Supplementary materials

#	Oligo name	Sequence [5'–3']
1	Microscale thermophoresis dsDNA sequences	CACTGCCCA**XXXXXXXX**TTCTTGA
2	X-ray crystallography dsDNA sequences	AGT**XXXX**TGTTC
3	EMSA-seq **CORE** library	TCGTCGGCAGCGTCAGATGTGTATCACTGCCCAGT**NNNN**TGTTCTT GATCACCGCTCCGACTGCAGAAAA
4	EMSA-seq **FLANK** library	TCGTCGGCAGCGTCAGATGTGTATCACTGC**NNNNN**CAAG**NNNNN**T TGATCACCGCTCCGACTGCAGAAAA
5	EMSA-seq **ALL** library	TCGTCGGCAGCGTCAGATGTGTATCACTGC**NNNNNNNNNNNNN** TTGATCACCGCTCCGACTGCAGAAAA
6	EMSA-seq positive control	TGCAGAACAGGTTTGTCTTTTGCTCACTGCCCAGTCAAGTGTTCTTG AGCAGAACTTAGAGGCGAGGTACGA
7	EMSA-seq negative control	CGTTACGACAGCAGAGTAGTGATGTGGCCTGGGCCCCTACGCGGCC GCCTGTAAGACTCACTCATCTCGGCT
8	EMSA-seq mutant library dsDNA preparation reverse primer	Alexa Fluor 647-TTTTCTGCAGTCGGAGCGGTGA
9	Negative control forward primer	CGTTACGACAGCAGAGTAGTGATG
10	Negative control reverse primer	AGCCGAGATGAGTGAGTCTTACAG
11	Positive control forward primer	ACTGTCTGAGGAGTGTCGTGTGCT
12	Positive control reverse primer	GTGAGTGAAGTGGTGCTGAGTCGT
13	Forward Illumina library preparation primer	AATGATACGGCGACCACCGAGATCTACACTAGATCGCTCGTCGGCAG CGTCAGATGTGTAT
14	Reverse Illumina library preparation primer (Ns indicate location of unique index)	CAAGCAGAAGACGGCATACGAGAT**NNNNNNNN**GTCTCGTGGGCT CGGAGATGTG
15	Illumina read primer 2 (used for **FLANK** and **ALL** libraries)	TCGTCGGCAGCGTCAGATGTGTATCACTGC
16	Illumina indexing primer	TCACCGCTCCGACTGCAGAAAA

Supplementary Table S1: Oligonucleotides used in this study. N, positions where equal ratios of nucleotides (A:25, C:25, G:25, T:25) were incorporated randomly during DNA synthesis; X, specific nucleotide combinations were introduced (i.e. not every possible combination was used). Underlined nucleotides are primer sequences used for qPCR and Illumina sequencing library preparation.

Category	Package Name	Version	Installation source
Bioinformatics	`bedtools`	2.30.0	System
Bioinformatics	`FIMO`	5.5.7	System
Bioinformatics (Python)	`biopython`	1.85	Pip
Bioinformatics (Python)	`logomaker`	0.8	Pip
Bioinformatics (Python)	`modisco-lite`	2.2.1	Pip
Bioinformatics (Python)	`pybigwig`	0.3.23	Pip
Bioinformatics (Python)	`pyfaidx`	0.8.1.3	Pip
Bioinformatics (Python)	`tangermeme`	0.4.2	Pip
Data Science & Viz	`altair`	5.4.1	Pip
Data Science & Viz	`bokeh`	3.7.0	Pip
Data Science & Viz	`h5py`	3.12.1	Pip
Data Science & Viz	`matplotlib`	3.10.1	Pip
Data Science & Viz	`networkx`	3.1	Pip
Data Science & Viz	`numpy`	1.26.4	Pip

Data Science & Viz	pandas	2.2.2	Pip
Data Science & Viz	plotly	6.0.1	Pip
Data Science & Viz	rich	13.7.1	Pip
Data Science & Viz	scipy	1.14.1	Conda
Data Science & Viz	seaborn	0.13.2	Pip
EMSA-seq data processing	apeglm	1.32.0	CRAN
EMSA-seq data processing	DESeq2	1.50.0	Bioconductor
EMSA-seq data processing	ggplot2	4.0.0	CRAN
EMSA-seq data processing	pheatmap	1.0.13	CRAN
EMSA-seq data processing	RColorBrewer	1.1-3	CRAN
EMSA-seq data processing	tidyverse	2.0.0	CRAN
Hardware (GPU/CUDA)	nvidia-cuda-runtime-cu12	12.1.105	Pip
Hardware (GPU/CUDA)	nvidia-cudnn-cu12	9.1.0.70	Pip
Jupyter Ecosystem	ipykernel	6.15.0	Conda
Jupyter Ecosystem	ipython	8.14.0	Conda
Jupyter Ecosystem	jupyterlab	4.0.6	Conda
Jupyter Ecosystem	nbconvert	7.8.0	Conda
Jupyter Ecosystem	notebook	7.0.4	Conda
Machine Learning & AI	lightning	2.5.0	Pip
Machine Learning & AI	pytorch-lightning	2.5.0	Pip
Machine Learning & AI	scikit-learn	1.5.2	Conda
Machine Learning & AI	shap	0.48.0	Pip
Machine Learning & AI	torch	2.4.0	Pip
Machine Learning & AI	torchmetrics	1.4.1	Pip
Machine Learning & AI	wandb	0.17.6	Pip
System & Core	pip	23.1.2	Conda
System & Core	python	3.11.10	Conda
System & Core	requests	2.29.0	Conda
System & Core	tqdm	4.65.0	Conda
System Libraries	gcc_impl_linux-64	14.2.0	Conda
System Libraries	gstreamer	1.24.7	Conda
System Libraries	openssl	3.4.1	Conda
System Libraries	xorg-libx11	1.8.10	Conda

Supplementary Table S2: Software and software modules used in this project.

Name	Created	Run time	Kernel _size	Model. kernel _size	Model. num_ channels	Model. pool _output _size	Num _channels	Pool _output _size	epoch	Train _loss _epoch	Train _loss _step	trainer/ global _step	val_loss
rare-sweep-16	2025-10-14T18:16:48.000Z	44	13	13	82	178	82	178	36	0.092099555	0.052138545	221	0.06079312
generous-sweep-76	2025-10-14T19:05:21.000Z	45	36	36	80	209	80	209	40	0.050105657	0.039100494	245	0.06141796
earnest-sweep-40	2025-10-14T18:35:36.000Z	43	15	15	77	92	77	92	43	0.027660601	0.034931377	263	0.06260511
dainty-sweep-96	2025-10-14T19:21:08.000Z	41	28	28	74	84	74	84	38	0.055511702	0.023969289	233	0.07203593
lunar-sweep-4	2025-10-14T18:07:18.000Z	43	12	12	98	108	98	108	45	0.03395161	0.03194388	275	0.07892106
sleek-sweep-56	2025-10-14T18:49:21.000Z	40	13	13	97	94	97	94	33	0.035093531	0.027831677	203	0.08082398
feasible-sweep-66	2025-10-14T18:57:09.000Z	42	14	14	104	173	104	173	45	0.041814271	0.025270987	275	0.08877626
clear-sweep-52	2025-10-14T18:45:48.000Z	41	17	17	74	214	74	214	50	0.035827693	0.015849298	305	0.09375614
bumbling-sweep-25	2025-10-14T18:23:55.000Z	42	23	23	85	73	85	73	43	0.058448948	0.07701762	263	0.0940453
icy-sweep-19	2025-10-14T18:19:14.000Z	39	22	22	72	65	72	65	35	0.095430799	0.033007555	215	0.09645522
eager-sweep-22	2025-10-14T18:21:34.000Z	41	21	21	46	79	46	79	46	0.074601941	0.124091104	281	0.09753805
ancient-sweep-30	2025-10-14T18:27:49.000Z	42	33	33	42	187	42	187	29	0.064417042	0.138720125	179	0.09792756
fallen-sweep-41	2025-10-14T18:36:23.000Z	43	24	24	84	71	84	71	39	0.044630457	0.014613479	239	0.09877452
eager-sweep-1	2025-10-14T18:04:37.000Z	57	14	14	93	196	93	196	32	0.103157468	0.077240862	197	0.10162681
vocal-sweep-5	2025-10-14T18:08:05.000Z	41	14	14	106	139	106	139	25	0.092669308	0.059204038	155	0.10633692
resilient-sweep-2	2025-10-14T18:05:39.000Z	47	13	13	85	89	85	89	39	0.069771461	0.067813501	239	0.10813407
woven-sweep-7	2025-10-14T18:09:39.000Z	42	23	23	41	84	41	84	40	0.068083309	0.042314664	245	0.11088385
avid-sweep-46	2025-10-14T18:40:53.000Z	43	32	32	88	221	88	221	31	0.060312331	0.020770879	191	0.11202669
genial-sweep-84	2025-10-14T19:11:45.000Z	39	17	17	51	157	51	157	35	0.078713223	0.046864759	215	0.11324269
giddy-sweep-82	2025-10-14T19:10:01.000Z	45	22	22	119	223	119	223	30	0.103911616	0.057643339	185	0.12130735
vocal-sweep-36	2025-10-14T18:32:24.000Z	45	41	41	105	244	105	244	38	0.037935	0.046485208	233	0.12511574

dashing-sweep-17	2025-10-14T18:17:40.000Z	42	12	12	84	214	84	214	37	0.121385433	0.155370533	227	0.1261221
splendid-sweep-12	2025-10-14T18:13:33.000Z	41	18	18	80	83	80	83	27	0.102476716	0.093761712	167	0.14570934
fallen-sweep-68	2025-10-14T18:58:42.000Z	41	17	17	89	229	89	229	37	0.077765495	0.065464415	227	0.14893766
valiant-sweep-59	2025-10-14T18:51:41.000Z	44	10	10	100	74	100	74	26	0.097072981	0.083956286	161	0.15515105
sleek-sweep-86	2025-10-14T19:13:19.000Z	38	32	32	40	127	40	127	25	0.205783024	0.270869613	155	0.16100238
silver-sweep-11	2025-10-14T18:12:41.000Z	44	15	15	79	170	79	170	33	0.226546347	0.501060903	203	0.16479965
pleasant-sweep-88	2025-10-14T19:15:04.000Z	38	11	11	45	255	45	255	22	0.169882029	0.134999529	137	0.16814552
worthy-sweep-50	2025-10-14T18:44:00.000Z	41	13	13	90	122	90	122	20	0.14156507	0.085205883	125	0.16936144
dry-sweep-70	2025-10-14T19:00:21.000Z	42	29	29	106	212	106	212	27	0.183797911	0.106086105	167	0.17228262
major-sweep-77	2025-10-14T19:06:13.000Z	40	10	10	41	83	41	83	24	0.258832783	0.328919888	149	0.17457601
earthy-sweep-8	2025-10-14T18:10:25.000Z	43	19	19	98	83	98	83	19	0.248645246	0.528274536	119	0.17834279
generous-sweep-62	2025-10-14T18:54:07.000Z	41	31	31	78	153	78	153	35	0.088540852	0.04771265	215	0.18333368
dark-sweep-23	2025-10-14T18:22:21.000Z	43	11	11	83	176	83	176	29	0.464718968	0.059250154	179	0.19072567
glowing-sweep-6	2025-10-14T18:08:52.000Z	42	10	10	86	117	86	117	23	0.10110683	0.096215166	143	0.193546
true-sweep-3	2025-10-14T18:06:31.000Z	43	38	38	87	211	87	211	22	0.201571524	0.266815126	137	0.19723153
astral-sweep-35	2025-10-14T18:31:37.000Z	41	10	10	74	69	74	69	26	0.159597248	0.107509956	161	0.19942515
comic-sweep-44	2025-10-14T18:38:49.000Z	47	17	17	118	178	118	178	42	0.09949059	0.138869986	257	0.20102094
clean-sweep-97	2025-10-14T19:21:55.000Z	43	17	17	128	237	128	237	22	0.201687798	0.214614123	137	0.20114811
deep-sweep-61	2025-10-14T18:53:20.000Z	42	11	11	51	99	51	99	22	0.175707683	0.167355657	137	0.21037772
celestial-sweep-31	2025-10-14T18:28:35.000Z	41	16	16	65	148	65	148	20	0.210957915	0.130622759	125	0.21257144
zesty-sweep-65	2025-10-14T18:56:22.000Z	41	27	27	122	98	122	98	20	0.172561899	0.049167894	125	0.22467786
fiery-sweep-93	2025-10-14T19:18:53.000Z	38	31	31	72	75	72	75	20	0.312247545	0.075045511	125	0.22656938
lilac-sweep-32	2025-10-14T18:29:22.000Z	43	33	33	115	170	115	170	17	0.212438926	0.145025536	107	0.22749431
vivid-sweep-87	2025-10-14T19:14:17.000Z	42	17	17	89	81	89	81	30	0.110402443	0.053915456	185	0.23991743
sweet-sweep-45	2025-10-14T18:39:41.000Z	43	33	33	92	204	92	204	30	0.278908879	0.152278692	185	0.25460652

fancy-sweep-20	2025-10-14T18:20:01.000Z	41	14	14	75	71	75	71	24	0.136343464	0.03814042	149	0.25938007
happy-sweep-26	2025-10-14T18:24:42.000Z	41	14	14	80	205	80	205	17	0.207686484	0.194484442	107	0.27681306
still-sweep-57	2025-10-14T18:50:08.000Z	42	12	12	93	146	93	146	16	0.241158143	0.140067652	101	0.27777728
polar-sweep-42	2025-10-14T18:37:10.000Z	43	15	15	73	108	73	108	30	0.38114816	0.09340331	185	0.28933746
vibrant-sweep-69	2025-10-14T18:59:29.000Z	43	30	30	101	156	101	156	19	0.20735459	0.164394647	119	0.31023651
playful-sweep-24	2025-10-14T18:23:08.000Z	39	16	16	43	127	43	127	29	0.411148876	0.027755052	179	0.32302809
solar-sweep-78	2025-10-14T19:06:59.000Z	38	27	27	38	154	38	154	17	0.373859853	0.345107615	107	0.33810845
floral-sweep-58	2025-10-14T18:50:55.000Z	42	15	15	100	182	100	182	27	0.171617448	0.509374619	167	0.35908693
legendary-sweep-27	2025-10-14T18:25:28.000Z	42	12	12	92	97	92	97	17	0.237132609	0.311489999	107	0.37864071
pleasant-sweep-13	2025-10-14T18:14:28.000Z	41	19	19	90	157	90	157	20	0.558061719	0.070564911	125	0.38354969
rural-sweep-55	2025-10-14T18:48:29.000Z	45	29	29	126	105	126	105	25	0.417155832	0.076968536	155	0.40800485
super-sweep-18	2025-10-14T18:18:27.000Z	42	17	17	89	118	89	118	21	0.373695791	0.573626935	131	0.4227708
worldly-sweep-54	2025-10-14T18:47:22.000Z	40	34	34	39	85	39	85	17	0.335975021	0.265072048	107	0.42611802
playful-sweep-90	2025-10-14T19:16:32.000Z	38	36	36	89	145	89	145	13	0.546335816	0.387940019	83	0.47274747
earthy-sweep-10	2025-10-14T18:11:59.000Z	37	11	11	117	113	117	113	13	0.460335344	1.519062757	83	0.48649496
usual-sweep-60	2025-10-14T18:52:33.000Z	42	17	17	123	248	123	248	22	0.369553268	0.249619186	137	0.51050031
electric-sweep-94	2025-10-14T19:19:39.000Z	38	21	21	82	232	82	232	26	0.306021899	0.336771607	161	0.51620746
eternal-sweep-43	2025-10-14T18:38:02.000Z	39	19	19	88	79	88	79	21	0.561744332	1.389275432	131	0.52278948
fine-sweep-49	2025-10-14T18:43:13.000Z	39	24	24	69	214	69	214	22	0.551522255	1.655740499	137	0.52992803
elated-sweep-75	2025-10-14T19:04:34.000Z	40	17	17	128	101	128	101	20	0.486647308	0.38857162	125	0.5370307
earthy-sweep-47	2025-10-14T18:41:40.000Z	38	15	15	111	184	111	184	18	0.592418075	0.20092541	113	0.54657716
vital-sweep-98	2025-10-14T19:22:42.000Z	38	26	26	102	119	102	119	24	0.703357279	0.248088241	149	0.56440133
pleasant-sweep-99	2025-10-14T19:23:29.000Z	38	29	29	43	133	43	133	20	0.547877192	0.087132648	125	0.56682849
curious-sweep-38	2025-10-14T18:34:03.000Z	39	29	29	112	247	112	247	11	0.458060086	0.415527821	71	0.58450752
comic-sweep-100	2025-10-14T19:24:15.000Z	40	22	22	63	138	63	138	20	0.680905223	0.222422048	125	0.60747534

fine-sweep-83	2025-10-14T19:10:53.000Z	44	37	37	124	88	124	88	21	0.726376832	0.319216877	131	0.6378991
summer-sweep-51	2025-10-14T18:45:01.000Z	41	31	31	59	233	59	233	20	0.723827243	0.336398929	125	0.64508468
sunny-sweep-85	2025-10-14T19:12:32.000Z	41	37	37	35	189	35	189	19	0.722772181	0.295447856	119	0.66011441
genial-sweep-29	2025-10-14T18:27:02.000Z	38	27	27	47	88	47	88	12	0.543634593	0.479541332	77	0.68855208
still-sweep-63	2025-10-14T18:54:54.000Z	42	22	22	65	139	65	139	13	0.663317323	0.919211388	83	0.70890892
still-sweep-71	2025-10-14T19:01:08.000Z	43	13	13	91	84	91	84	24	0.80978626	0.739283979	149	0.72018272
floral-sweep-33	2025-10-14T18:30:09.000Z	41	37	37	35	215	35	215	13	0.81628406	0.973987937	83	0.7256211
still-sweep-37	2025-10-14T18:33:16.000Z	40	26	26	118	209	118	209	15	0.990578592	0.079417422	95	0.87831563
glad-sweep-72	2025-10-14T19:02:00.000Z	38	33	33	68	116	68	116	15	0.996387124	0.258243501	95	0.87917978
sandy-sweep-34	2025-10-14T18:30:56.000Z	37	26	26	117	98	117	98	5	0.999137282	0.103736036	35	0.88300771
glowing-sweep-91	2025-10-14T19:17:14.000Z	46	39	39	119	253	119	253	19	0.998232484	0.136228129	119	0.88309598
vocal-sweep-21	2025-10-14T18:20:48.000Z	39	29	29	44	78	44	78	18	0.984303832	0.631527662	113	0.8832258
eager-sweep-79	2025-10-14T19:07:46.000Z	41	22	22	103	124	103	124	13	0.997176349	1.133627057	83	0.88361543
vague-sweep-67	2025-10-14T18:57:56.000Z	40	30	30	116	255	116	255	5	0.996010721	5.174656868	35	0.88390696
sandy-sweep-39	2025-10-14T18:34:49.000Z	39	35	35	55	225	55	225	6	0.992671847	0.813077211	41	0.88474238
stoic-sweep-89	2025-10-14T19:15:45.000Z	39	13	13	58	165	58	165	7	0.9969064	0.491814911	47	0.88565797
rosy-sweep-28	2025-10-14T18:26:15.000Z	38	28	28	33	144	33	144	5	0.993139088	0.187875673	35	0.88584447
vibrant-sweep-53	2025-10-14T18:46:35.000Z	40	19	19	109	183	109	183	6	1.002271175	0.367721677	41	0.88670015
kind-sweep-48	2025-10-14T18:42:26.000Z	43	30	30	45	222	45	222	19	0.997078717	0.104206286	119	0.8876754
dutiful-sweep-14	2025-10-14T18:15:14.000Z	40	14	14	118	189	118	189	7	0.997144938	0.498690814	47	0.88827848
brisk-sweep-74	2025-10-14T19:03:52.000Z	36	11	11	63	229	63	229	5	0.997130811	0.248213708	35	0.88859791
crimson-sweep-9	2025-10-14T18:11:12.000Z	38	40	40	59	189	59	189	14	0.997266531	1.4479599	89	0.8888225
eager-sweep-92	2025-10-14T19:18:06.000Z	39	35	35	117	163	117	163	11	0.997123599	1.325618029	71	0.88888121
eternal-sweep-81	2025-10-14T19:09:14.000Z	41	32	32	51	137	51	137	5	0.998182774	0.149682894	35	0.88926977
denim-sweep-64	2025-10-14T18:55:40.000Z	36	34	34	63	244	63	244	6	0.997027516	1.010430336	41	0.88979542

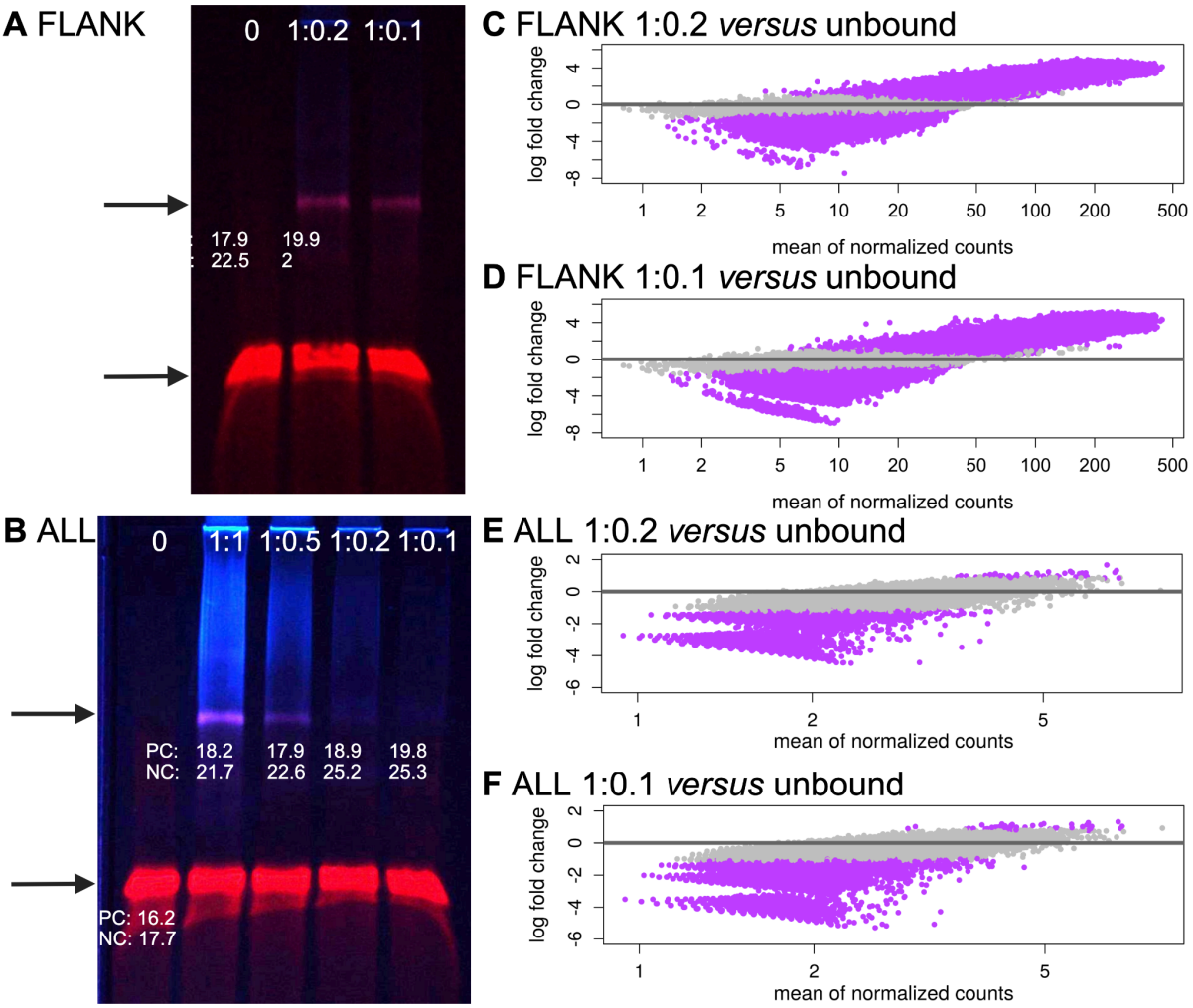
mild-sweep-73	2025-10-14T19:03:10.000Z	38	11	11	96	88	96	88	5	0.99800843	0.1778934	35	0.89094591
solar-sweep-15	2025-10-14T18:16:01.000Z	40	36	36	43	242	43	242	17	0.998658538	1.338091612	107	0.89097923
faithful-sweep-80	2025-10-14T19:08:33.000Z	35	33	33	64	175	64	175	5	1.00009954	0.30474934	35	0.89459276
blooming-sweep-95	2025-10-14T19:20:21.000Z	42	15	15	127	247	127	247	9	1.001496792	0.18563664	59	

Supplementary Table S3: Optimal hyperparameter settings for the VCNNBPNet models. Note: these settings were identical for all models: `batch_size = 64`, `classify = FALSE`, `dense_sizes = [128,64]`, `dilations = [1,1,2,4,8]`, `input_channels = 4`, `input_length = 24`, `learning_rate = 0.001`, `model.dense_sizes = [128,64]`, `model.dilations = [1,1,2,4,8]`, `num_workers = 24`, `preprocess = FALSE`, and `scaling_method = standardise`.

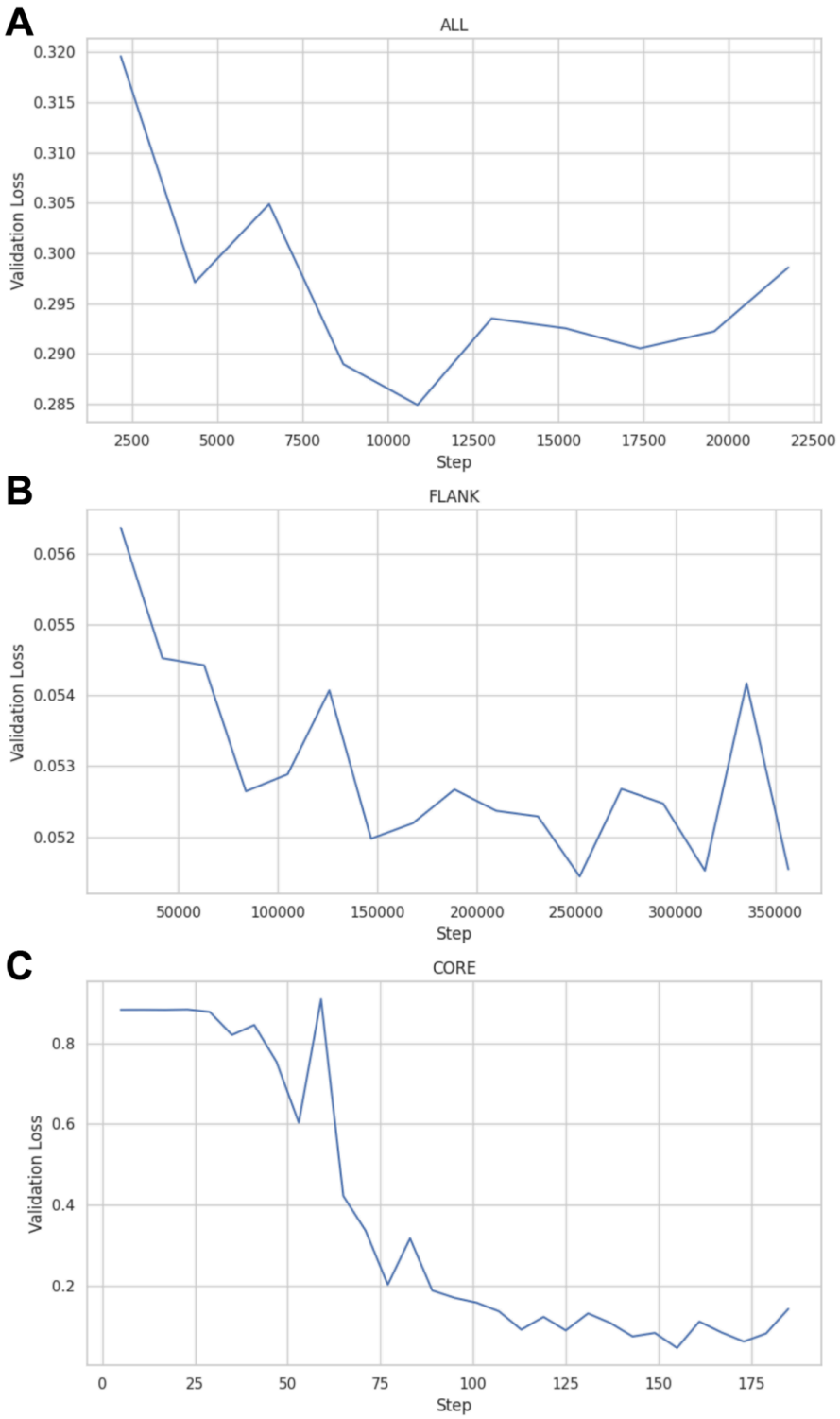
ChipSeq Target	GSM Accession IDs
GATA1	GSM1003608, GSM1067274, GSM1278240, GSM1816080, GSM1816081, GSM1921310, GSM1921315, GSM1921321, GSM1921327, GSM1921332, GSM2452102, GSM2877105, GSM2877106, GSM2877113, GSM2877114, GSM2877121, GSM2877122, GSM3177416, GSM3177417, GSM3177418, GSM3177419, GSM3177420, GSM3177421, GSM3177422, GSM3177423, GSM3523237, GSM3523244, GSM3762809, GSM3762810, GSM3762813, GSM3762817, GSM3783517, GSM3832646, GSM3832647, GSM3832653, GSM3832654, GSM3854067, GSM3854068, GSM3854083, GSM3854084, GSM3854099, GSM3854100, GSM3854115, GSM3854116, GSM3854131, GSM3854132, GSM4096234, GSM4096235, GSM4096236, GSM4613166, GSM4613167, GSM4613168, GSM4613169, GSM4613171, GSM4613172, GSM4613173, GSM4613174, GSM4613175, GSM4613176, GSM4613183, GSM4613184, GSM4613185, GSM4613186, GSM467647, GSM4761236, GSM4761237, GSM4818700, GSM4818708, GSM5129496, GSM5129497, GSM5129498, GSM5129499, GSM5129500, GSM5129501, GSM5271205, GSM5271206, GSM5271209, GSM5271210, GSM5271219, GSM5271220, GSM5271222, GSM5271223, GSM5341623, GSM5575500, GSM5575501, GSM5696922, GSM5696923, GSM5696924, GSM5696926, GSM5696927, GSM5696928, GSM5696930, GSM5696931, GSM5696932, GSM5771686, GSM5771687, GSM5771688, GSM5771689, GSM607949, GSM610335, GSM6321450, GSM6321451, GSM6321454, GSM6321455, GSM6463411, GSM6463412, GSM6463413, GSM651546, GSM651547, GSM6661430, GSM6661431, GSM6661432, GSM6661433, GSM722392, GSM722393, GSM722394, GSM722395, GSM722412, GSM722413, GSM788367, GSM804013, GSM804014, GSM935333, GSM935465, GSM935540, GSM970257, GSM970258
MYOD1	GSM1218849, GSM1218850, GSM1218851, GSM1239474, GSM2214114, GSM2259152, GSM2259153, GSM2259154, GSM3831286, GSM3831287, GSM4072349, GSM4072350, GSM4072354, GSM4072355, GSM5261170, GSM5261171, GSM5261172, GSM6280737, GSM6280738, GSM6280739, GSM6280740, GSM6626408, GSM6626409, GSM6626410, GSM6626411, GSM6626416, GSM6626417, GSM6626418, GSM6626419, GSM7720563, GSM7720564
NKX2.1	GSM1246715, GSM1246716, GSM2310996, GSM2310998, GSM5556351, GSM5556352, GSM5556353, GSM5556354, GSM5556355, GSM5556356, GSM5556357, GSM5556368, GSM5556369, GSM5556370, GSM5556371, GSM5556372, GSM5556373, GSM983098, GSM983100, GSM983102, GSM983104
NKX2.5	GSM2372592, GSM2372593, GSM2372594, GSM4829313, GSM4829316, GSM5838060, GSM5838061, GSM5838062, GSM5838077, GSM5838079
RXRA	GSM1010767, GSM1019136, GSM1239520, GSM1480741, GSM2877302, GSM2877303, GSM2877304, GSM2877305, GSM2877306, GSM2877307, GSM3384456, GSM3384457, GSM3384458, GSM3384471, GSM3384472, GSM3384473, GSM3634227, GSM3634228, GSM3636221, GSM3636222, GSM4083801, GSM468181, GSM468184, GSM468199, GSM468204, GSM468213, GSM468214, GSM5085851, GSM5085852, GSM5213954, GSM5213955, GSM624142, GSM791405, GSM791406, GSM803341, GSM803452, GSM803506

Supplementary Table S4: Gene Expression Omnibus (https://www.ncbi.nlm.nih.gov/geo/) repository IDs of ChIP-seq data used for validation. The data was downloaded from ChIP-Atlas ([95]).

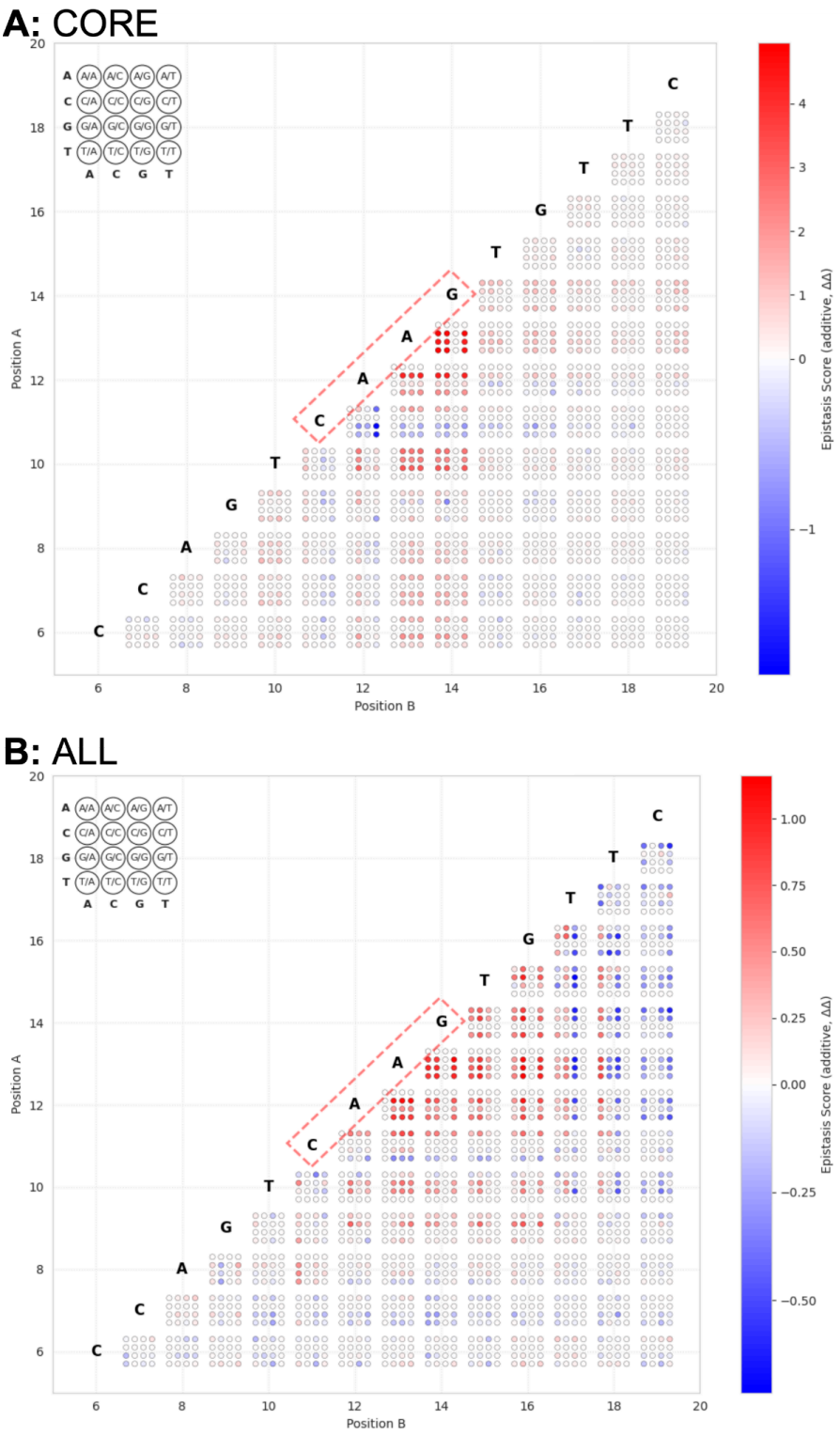
Supplementary results



Supplementary Figure S1: Electromobility shift assays with NKX2.1 (blue) and **A: FLANK** (red) or **B: ALL** (red) mutant libraries. The DNA to protein molar ratios of each lane are indicated at the top (0 has no protein). The top arrow indicates NKX2.1-bound DNA and the lower arrow indicates unbound DNA. Quantitative PCR was performed for the positive control (PC) and negative control (NC) using DNA extracted from the gel and average cycle threshold values for each reaction are indicated below the corresponding bands. The `DESeq2` results for the FLANK library **C:** 1:0.2 and **D:** 1:0.1 *versus* unbound. The `DESeq2` results for the **ALL** library **E:** 1:0.2 and **F:** 1:0.1 *versus* unbound.



Supplementary Figure S2: The validation loss (mean squared error) for the VCNNBPNet models trained using three different libraries: **A: ALL**, **B: FLANK**, and **C: CORE**. The *x*-axis represents the training "Step" (indicating individual weight updates), while the *y*-axis shows the models' error as determined by the validation dataset.



Supplementary Figure S3: Nucleotide interdependency map of the NKX2.1 binding site for the **A: CORE** and **B: ALL** models. The wildtype thyroglobulin promoter binding site sequence is shown diagonally with a red-dashed box enclosing the core nucleotides. For each double SNV, position A is on the y-axis and position B on the x-axis. The epistasis score is shown with a red-blue colour scale where a synergistic effect is red and an antagonistic effect is blue. The right side of the figure provides an example of how to read the map. Each square of 16 dots represents the variable combination of two nucleotide positions. Each possible nucleotide combination is depicted.