Biology:

Heat loss in Emperor Penguins.

Aim:

In this investigate, I intend to explore the way Emperor Penguins form large huddles of birds to keep themselves warm. Emperor Penguins are the largest of their species, and grow up to 1.15m tall. As means of insulation, they have four layers of scale like feathers, and large reserves of body fat to burn for warmth. Nevertheless, in their homeland, Antarctica, temperatures can drop to 60^{o} below zero, and the penguins on their own could not survive. They have however evolved another method of keeping warm: the birds gather in vast numbers and huddle together in huge colonies, or 'rookeries.' Within the colony, each bird takers a turn on both the inside of the group, and on the outside, providing warmth for every individual. I intend to find out how effective these immense gatherings (sometimes containing thousands of birds) are by simulating some with an experiment, and also hope to find out if the size of a huddle is related to the heat lost from the penguins.

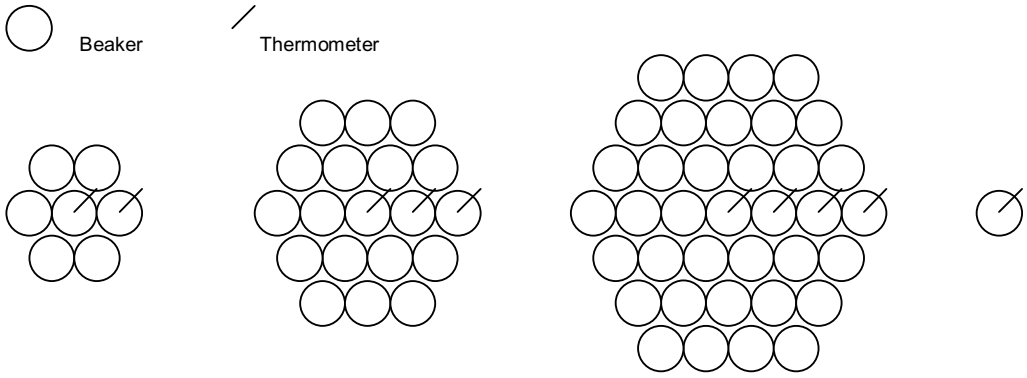
Equipment:

33 small glass beakers
6 thermometers
3 stopwatches
2 elastic bands
1 kettle and water supply (for hot water)
Data recording equipment

Plan:

I wish to find out how varying the amount of birds affects the temperature of the huddle, and how effective the huddle is at keeping the penguins warm. I will use glass beakers filled with hot water to simulate the penguins, and will place the beakers in huddle formations. Each huddle will consist of a central beaker, surrounded by varying 'layers' of more beakers. The smallest huddle will contain only 1 layer, the next huddle will contain 2 layers, and the third huddle 3 layers, all with an additional beaker placed in the centre (fig. 1). I will repeat all experiments three times, and then take an average, to ensure more accurate results.

Fig. 1



Huddle I:	Huddle II:	Huddle III:	Control:
1 layer, 7 beakers	2 layers, 19 beakers	3 layers, 33 beakers	No layers, 1 beaker

I will carry out experiments on Huddles I & II and the Control simultaneously, and do Huddle III on its own, due to limitations in numbers of beakers/thermometers. I will maker sure that all the beakers, as in a real rookery, are all touching. To keep groups held together, they will be encircled by an elastic band. The hot water will come from a kettle.

To time the experiment(s) I will use stopwatches. Every 60 seconds, the temperature of the thermometers will be measured. The beakers will be left to cool for 20 minutes. The starting temperature of the water, the amount of water per beaker, the time periods over which the temperatures are measured, the (circular) shape of the hud dles will all be kept exactly the same, or at least as similar as is possible. The starting temperature of the water will be 70^{o}.

Prediction:

I predict that increasing the amount of beakers will decrease the amount of heat they lose, because the more penguins in a huddle, the less surface area exposed to the air per penguin. In my control experiment, with 1 beaker, the entire surface is exposed, meaning that more heat can be lost by convection, cooling the water faster. In Huddle I, each beaker is in contact with at least 3 others, meaning less of the beakers' surface is exposed to the air. Heat lost from 1 beaker can be transferred to another beaker, and visa-versa, allowing beakers in a huddle to retain more heat that they would unaccompanied.

In Huddle III, all beakers in layers 1 & 2, along with the central beaker, are all in contact with 5 other beakers. However, beakers in the outside layer are touching only 3 others. I predict that because of this, beakers on the inside layer(s) will all cool at the same rate, and beakers on the outside layer, will all cool faster.

Pre-Test

Before my final experiment, I conducted a pre-test, to ensure that my method was sound. My pre-test consisted of a 1 layer arrangement, similar to Huddle I in my final experiment. The results are shown below.

Fig.

	Temperature	
Time (minutes)	**Central Cup**	**First Layer**
0	72	70
1	66.5	69
2	63.5	67.5
3	61	65
4	58.5	64
5	56.0	63
6	55	62
7	53.5	61
8	52	60
9	50.5	59
10	49.5	58
11	48	57
12	46	56.5
13	45	55.5
14	43.5	53
15	42	53.5
16	41	53
17	39.5	53
18	38	52
19	37	52
20	36.5	52

My preliminary test was conducted, and thought it went well I discovered that fixing the starting temperature of the water was extremely difficult and time consuming when using only a kettle. I decided to start my experiment at round about 75^{o}. I then continued on to my final experiments. Their results are shown below, along with averages and accompanying graphs.

Results:

Fig.				
Control				
Time (seconds)	**Experiment 1**	**Experiment 2**	**Experiment 3**	**Average**
0	67	70.5	73	70.2
1	63	67	69	66.3
2	60	64	66.5	63.5
3	58.5	60	64	60.8
4	56	57.5	62	58.5
5	54	54	60	56.0
6	52.5	53.5	58.5	54.8
7	51	52	57	53.3
8	49	51	56.5	52.2
9	48	50	54	50.7
10	47	49	52.5	49.5
11	46	48.5	50	48.2
12	45.5	47	48	46.8
13	44	46.5	44	44.8
14	43	45	42	43.3
15	42	44	40	42.0
16	41	43	39.5	41.2
17	40.5	42	36	39.5
18	39	41	34	38.0
19	38	40	33	37.0
20	37.5	39	32.5	36.3

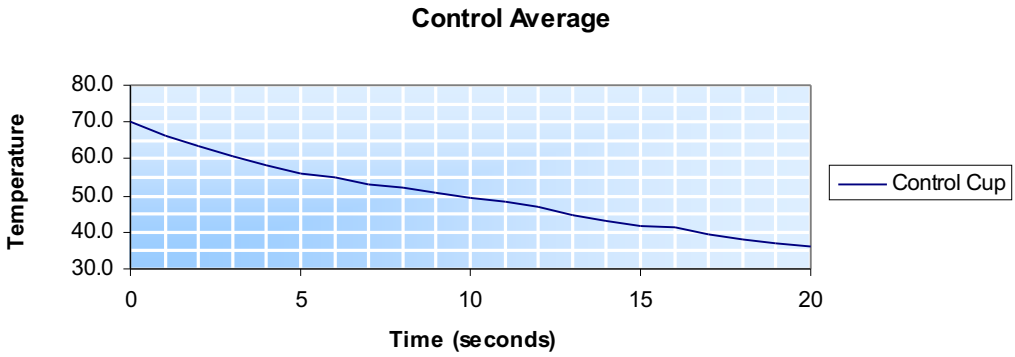


Fig.

Huddle I								
	Experiment 1		Experiment 2		Experiment 3		Averages	
Time (seconds)	*Centre*	*Layer 1*	*Centre*	*Layer 1*	*Centre*	*Layer 1*	*Centre*	*Layer 1*
0	75	74	71	70	73.5	75	73.2	74.2
1	74	73	70	69	72	72	72.0	72.3
2	73.5	70.5	69	67.5	71.5	70	71.3	70.7
3	70	68	68	65	69	69	69.0	68.7
4	69.5	65	67.5	64	68.5	68	68.5	67.2
5	68	64.5	66	63	67	66	67.0	65.8
6	65	63	65.5	62	66.5	65	65.7	64.8
7	64	61	64	61	65	64	64.3	63.3
8	63.5	59	63.5	60	64	63	63.7	62.0
9	62	56.5	62	59	63	62	62.3	60.5
10	60	54	61	58	62	60	61.0	58.7
11	58	54	60	57	61	59	59.7	58.0
12	56	53.5	59	56.5	60	58	58.3	57.2
13	55	53	58.5	55.5	59	57	57.5	56.3
14	53.5	53	57	53	59	56	56.5	56.0
15	53	53	56	53.5	58	55.5	55.7	55.5
16	52	52	56	53	58	54	55.3	54.7
17	52.5	52.5	56	53	58	53	55.5	54.5
18	52	52	55	52	58	53	55.0	54.3
19	52	51	55.5	52	58	52	55.2	53.7
20	52	51	55	52	58.5	52	55.2	53.8

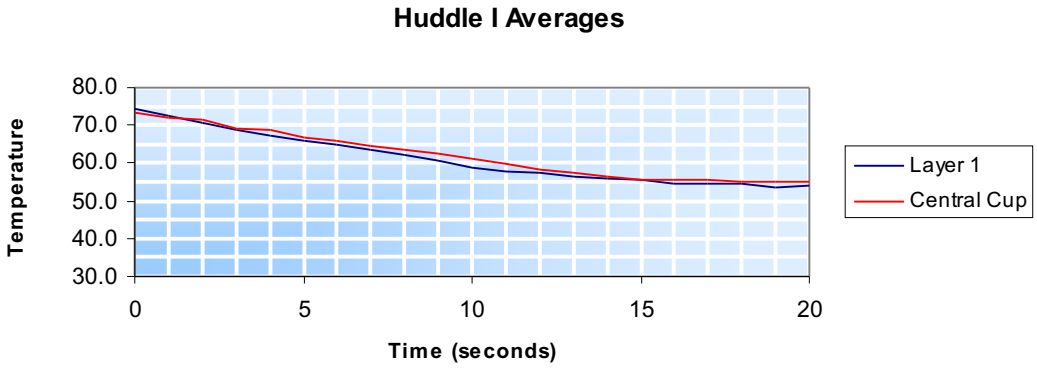


Fig.

Huddle II

	Experiment 1			Experiment 2			Experiment 3			Averages		
Time (secs.)	***Centre***	***L1***	***L2***	***Centre***	***L1***	***L2***	***Centre***	***L 1***	***L2***	***Centre***	***L1***	***L2***
0	75	75	74	70	70.5	68	73.5	72	70	72.8	72.5	70.7
1	75.5	74	73.5	70	70	66	73	72	69.5	72.8	72.0	69.7
2	75	74.5	71.5	70	69.5	64	73	71	68.5	72.7	71.7	68.0
3	75	73	70	69	69	62	73	71	67	72.3	71.0	66.3
4	74	73	69	69.5	68.5	61	72.5	70	65.5	72.0	70.5	65.2
5	74.5	72	68.5	68	67	60	72	70	64.5	71.5	69.7	64.3
6	74.5	71	67	68	67.5	59	72	69.5	63	71.5	69.3	63.0
7	73	70.5	65	67	66.5	58	71	69	62	70.3	68.7	61.7
8	73	69	64.5	67.5	65	57	71	68.5	61	70.5	67.5	60.8
9	73	68	63	65	64	56	70	68	60	69.3	66.7	59.7
10	72	67	62	65	63.5	55	70.5	67	59.5	69.2	65.8	58.8
11	72	63.5	61	64	62	54.5	69	66	58	68.3	63.8	57.8
12	71.5	62	60	63	71.5	53	69	65	57	67.8	62.8	56.7
13	71	61	59.5	62.5	60	52	68	64.5	56	67.2	61.8	55.8
14	60	60	58	62	60	51	67.5	63	55	63.2	61.0	54.7
15	60	59	57	61.5	59	50.5	65	62	54	62.2	60.0	53.8
16	59	58	56.5	60	56	49	63	61	53	60.7	58.3	52.8
17	58.5	56	55	59	54.5	48	62	60.5	52	59.8	57.0	51.7
18	57	55	53	58.5	53	47	61.5	59	51	59.0	55.7	50.3
19	56	54.5	52	57.5	52	46	60	58	50	57.8	54.8	49.3
20	55	53.5	51.5	56	51.5	45	59	57	50.5	56.7	54.0	49.0

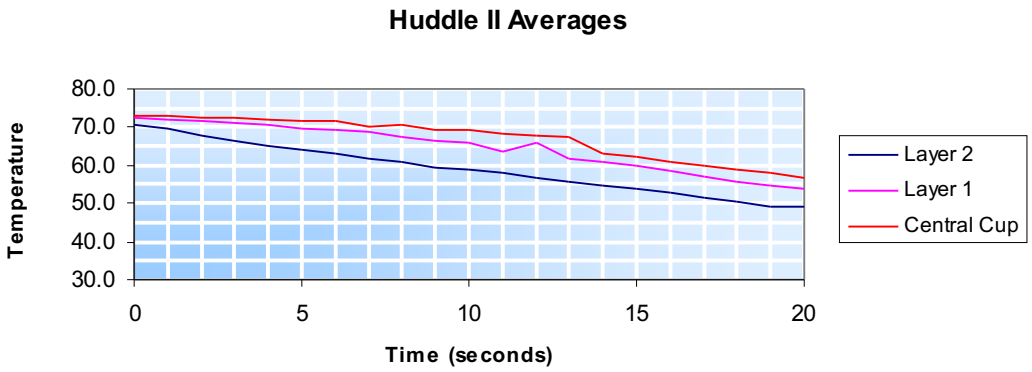


Fig.

Huddle III																
	Experiment 1				Experiment 2				Experiment 3				Averages			
Time (secs.)	***C***	***L1***	***L2***	***L3***	***C***	***L1***	***L2***	***L3***	***C***	***L 1***	***L2***	***L3***	***C***	***L1***	***L2***	***L3***
0	80	77	75.5	78	75	75	73.5	71	78	78	76	73	77.7	76.7	75.0	74.0
1	80	77	78.5	78	75	75	73	71	78	77	75.5	73	77.7	76.3	75.7	74.0
2	80	77	77	76	75	74	71.5	69	78	76.5	74.5	72	77.7	75.8	74.3	72.3
3	80	76	76	75	74	74	70.5	67	78	76	74	71	77.3	75.3	73.5	71.0
4	80	76.5	75	74	74	73	69.5	66	77	75	72.5	70	77.0	74.8	72.3	70.0
5	79.5	77	74	73	73	72	68.5	65	77	75	72	69	76.5	74.7	71.5	69.0
6	79.5	76	73	72	73.5	72	68	64	77.5	74	71	68	76.8	74.0	70.7	68.0
7	78	75	72	70	72	71	67	63	76	74	70.5	67.5	75.3	73.3	69.8	66.8
8	78	74	71	69	72.5	70	66	62.5	76.5	73	69.5	66	75.7	72.3	68.8	65.8
9	78	73	70	68.5	70	69	65	61.5	75	73	69.5	65	74.3	71.7	68.2	65.0
10	77	72	69.5	68	70	68	64.5	60	75	72	68	64	74.0	70.7	67.3	64.0
11	77	68	67	67	69	67	63	59	74	71.5	67	63	73.3	68.8	65.7	63.0
12	76.5	67	66	66.5	68	66	62	58	74	70	66	62	72.8	67.7	64.7	62.2
13	76	66	66	64	67	65	61	57	73	69	65	61	72.0	66.7	64.0	60.7
14	70	65	65	63	67.5	65	60.5	56	72	68	64	60	69.8	66.0	63.2	59.7
15	68	64	63	62	66	64	59.5	55	70	67	63	59	68.0	65.0	61.8	58.7
16	65	63	62	61	65	61	57.5	54	68	66	62	58	66.0	63.3	60.5	57.7
17	63	61	60.5	60.5	65	59	56	53	67	65	61	57	65.0	61.7	59.2	56.8
18	62.5	60	59	58	64	58	55	52	66	64	60	56	64.2	60.7	58.0	55.3
19	61	59	58	57	63	57	54	51	65	63	59	55	63.0	59.7	57.0	54.3
20	*62*	*58*	*57.5*	*57*	*63*	*56*	*52*	*50*	*65*	*62*	*59.5*	*57*	*63.3*	*58.7*	*56.3*	*54.7*

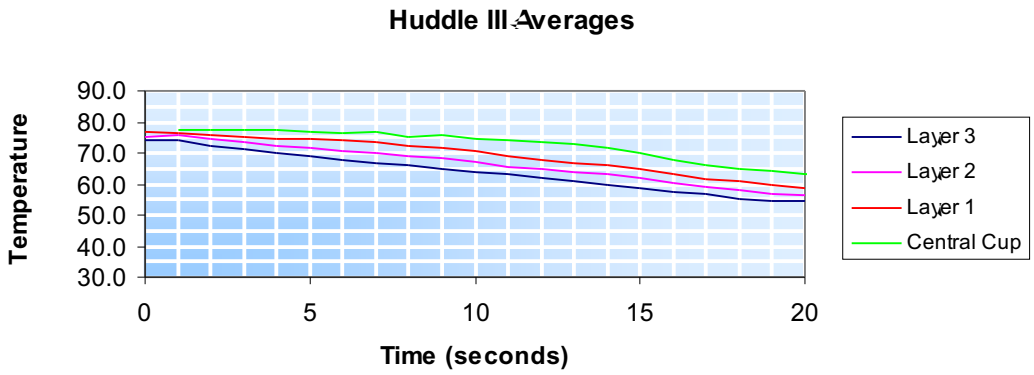


Fig.

Central Cup Averages Comparison

Time (seconds)	Control	Huddle I	Huddle II	Huddle III
0	70.2	73.2	72.8	77.7
1	66.3	72.0	72.8	77.7
2	63.5	71.3	72.7	77.7
3	60.8	69.0	72.3	77.3
4	58.5	68.5	72.0	77.0
5	56.0	67.0	71.5	76.5
6	54.8	65.7	71.5	76.8
7	53.3	64.3	70.3	75.3
8	52.2	63.7	70.5	75.7
9	50.7	62.3	69.3	74.3
10	49.5	61.0	69.2	74.0
11	48.2	59.7	68.3	73.3
12	46.8	58.3	67.8	72.8
13	44.8	57.5	67.2	72.0
14	43.3	56.5	63.2	69.8
15	42.0	55.7	62.2	68.0
16	41.2	55.3	60.7	66.0
17	39.5	55.5	59.8	65.0
18	38.0	55.0	59.0	64.2
19	37.0	55.2	57.8	63.0
20	*36.3*	*55.2*	*56.7*	*63.3*

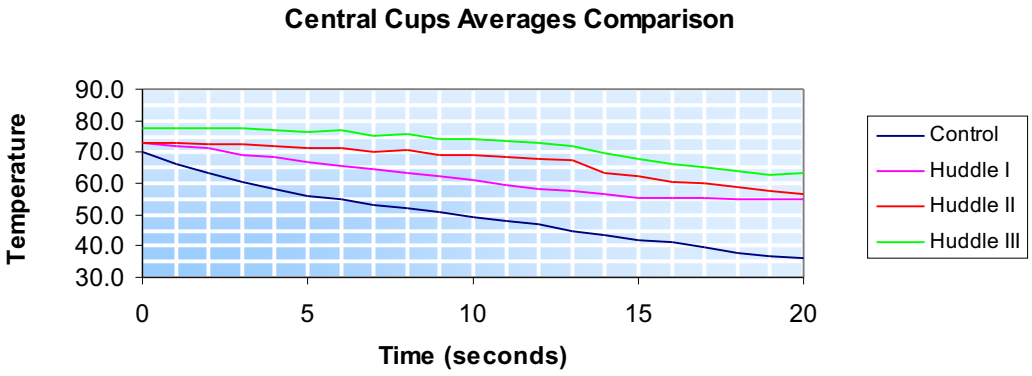


Fig.

Average Heat Lost from Central Cups (°C)

	Control	Huddle I	Huddle II	Huddle III
	70.2	73.2	72.8	77.7
-	36.3	55.2	56.7	63.3
	33.8	*18.0*	*16.2*	*14.3*

Fig.

Average Heat Lost from Outer Cups (°C)

	Control	Huddle I	Huddle II	Huddle III
	70.2	74.2	70.7	74.0
-	36.3	53.8	49.0	54.7
	33.8	*20.3*	*21.7*	*19.3*

Analysis:

From my results, my prediction seems accurate. The control cup cooled down the fastest, and in the 20 minutes, its temperature dropped by an average of 33.8°. The largest huddle formation, Huddle III, however, only dropped by 14.3° in the centre. This means that by huddling, 19.5° of heat was retained in the huddle centre, proving just how effective the penguin's strategy is. Even on the outside of the huddle, the average temperature drop was only 19.3° in Huddle III.

My graphs also show that huddling, as stated in my prediction, provides most heat in the centre of the huddle, because the centre has more layers of insulation around it.

Conclusion:

Huddling is an extremely effective method of heat loss prevention, as can be seen from my experiments. Penguins in the centre of the huddle, from my results, could stand to lose more than 50% less heat than they would do on their own. Even penguins on the outside and middle layers of the huddle stand to gain from the insulation huddling provides.

Evaluation:

Although my experiment was successful, there was lots I could have done to improve it. For example, the thermometers used to read the temperatures had to be read manually by eye, and provided very imp recise results. I could have gained by using electronic thermometers, with a computer and/or data logger to obtain my results.

I could also have made the starting temperatures of the water all the same, by using a different method of heating combined with the above thermometers.

In real life, penguins move constantly within the huddle to give everyone a chance in the middle and to create heat via movement and friction. My experiment did not reflect this movement, which is very important to the huddle.