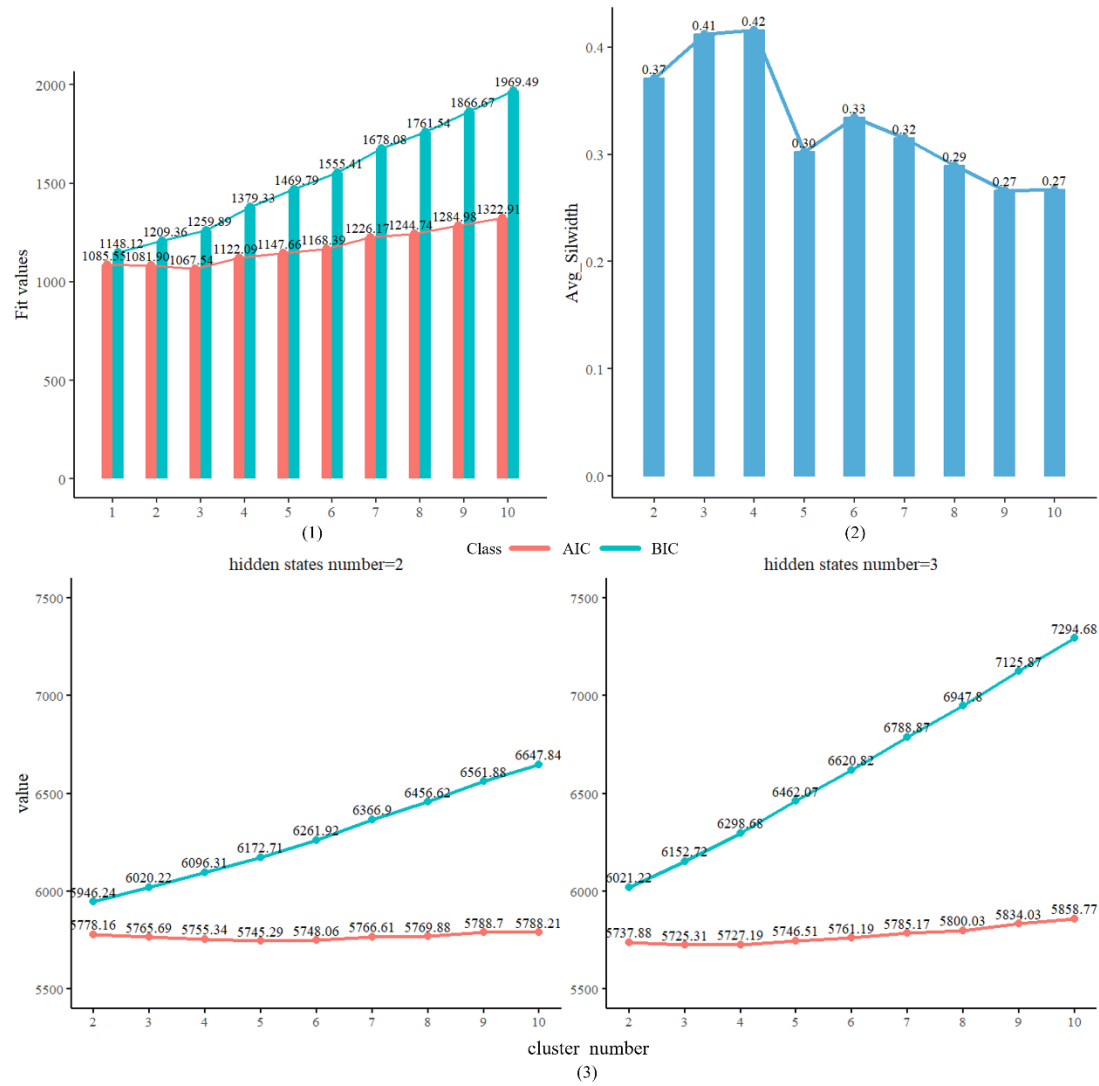


Figure S1 Optimal number of clusters by AIC, BIC, and silhouette value: (1) LCA, the AIC gets minimum at 3 clusters (1067.54), whereas the BIC shows a consistent upward trend with the smallest increment observed at 3 clusters ($50.53 = 1259.89 - 1209.36$). (2) SOM, maximum at 4 clusters (silhouette value = 0.42). (3) MHMM, the AIC gets the minimum at 3 clusters and 3 hidden states, the BIC gets the smallest increment observed at 3 clusters.

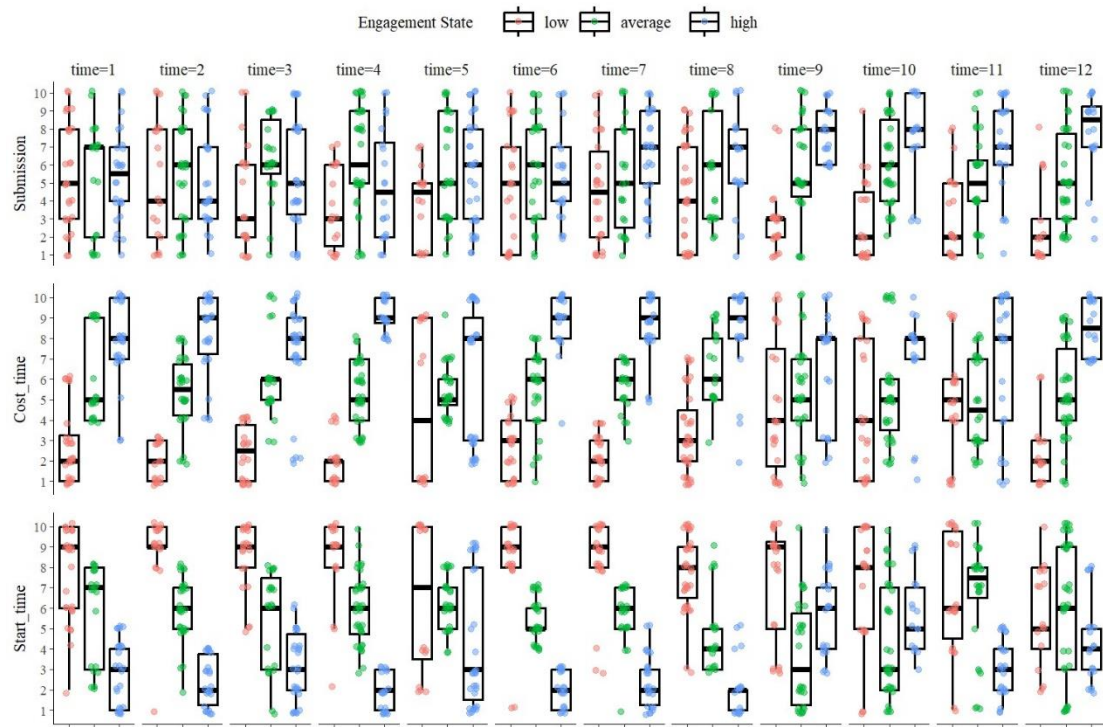
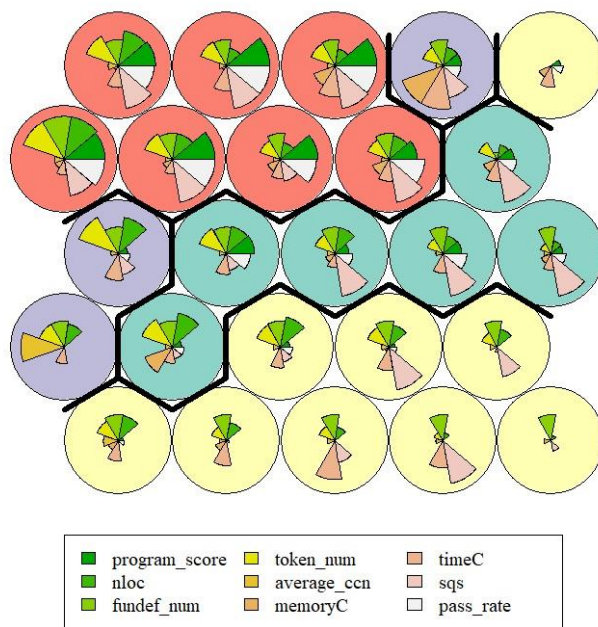
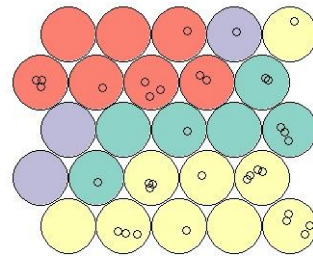


Figure S2 Boxplot of each indicator for each cluster across 12 tests.

Code Metrics Visualization Map: $t = 1$



Math



CS

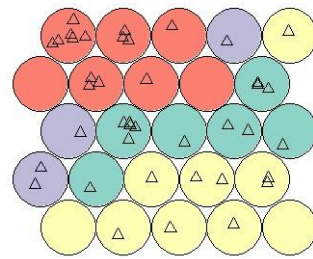
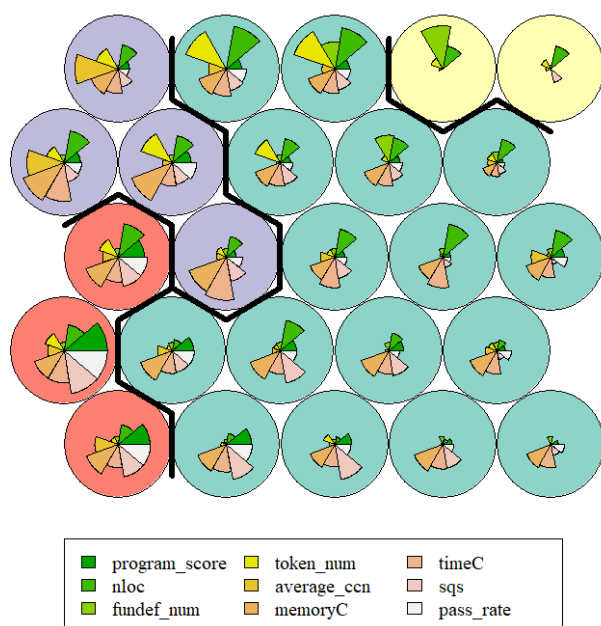
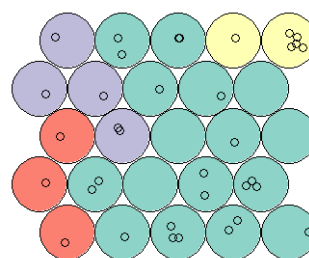


Figure S3 Mapping plots of code metrics at $t = 1$ with four clusters.

Code Metrics Visualization Map: t = 2



Math



CS

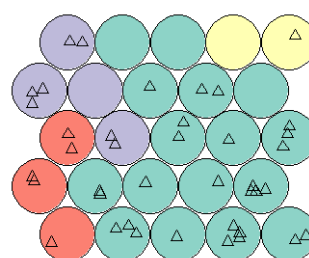
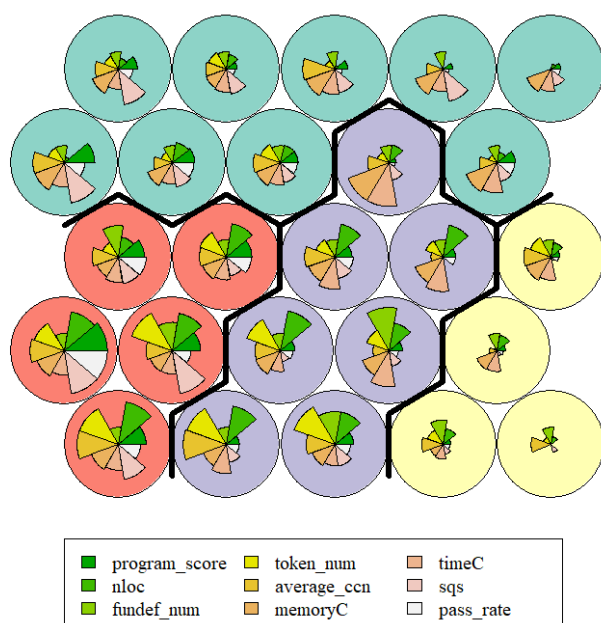
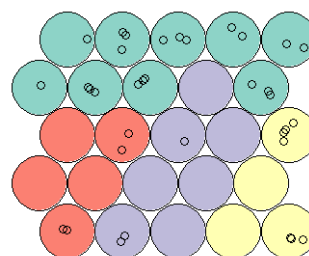


Figure S4 Mapping plots of code metrics at t = 2 with four clusters.

Code Metrics Visualization Map: t = 3



Math



CS

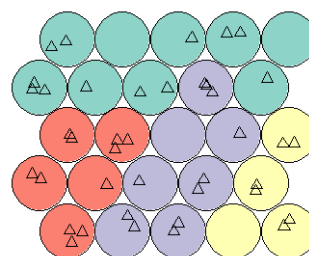
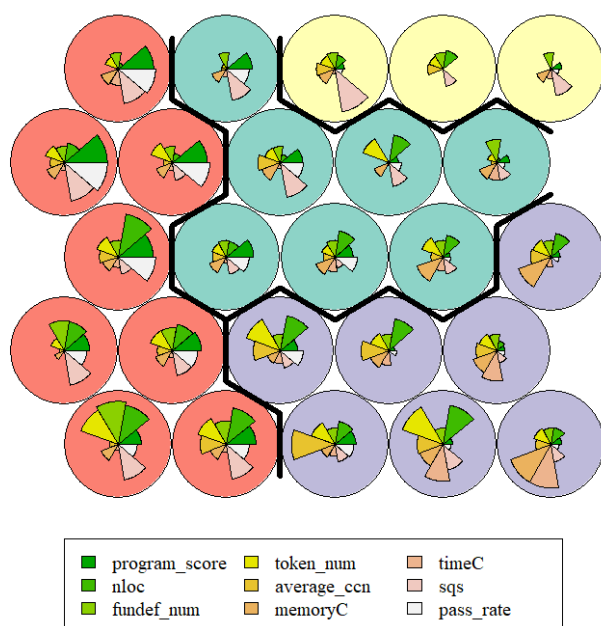
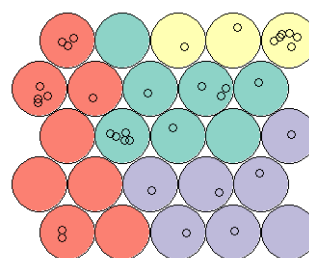


Figure S5 Mapping plots of code metrics at t = 3 with four clusters.

Code Metrics Visualization Map: t = 4



Math



CS

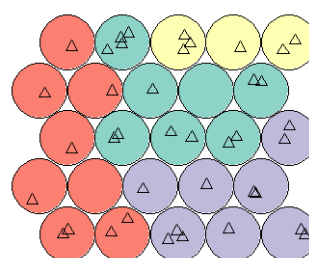
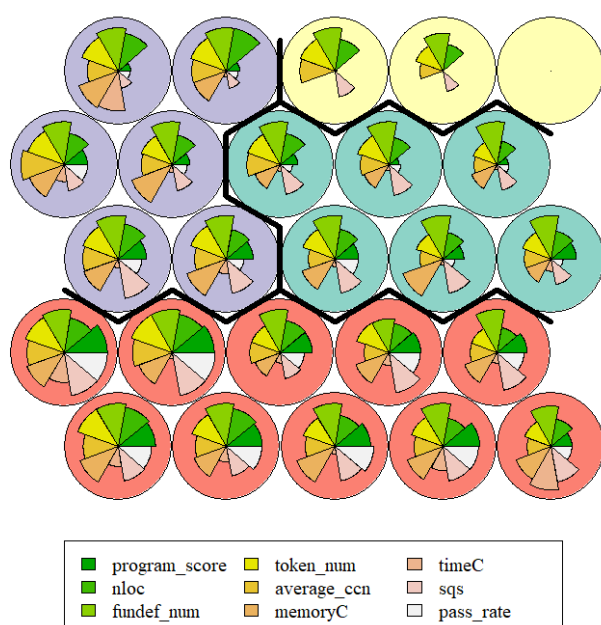
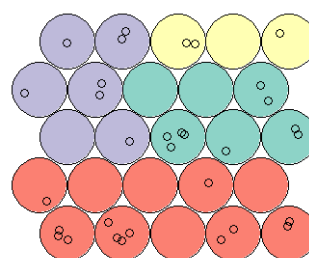


Figure S6 Mapping plots of code metrics at t = 4 with four clusters.

Code Metrics Visualization Map: t = 5



Math



CS

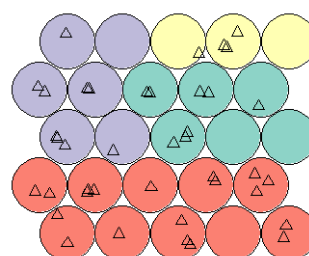
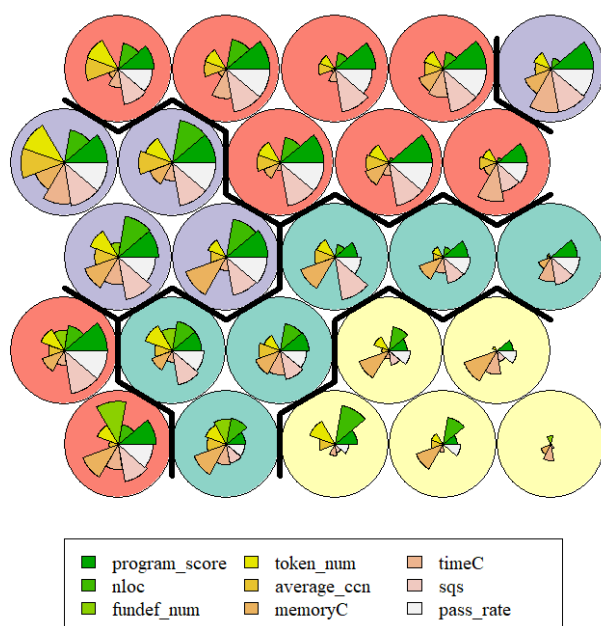
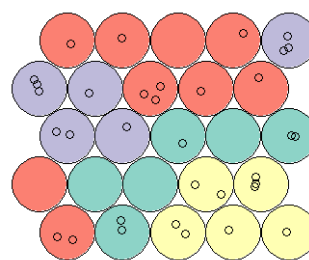


Figure S7 Mapping plots of code metrics at t = 5 with four clusters.

Code Metrics Visualization Map: t = 6



Math



CS

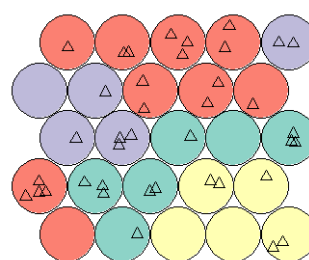
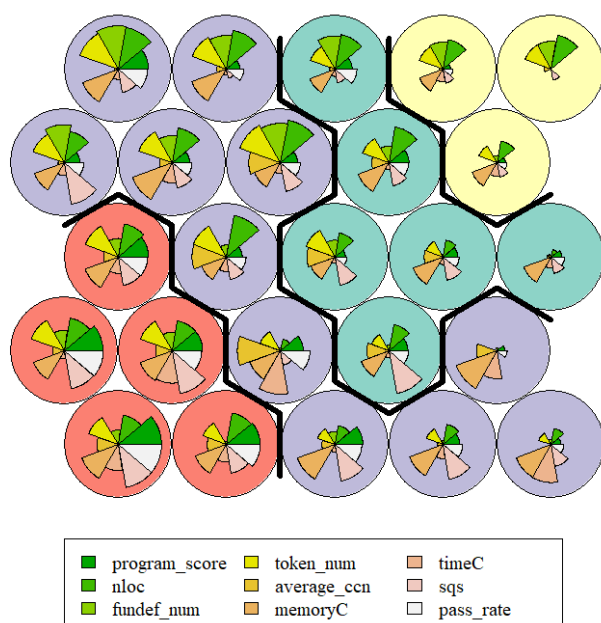
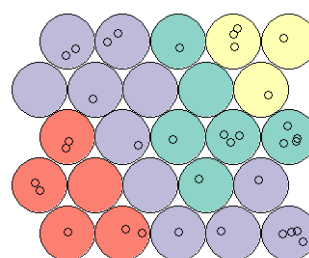


Figure S8 Mapping plots of code metrics at t = 6 with four clusters.

Code Metrics Visualization Map: t = 7



Math



CS

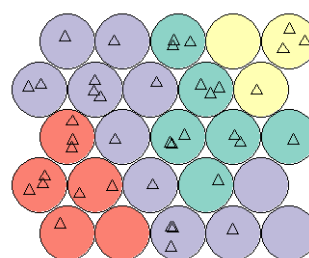
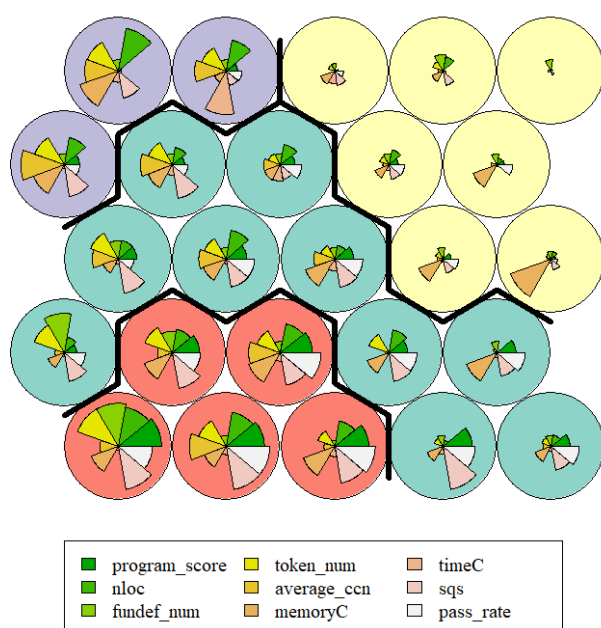
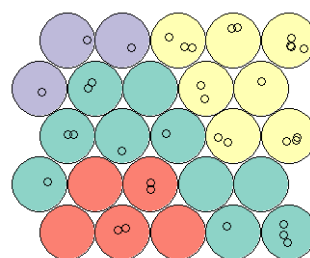


Figure S9 Mapping plots of code metrics at t = 7 with four clusters.

Code Metrics Visualization Map: t = 8



Math



CS

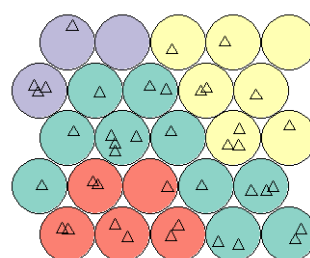
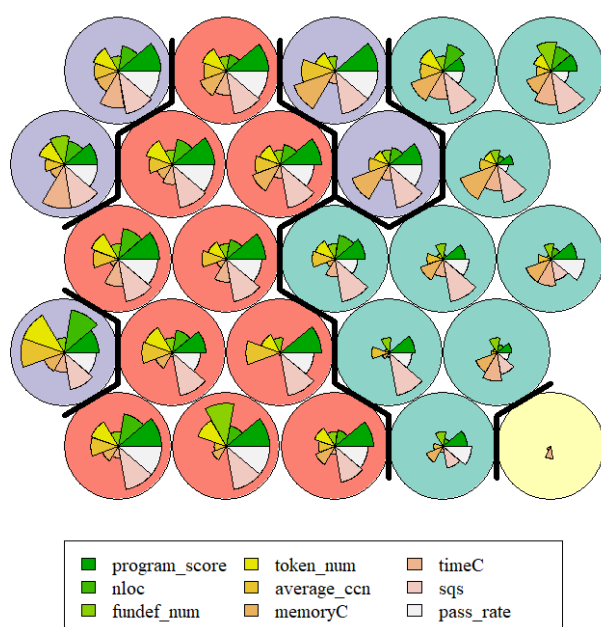
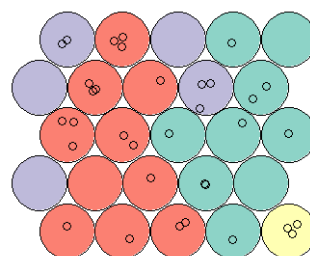


Figure S10 Mapping plots of code metrics at t = 8 with four clusters.

Code Metrics Visualization Map: t = 9



Math



CS

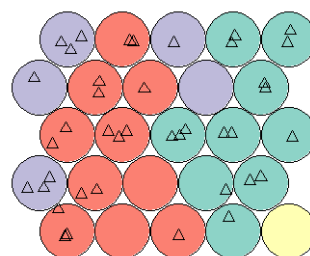
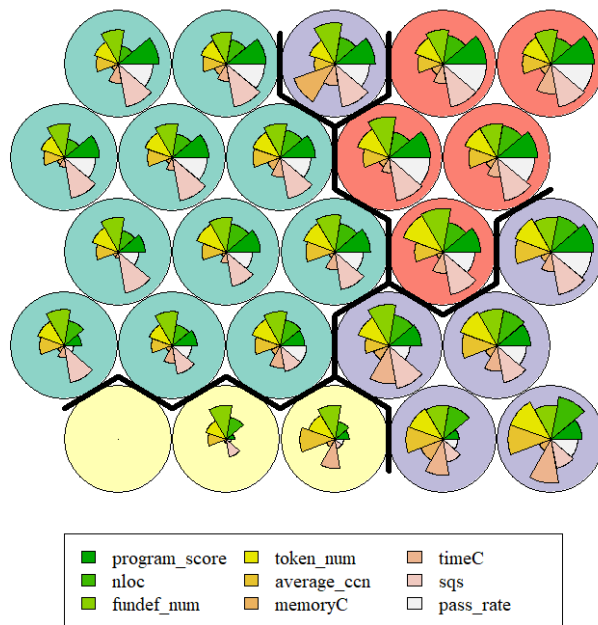
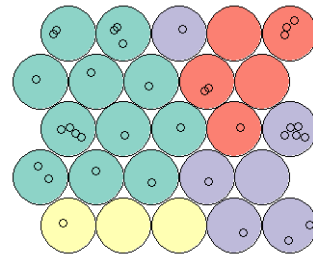


Figure S11 Mapping plots of code metrics at t = 9 with four clusters.

Code Metrics Visualization Map: t = 10



Math



CS

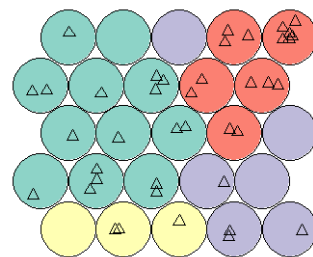
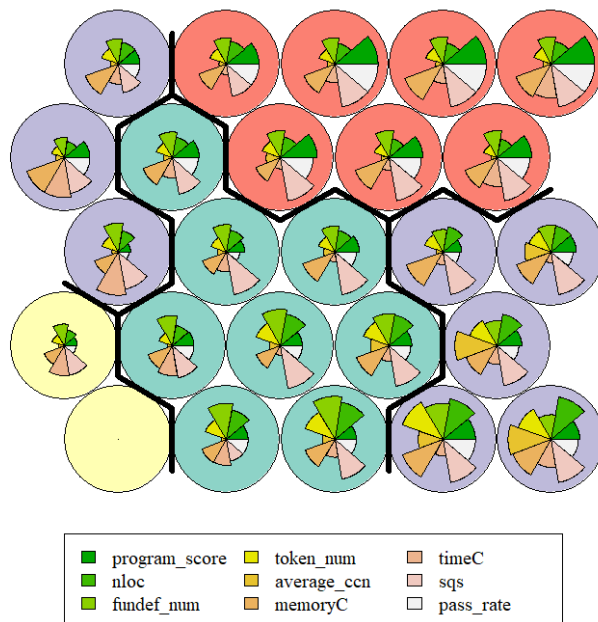
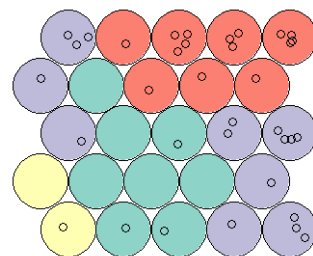


Figure S12 Mapping plots of code metrics at t = 10 with four clusters.

Code Metrics Visualization Map: t = 11



Math



CS

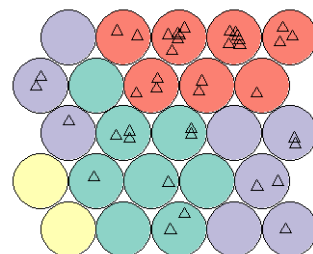
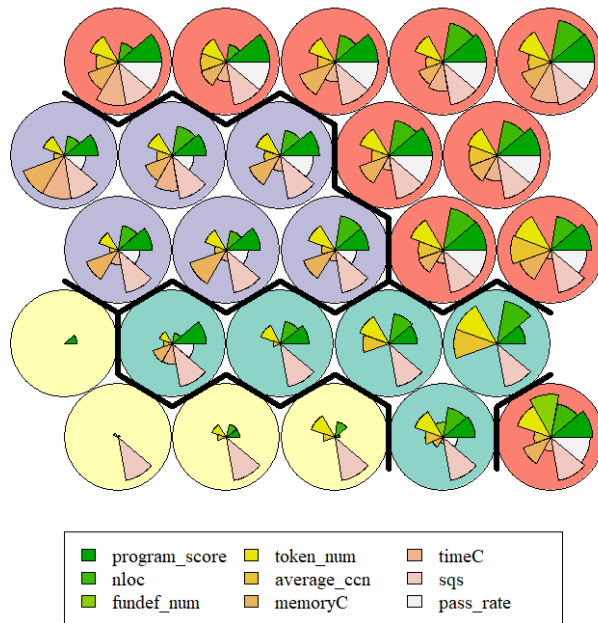
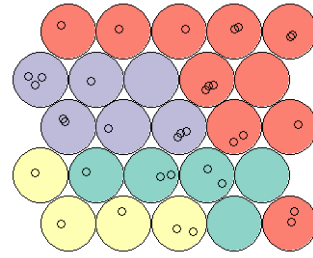


Figure S13 Mapping plots of code metrics at t = 11 with four clusters.

Code Metrics Visualization Map: t = 12



Math



CS

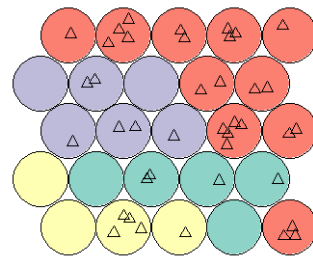


Figure S14 Mapping plots of code metrics at t = 12 with four clusters.

Table S1 Results of one-way ANOVA on 3 clusters of each engagement indicator.

Indicator	Df	Sum Sq	Mean Sq	F value	η^2	ω^2	Pr(>F)
submission	2	1.5719	0.7859	17.2160	0.0370	0.0348	0.0000****
	897	40.9494	0.0457				
cost_time	2	14.7108	7.3554	109.5189	0.1963	0.1943	0.0000****
	897	60.2434	0.0672				
start_time	2	7.2865	3.6432	91.4923	0.1694	0.1674	0.0000****
	897	35.7187	0.0398				

Table S2 Tukey test for pairwise comparisons of engagement clusters of LCA with p-value correction

Indicator	comparison	diff	lwr	upr	p-adj
submission	low-average	0.0838	0.0265	0.1410	0.0018***
	low-high	0.0702	0.0132	0.1272	0.0109**
	average-high	-0.0136	-0.0709	0.0438	0.8440
cost_time	low-average	0.1696	0.1156	0.2237	0.0000****
	low-high	0.3247	0.2709	0.3785	0.0000****
	average-high	0.1550	0.1009	0.2091	0.0000****
start_time	low-average	-0.0918	-0.1444	-0.0392	0.0001****
	low-high	-0.1908	-0.2432	-0.1384	0.0000****
	average-high	-0.0990	-0.1517	-0.0463	0.0000****

Table S3 Results of the Kruskal-Wallis test on 4 clusters of each code metrics indicator.

Indicators	df	SumSq	MeanSq	F-value	η^2	ω^2	p.value
nloc	3	4.94E+06	1.65E+06	26.8404	0.0830	0.0798	0.0000****
fundef_number	3	1.49E+06	4.97E+05	13.2852	0.0429	0.0396	0.0000****
token_number	3	5.78E+06	1.93E+06	31.8740	0.0970	0.0939	0.0000****
average_ccn	3	1.72E+06	5.72E+05	8.8125	0.0288	0.0255	0.0000****
memoryC	3	7.85E+06	2.62E+06	45.1126	0.1320	0.1289	0.0000****
timeC	3	6.57E+06	2.19E+06	36.8492	0.1105	0.1074	0.0000****
sqs	3	4.04E+06	1.35E+06	22.5532	0.0707	0.0674	0.0000****
pass_rate	3	2.69E+07	8.95E+06	248.1135	0.4554	0.4533	0.0000****
program_score	3	3.01E+07	1.00E+07	304.8031	0.5068	0.5048	0.0000****

Table S4 Dunn test for pairwise comparisons of code metrics clusters of SOM with p-value correction

Indicators	comparison	r	Cohen's d	Z	P.adj
program_score	low - average	0.2683	1.2953	8.0224	0.0000****
	low - good	-0.0122	-0.0546	-0.3637	0.7161
	average - good	-0.2579	-1.1694	-7.7114	0.0000****
	low - oe	-0.4925	-1.8569	-14.7259	0.0000****
	average - oe	-0.6486	-3.5492	-19.3924	0.0000****
	good - oe	-0.4223	-1.6168	-12.6272	0.0000****
nloc	low - average	0.0551	0.1950	1.6476	0.1989
	low - good	-0.1929	-0.6082	-5.7663	0.0000****
	average - good	-0.2070	-0.7078	-6.1893	0.0000****
	low - oe	-0.2000	-0.5350	-5.9811	0.0000****
	average - oe	-0.2096	-0.6807	-6.2656	0.0000****
	good - oe	0.0164	0.1035	0.4899	0.6242
fundef_number	low - average	0.0720	0.2154	2.1534	0.0626*
	low - good	-0.0899	-0.2366	-2.6876	0.0216**
	average - good	-0.1393	-0.4010	-4.1657	0.0001****
	low - oe	-0.1424	-0.2307	-4.2588	0.0001****
	average - oe	-0.1820	-0.4525	-5.4417	0.0000****
	good - oe	-0.0358	0.0397	-1.0694	0.2849
token_number	low - average	0.0739	0.2563	2.2083	0.0544*
	low - good	-0.1796	-0.5462	-5.3692	0.0000****
	average - good	-0.2136	-0.7157	-6.3864	0.0000****
	low - oe	-0.2240	-0.5954	-6.6983	0.0000****
	average - oe	-0.2468	-0.7836	-7.3802	0.0000****
	good - oe	-0.0181	-0.0388	-0.5399	0.5892
average_ccn	low - average	0.0723	0.3032	2.1619	0.0919*
	low - good	-0.1127	-0.4386	-3.3701	0.0030***
	average - good	-0.1581	-0.6152	-4.7258	0.0000****
	low - oe	-0.0611	-0.1609	-1.8262	0.1357
	average - oe	-0.1195	-0.4156	-3.5719	0.0018***
	good - oe	0.0588	0.2718	1.7591	0.0786*
memoryC	low - average	0.1798	0.7729	5.3761	0.0000****

	low - good	-0.2220	-0.4721	-6.6383	0.0000****
	average - good	-0.3459	-1.1807	-10.3422	0.0000****
	low - oe	-0.1104	-0.1688	-3.3016	0.0010***
	average - oe	-0.2651	-1.2290	-7.9253	0.0000****
	good - oe	0.1246	0.4400	3.7257	0.0004****
timeC	low - average	0.1463	0.3930	4.3737	0.0000****
	low - good	-0.1570	-0.5817	-4.6947	0.0000****
	average - good	-0.2623	-0.7338	-7.8427	0.0000****
	low - oe	-0.1895	-0.4698	-5.6671	0.0000****
	average - oe	-0.2926	-0.7897	-8.7494	0.0000****
	good - oe	-0.0102	0.2256	-0.3047	0.7606
sqs	low - average	0.1861	0.5963	5.5637	0.0000****
	low - good	0.0581	0.0594	1.7380	0.0822*
	average - good	-0.1250	-0.4582	-3.7376	0.0006****
	low - oe	-0.0933	-0.2557	-2.7898	0.0105**
	average - oe	-0.2581	-0.7561	-7.7177	0.0000****
	good - oe	-0.1404	-0.2842	-4.1991	0.0001****
pass_rate	low - average	0.2280	1.0298	6.8159	0.0000****
	low - good	-0.0125	-0.0755	-0.3744	0.7081
	average - good	-0.2209	-1.0072	-6.6047	0.0000****
	low - oe	-0.4843	-1.7311	-14.4804	0.0000****
	average - oe	-0.6019	-2.8312	-17.9964	0.0000****
	good - oe	-0.4147	-1.5437	-12.3999	0.0000****
program_score	low - average	0.2683	1.2953	8.0224	0.0000****
	low - good	-0.0122	-0.0546	-0.3637	0.7161
	average - good	-0.2579	-1.1694	-7.7114	0.0000****
	low - oe	-0.4925	-1.8569	-14.7259	0.0000****
	average - oe	-0.6486	-3.5492	-19.3924	0.0000****
	good - oe	-0.4223	-1.6168	-12.6272	0.0000****