2849 words

Salinity in bodies of water and specific heat capacity

Research Question: What is the effect of sodium chloride solution concentration ($moldm^{-3}$) upon the specific heat capacity of the solution ($Jg^{-1}\ {}^{o}C^{-1}$)?

Commented [A1]: Research design, first strand: Independent and dependent variables are identified, but there is no description of the system in which the research question is embedded.

Background

Above 0 K, all particles in matter have vibrational and kinetic energy [1] When heat is applied, the intermolecular forces in matter will weaken and its particles will vibrate faster, causing an increase in temperature [2]The stronger the intermolecular forces, the more energy will be required to weaken them, increasing particle motion and temperature [3]

Specific heat capacity is defined as the energy required to increase the temperature of 1 g of a material by 1 ^{o}C[4] .

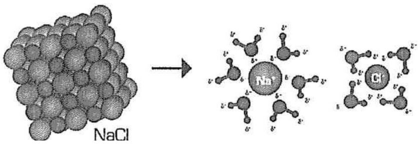
Due to their polar H-O covalent bonds, strong hydrogen bonds will exist between opposite poles of water molecules. These will require a large amount of energy to break[5]. Thus, water will have a high specific heat capacity and its temperature will stay relatively stable as external temperature fluctuates (USGS, n.d.).

Commented [A2]: Research design, first strand: Uses pertinent background theory.

This causes the temperatures of bodies of water to remain mostly constant. Most aquatic species live in a narrow temperature range, and this is fundamental for maintenance of aquatic ecosystems [6]

Saline bodies of water have dissolved salts that affect their specific heat capacity [7]When dissolved, the ionic bonds holding ions in a strong lattice will break due to their attraction to the poles of water molecules. The electrostatic attraction between the ions and the oppositely charged pole of water molecules will cause them to be held in a rigid cage, or solvation shell, as below:

Figure 1. Dissolution of sodium chloride (Marks & Carpi, 2017)



This rigid cage restricts the motion of the dissolved ions. Added heat will further increase the kinetic energy of the water molecules in lieu of the dissolved ions. This results in a lower specific heat capacity of the solution as the same mass of solution will have greater increase in temperature [8]

[1] (Muir, 2010).
[2] (Ophardt, 2003)
[3] (Parkinson, 2000).
[4] (Wu, 2018).
[5] (Boundless, 2019)
[6] (USGS, 2018).
[7] (Urban, 1932; USGS, 2018).
[8] (Zinck , 2015).

The salinity of bodies of water have shown changes over the past century such as through agricultural runoff, the melting of glaciers by global climate change and salt water intrusion[9]. This will have an impact on their thermal properties.

I expect an increasing NaCl concentration to cause a decreasing specific heat capacity. Thus, I also expect for the NaCl solution's change in temperature to increase with increasing salt concentration.

Independent variable: Concentration of NaCl (moldm^{-3}). I will change it by preparing solutions of different concentrations with NaCl powder (measured with an electronic scale) and distilled water in a volumetric flask. I have chosen a range of 0, 0.250, 0.500, 0.750 and 1.000 moldm^{-3} The lower value, was chosen as control, and the upper, as a more concentrated solution could not be reached due to the increasing precipitation of impurities by the common ion effect [10]. Increasing the concentration of NaCl, also increases dissolved ions, which will resist a change in kinetic energy. The water molecules will have higher kinetic energy and the same thermal energy applied will result in a greater increase in the solution's temperature causing a lower specific heat capacity.
Dependent variables: Change in temperature of 250.0 cm^3 of NaCl solution using an electric kettle. The mean change in temperature at 0 moldm^{-3} sodium chloride solution, assuming its specific heat capacity is the theoretical value, can be used to derive the added heat in joules with the specific heat capacity formula.

The NaCl solution will also be massed to calculate the heat added and then the specific heat capacity of all trials. This will help elucidate the relationship between NaCl solution concentration and the specific heat capacity of the solution. 3 repeats will be done for each concentration to create means, minimizing random error in the results.

Controlled variables

Heating time: 40s controlled with a smartphone stopwatch. Different heating times would result in different amounts of heat added.
Heating apparatus: Always used the same electric kettle. Between trials, the kettle was allowed to cool down to 20°C, monitored with a thermometer. Different electric kettle may have a slightly different wattage so, a different amount of heat will be added in the same heating time.
Source of NaCl: Obtained from the same container. Different sources may have different amounts of impurities.

Method

Materials

- 4 dm^3 distilled water
- 150 g sodium chloride powder
- digital thermometer (±0.1°C)
- 250 cm^3 beaker
- 250.0 cm^3 volumetric flask (±0.6 cm^3)
- digital scale (±0.01g)
- 2200 W Sunbeam Express electronic kettle
- filter funnel
- stirring rod
- Weighing paper
- plastic spoon

[9] (Jenkins, 2009; Inside Science News Service, 2012)
[10] (Clark, 2011)

Commented [A3]: Research design, second strand: The candidate identifies the independent and dependent variables. They explain the chosen range and how the variables will be measured. The selected range does not relate well to the context; the concentration in oceans is in average approximately 0.6 M.

Commented [A4]: Research design, second strand: Relevant controlled variables are identified, and the candidate explains the methods used for controlling them—however, there is no consideration of the temperature of the surroundings, which should have been monitored. There is no attempt shown to control heat losses. The candidate records the temperature of the system.

Commented [A5]: Research design, second strand: It is not mandatory to include a list of materials/apparatus if both instruments and their sizes are clear in the methodology.

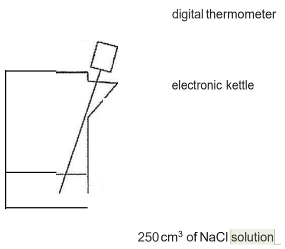
1. Ensure all equipment and glassware are clean by rinsing with distilled water, and drying with a paper towel.
2. Tare digital scale and record the mass of the volumetric flask.
3. Measure mass of sodium chloride powder using a plastic spoon, according to table below.

Table1. Desired NaCl concentration (mol.dm^{-3}) versus mass of NaCl powder added(±0.01 g)

Desired concentration of sodium chloride (moldm^{-3})	Mass of sodium chloride powder added (g) (±0.01 g)
0 ±0*	0.00
0.250 ±0.001	3.65
0.500 ±0.002	7.31
0.750 ±0.002	10.96
1.000 ±0.003	14.61

*All absolute errors are to one significant figure.

4. Add the mass of NaCl to volumetric flask with a funnel and fill to 250 cm^{3}graduation at eye level with distilled water. Homogenize.
5. Measure the mass of the flask and its contents with the scale.
6. Add the contents of the volumetric flask to a 250 cm^3 beaker and mix them with the rod until salt is dissolved.
7. Measure and record the temperature with the thermometer.
8. Ensure the temperature inside the empty electronic kettle is 23.0 °C. Pour contents of the 250 cm^3 beaker into the kettle using a filter funnel, keeping the thermometer in the kettle. Turn on the kettle and allow it to run for 40s.
9. After 40s, record the final temperature of the solution. Empty contents of the kettle into a sink.
10. Allow the kettle to cool until it returns to 23.0 °C.
11. Repeat (1) to (10), increasing the concentration of the solution by one increment. Repeat (11) to have a total of 3 repeats for each of the 5 concentrations of NaCl.
12. *Figure 2. Diagram of testing apparatus*



Commented [A6]: Research design, second strand: Enough details are provided to repeat the procedure.

Data analysis, first strand: The communication of data is clear and precise.

Commented [A7]: Data analysis, second strand: Uncertainties are considered.

Commented [A8]: Research design, third strand: The description of the methodology allows for the investigation to be reproduced. It is detailed and avoids repetitions and unnecessary information.

Commented [A9]: Research design, second strand: The methodology allows for collection of enough data. A minimum of five points is needed to establish a trend, however the candidate only states the value. It would be more useful if the candidate had considered concordant values.

Commented [A10]: Research design, third strand: The diagram shows the thermometer in the correct position. Diagrams or pictures that do not add value are unnecessary.

Figure 3. Example calculation of mass of NaCl powder needed for desired concentration.

$n = cV$[11]

$n = \frac{m}{M}$

$cV = \frac{m}{M}$

$m = McV$

Desired concentration of NaCl $c = 1.000\ mol.dm^{-3}$

$M_{NaCl} = 58.44\ gmol^{-1}$

Volume of solution $= 250.0\ cm^3 = 0.2500\ dm^3$

$m = 1 \times 0.25 \times 58.44$

$= 14.61$ g

Commented [A11]: **Data analysis, first strand:** The processing of data is clear and precise. SI units are preferred, but only imperial units (gallon, feet, etc.) are not accepted.

Safety, ethical and environmental concerns

Safety glasses must be used in the lab to protect eyes. Handle glassware with care and if glass shatters, use a brush to clear shards.

No chemicals should be consumed. Keep kettle and scale away from benchend in a dry environment.

Handle hot water and heated electric kettle with care[12].

NaCl and distilled water are not classified as hazardous chemicals and were disposed down the sink. There are no ethical issues.

Commented [A12]: **Research design, second strand:** The candidate considers pertinent safety, ethical and environmental issues. Pictograms should be discouraged.

[11] (IBO, 2016)

[12] (Ecosolve, 2020)

Raw data collection and processing

Table 2. NaCl concentration (moldm^{-3}) versus initial rate of temperature increase of 250.0 ±0.6 dm^3 NaCl solution (slow/moderate/rapid)

Sodium chloride Concentration (mol.dm^{-3}))	Initial rate of temperature increase of 250.0 ±0.6 dm^3 of sodium chloride solution (slow/ moderate/ rapid)		
	Trial 1	Trial 2	Trial 3
0 ±0	slow	slow	slow
0.250 ±0.001	moderate	moderate	slow
0.500 ±0.002	moderate	moderate	moderate
0.750 ±0.002	rapid	rapid	moderate
1.000 ±0.003	rapid	rapid	rapid

Commented [A13]: Data analysis, first strand: These are more inferences than qualitative data.

Data analysis, second strand: Evidence of consideration of uncertainties.

Table 3. NaCl concentration (moldm^{-3}) versus initial and final temperature of 250.0 ±0.6 dm^3 of solution (°C) (±0.1 °C)

Sodium chloride concentration (mol.dm $^{-3}$)	Tri l 1		Trial 2		Trial 3	
	Initial Temperature (±0.1º C)	Final Temperature (±0.1º C)	Initial Temperature (±0.1º C)	Final Temperature (±0.1º C)	Initial Temperature (±0.1º C)	Final Temperature (±0.2º C)
0 ±0	18.4	61.2	17.4	59.2	17.4	59.3
0.250 ±0.001	18.1	64.5	17.1	64.3	17.3	63.2
0.500 ±0.002	16.7	62.5	16.7	66.7	16.9	69.2
0.750 ±0.002	16.4	73.5	16.3	77.3	16.7	71.7
1.000 ±0.003	17.1	78.9	16.1	80.0	16.4	80.8

Commented [A14]: Data analysis, first strand: While only one example is needed for each calculation made, the report should include all raw data. If the number collected is too high, graphs can be used if properly labelled and reporting the pertinent uncertainties.

Commented [A15]: Data analysis, first strand: Minor slips are ignored when it is clear the candidate is trying to keep the number of decimal places consistent.

Figure 4. Example of sodium chloride concentration error propagation

NaCl powder mass= 14.61 ±0.01g

Percentage error for NaCl powder mass:

$\frac{0.01}{14.61}$ = 0.00068446…

= 0.0684…%

Water volume = 250.0 ±0.6 dm^3

$\frac{0.6}{250}$ = 0.0024

= 0.24 %

Total %error [NaCl]:

0.24% + 0.0684 % = ±0,3084 ...%

[NaCl] =1.000 mo.ldm^{-3} so

0.3768 ...% × 1 = 0.003084 ... = ± 0.003 mol.dm-3

Example: Trial 1 of 0.750 ±0.002 moldm^{-3} T_i= 16.4 ±0.1°C and T_f= 73.5 ±0.1°C.

Table 4. NaCl concentration (moldm^{-3}) versus change in temperature of 250.0 ±0.6 dm^3 of solution after 40 ±1 s of heating (±0.2 °C)

Sodium chloride concentration (mol dm^{-3})	Change in temperature of 250.0 ±0.6 dm^3 of sodium chloride solution (±0.2 °C)		
	Trial 1	Trial 2	Trial 3
0 ±0	42.8	41.8	41.9
0.250 ±0.001	46.4	47.2	45.9
0.500 ±0.002	45.8	50.0	52.3
0.750 ±0.002	57.1	61.0	55.0
1.000 ±0.003	61.8	63.9	64.4

Table 5. NaCl concentration (mol.dm^{-3}) versus mass of 250.0 ±0.6 cm^3 of solution (±0.01 g)

Sodium chloride concentration (moldm^{-3})	Mass of 250.0 ±0.6 dm^3 of sodium chloride solution (g) (±0.02 g)		
	Trial 1	Trial 2	Trial 3
0 ±0	248.66	248.59	248.50
0.250 ±0.001	250.80	250.63	250.61
0.500 ±0.002	252.86	252.80	252.90
0.750 ±0.002	255.78	255.81	255.73
1.000 ±0.003	258.60	258.51	258.49

Commented [A16]: Data analysis, first strand: A minor slip in the unit.

Commented [A17]: Data analysis, second strand: Uncertainties in temperature are correctly propagated.

Commented [A18]: Data analysis, first strand: Some inconsistencies in the use of units.

Commented [A19]: Data analysis, first strand: Again, the candidate enters the wrong unit here.

Table 6. NaCl concentration (mol.dm^{-3}) versus specific heat capacity of solution (Jg^{-1}C^{-1})

Sodium chloride concentration (mo ld m.^{3})	Specific heat capacity of sodium chloride solution (Jg^{-1o}C^{-1})		
	Trial 1	Trial 2	Trial 3
0 ±0	4.12 ±0.07	4.22 ±0.07	4.22 ±0.07
0.250 ±0.001	3.77 ±0.06	3.71 ±0.06	3.82 ±0.06
0.500 ±0.002	3.79 ±0.06	3.47 ±0.05	3.32 ±0.05
0.750 ±0.002	3.01 ±0.04	2.81 ±0.04	3.12 ±0.05
1.000 ±0.003	2.75 ±0.04	2.66 ±0.04	2.64 ±0.04

I assumed that the solution of 0 ±0 mol.dm^{-3} NaCl had the theoretical specific heat capacity of water, 4.186 Jg^{-1o}C^{-1}:

Equation 1. Specific heat capacity formula (180 , 2012)

$$Q = mc\Delta T$$

Equation 2. Formula for mean [13]

$$\mu = \frac{\sum_{i=1}^{k} f_i x_i}{n}$$

Figure 5. Calculation of heat added and error propagation

m = average mass of 0 ±0 moldm^{-3} sodium chloride solution:

$$\frac{248.66 + 248.59 + 248.50}{3} = 248.583 \text{ g}$$

Half range error:

$$\frac{258.66 - 258.50}{2} = \pm 0.08 \text{ g}$$

$$\frac{0.08}{248.5833\ldots} = \pm 0.03218\ldots\%$$

ΔT = average change in temperature of 0 ±0 moldm^{-3} sodium chloride solution after 40 ±1 s of heating:

$$\frac{42.8 + 41.8 + 41.9}{3} = 42.167\ ^\circ\text{C}$$

Half range error:

$$\frac{42.8 - 41.8}{2} = \pm 0.5\ ^\circ\text{C}$$

$$\frac{0.5}{42.167} = \pm 1.1858\ldots\%$$

c = specific heat capacity of water = 4.186 Jg$^{-1°}$C^{-1}

Q = heat added after 40 ±1 s of heating:

$$(248.583)(4.186)(42.167) = 43877.36\ldots \text{ J}$$

Total error:

$$1.1858\ldots\% + 0.03218\ldots\% = \pm 1.2180\ldots\%$$

$$1.2180\ldots\% \times 43877.36\ldots = 534.40569 = \pm 500 \text{ J}$$

$$= 43900 \pm 500 \text{ J}$$

Commented [A20]: Data analysis, second strand: This shows clear evidence of recording and correctly processing uncertainties.

Data analysis, first strand: Communication is clear and precise.

Commented [A21]: Data analysis, third strand: The processing is simple, but correctly done.

13 (IBO, 2012)

Figure 6. Example calculation for specific heat capacity

$$c = \frac{Q}{m\Delta T}$$
$$= \frac{43900}{(255.78)(57.1)}$$
$$= 3.006 \ldots \ \mathrm{Jg^{-1}{}^{\circ}C^{-1}}$$
$$= 3.0 \pm 0.2 \ \mathrm{Jg^{-1}{}^{\circ}C^{-1}}$$

Table 7. NaCl concentration (mol.dm^{3}) versus mean specific heat capacity of solution (Jg^{-1} °C^{-1}) and standard deviation

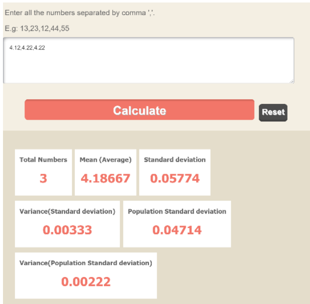
Sodium chloride concentration (mol.dm $^{-3}$)	Mean specific heat capacity of solution (J·g^{-1} ^{0}C^{-1})	Standard deviation
0 ±0	4.19 ±0.05	0.06
0.250 ±0.001	3.77 ±0.05	0.05
0.500 ±0.002	3.5 ±0.2	0.24
0.750 ±0.002	3.0 ±0.2	0.16
1.000 ±0.003	2.68 ±0.05	0.06

The half-range error was used above for the mean specific heat capacity. The mean was evaluated using Equation 2 and the standard deviation using the following formula:

Equation 3. Formula for standard deviation (IBO, 2012)

Commented [A22]: Data analysis, second strand: The image shows the values chosen in the example. The standard deviation is calculated over three values when a minimum of five is required. No outlier is identified.

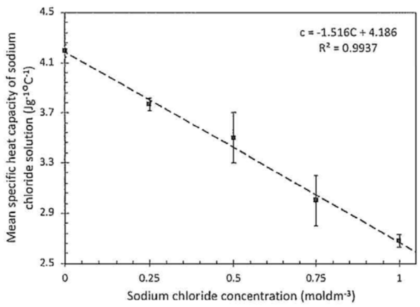
$$\sigma = \sqrt{\frac{\sum_{i=1}^{k} f_i (x_i - \mu)^2}{n}}$$



[14]

On Graph 1, a line of best fit was formed: $c = -1.516C + 4.186$. Where *c* is the specific heat capacity and *C* is the concentration of sodium chloride. There was a corresponding coefficient of determination of 0.9874.

Graph 1. NaCl concentration (mol.dm^{-3}) versus mean specific heat capacity of solution (Jg^{-1} °C^{-1})



Data was further processed by calculating ρ-value from the coefficient of determination, which indicates statistical relationship for a linear data-set[15].

The null and alternative hypotheses were produced.

H_0: there is no statistically significant difference in the average specific heat capacity as the concentration of NaCl changes.

H_1: there is a statistically significant difference in the average specific heat capacity as the concentration of NaCl changes.

A threshold value of 0.05 was chosen.

[14] https://www.easycalculation.com/statistics/standard-deviation.php

[15] This was per formed using an online calculator by Jeremy Stangroom (2020)

Commented [A23]: Data analysis, second strand: A line of best fit is presented. Error bars are not mandatory, but the candidate should explain how they were established if they are used. The candidate reports R^2 values and includes the equation of the trendline.

Commented [A24]: Data analysis, second strand: The candidate shows clear awareness of the impact of uncertainties on results and also applies a statistical analysis. While the use of ρ is controversial in the scientific community, the IB accepts it for deciding to accept the null hypothesis or the alternative instead.

Commented [A25]: Data analysis, second strand: The critical value is correctly chosen. No example is expected for this type of analysis.

A p-value of .000614 was returned by the calculator. This is much smaller than the threshold value. Hence, the alternative hypothesis, H_1, that there is a statistically significant difference in the average specific heat capacity as the concentration of NaCl changes is accepted.

Analysis and Conclusion

In Table 7, we observe a consistent decrease in the mean specific heat capacity of the solution as its concentration increases. This is also apparent in the great decrease from the minimum to maximum concentrations, from 4.19 ±0.05 to 2.68 ±0.05 $Jg^{-1o}C^{-1}$, representing a 36% decrease.

Graph 1 supports this by showing a strongly-fitting linear regression with a negative gradient of -1.516 $Jg^{-1o}C^{-1}$ $(mol.dm^{-3})^{-1}$. The strong fit is supported by the coefficient of determination, 0.9937, corresponding to a high coefficient of correlation of 0.9969 with +1 being a perfect one. There is no overlap of error bars, increasing the significance of the differences between each concentration.

Commented [A26]: Conclusion, first strand: The candidate interprets the relevance of the coefficient of determination and the fact that the error bars do not overlap.

There is an increasing change in temperature of the solution as its concentration increases - from an average of 42.2 °C at 0 ±0 $moldm^{-3}$ to 63.4 °C at 1.000 ±0.003 $mol.dm^{-3}$ indicating a lower specific heat capacity. There is also an increasing mass of the solution -from an average of 248.6 g at 0 ±0 $mol.dm^{-3}$ to 258.5 g at 1.000 ±0.003 $mol.dm^{-3}$. This suggests that,in the 250 cm^3 volume, a greater proportion of the particles are the heavier dissolved sodium and chloride ions, which induce heating in water molecules and a lower specific heat capacity.

Commented [A27]: Conclusion, first strand: There is a detailed consideration of the impact of errors on the results. Direction is stated and explained.

The variations in the data collected, suggest random errors. For example, at 0.250 ±0.001 $moldm^{-3}$ the records show 46.4, 47.2 and 45.9 °C. Variation was more significant in Table 4, which considers the solution's change in temperature, than in Table 5, which considers the solution's mass. There was a maximum percentage difference between any two changes in temperature at the same concentration of 13% in Table 4 (0.500 ±0.002 $moldm^{-3}$) as compared to a maximum percentage difference between masses of 0.08% (0.250 ±0.001g). We can attribute this to the greater effect of random error in the heating process and the lower magnitude of the change in temperature values.

Commented [A28]: Evaluation, first strand: The candidate explains methodological weakness.

With error bars and standard deviation, the spread of data, likely due to random error, was considered in Table 7 and in Graph 1. The error for concentration was near negligible because all values weren't visible as error bars on Graph 1, thus the mean specific heat capacity had very small errors save at 0.250 and 0.500 moldm·3• These exceptions were still minor as reflected in the low standard deviations, which are at maximum 7% of its paired average specific heat capacity value (at 0.500 ±0.002).

Two anomalies were apparent in the data collected in Table 4. Trial 1 for 0.500 ±0.002 $moldm^{-3}$ had a resulting change in temperature of 45.8 ±0.2 °C, 3.6 °C lower than the mean. Trial 2 for 0.750 ±0.002 $moldm^{-3}$ returned a change in temperature of 61.0 ±0.2 °C, 3.3 °C higher than the mean.

Commented [A29]: Conclusion, first strand: The candidate identifies anomalies and evaluates their impact on results. They explain why eliminating them would not significantly affect the results.

The calculated values for specific heat capacity, caused an increase in variation, measured by standard deviation, from 0.11 to 0.24 and from 0.08 to 0.16, respectively. Yet, the effect that these anomalies have on the mean specific heat capacity values is marginal. Removing Trial 1 for 0.500 ±0.002 $moldm^{-3}$ would result in a mean specific heat capacity of 3.4 instead of 3.5 and removing Trial 2 for 0.750 ±0.002 $mol.dm^{-3}$ would result in a mean of 3.1 instead of 3.0.

The qualitative observation s in Table 2 supports the trends presented in Graph 1 and Tables 3, 4, 5, 6 and 7.

Statistical analysis also supports the trend because the coefficient of determination of Graph 1 explains 98.74% of the variability in the data is caused by a change in the NaCl concentration. Thus, the alternative hypothesis, was accepted.

I hypothised an increasing NaCl concentration to cause a decreasing specific heat capacity and therefore, an increasing change in temperature of the solution.

To a large extent, my data and analysis supported this hypothesis. There is a negative correlation between NaCl concentration and the specific heat capacity of the solution as supported by the qualitative, raw and calculated quantitative data. The statistical analysis by the coefficient of determination and ρ-value reinforced this, showing a statistically significant difference in the average specific heat capacity as the concentration of NaCl changed.

I conclude that as NaCl solution concentration increases, the specific heat capacity of the solution decreases answering the research question. This suggests that the changing salinities of aquatic habitats via agricultural pollution and global climate change may have an impact on the thermal properties of their water and, consequently, the species that live within them.

Commented [A30]: Conclusion, first strand: The candidate answers the research question and addresses the hypothesis. The conclusion is justified through the detailed analysis. The equation is well used in the analysis and a holistic approach is taken.

The formed conclusion is supported by Lucy Qu's 2016 investigation into the relationship between salinity and specific heat capacity that showed a negative correlation. [16]

Commented [A31]: Conclusion, second strand: The candidate makes some comparison with a reliable reference. However, during evaluation more scientific context is presented, and from a holistic perspective credit is given.

Evaluation

The controlled variables were successfully controlled, minimizing their effect on results. This contributed to the low variation and errors in the raw and processed data.
The concentration of NaCl solution, was manipulated well with low, almost negligible, errors. These was at most 0.4% of a given concentration.

As a result of these low errors, there was no overlap of vertical or horizontal error bars in the calculated data, supporting the conclusion..

The selected range (0, 0.250, 0.500, 0.750 and 1.000 $moldm^{-3}$) was suitable in showing a relationship between the concentration of NaCl solution and its specific heat capacity as evidenced by the difference between each

[16] (Qu, 2016).

mean specific heat capacity value. The effect of the concentration should have considered closer range of values in terms of the context of changing salinities of aquatic habitats. However, due to the smaller difference between raw and calculated data points, the effect of the same magnitude errors would be greater. To counteract this, it would be necessary to use more precise measuring equipment, particularly a more precise digital thermometer with an error of ±0.01 °C.

Commented [A32]: Evaluation, first strand: There is a reasonable explanation of a methodological limitation in terms of the context.

Evaluation, second strand: The candidate explains how they could have avoided the limitation and justifies why they did not implement the suggested improvements.

I could have reduced the effect of the same magnitude errors in raw and calculated data using a wider range of values. However, this required an increase in the upper NaCl concentration value and higher concentrations induce the precipitation of impurities by the common ion effect. Thus, it would be necessary to use purer deionized water instead of distilled water and analytical NaCl.

Despite the internal temperature of the kettle being cooled to 23 °C, some residual heat on the immersion heater likely existed. As the heating process was consistent through all trials, this may have caused a systematic increase in the change in temperature of the 250 cm^3 NaCl solution after 40 s. Through the calculation of specific heat via theoretical values, any of this systematic error was negated, though its effect on the change in temperature remained. To reduce this systematic error, I could have used another heating apparatus with a removable immersion heater, allowing the heating apparatus to be cooled in a cool water bath between trials. This would have reduced any residual heat to cause a systematic increase in the change in temperature.

Commented [A33]: Evaluation, first strand: As a limitation this a little exagerrated.

Evaluation, second strand: The improvement is vague.

The absolute error of ±1 s, resulting from human reaction, came to form a 2.5% percentage error. Though minor, it increased random error and its effect on the calculated data. The human reaction error cannot be minimized, however its effect via random error can be curtailed by increasing the heating time. Though, as the heating time increases, the NaCl solution will begin to boil. To prevent the boiling of the sodium chloride solution but maintain a high heating time, a lower power electric kettle or immersion heater can be used.

Commented [A34]: Evaluation, first strand: The limitation is allowed considering it was the only kettle available.

Evaluation, second strand: If no other kettle is available, the suggestion is realistic.

I used the theoretical value for the specific heat capacity of water to calculate the heat added instead of a wattage value, because I was unable to derive it due to equipment limitations. By obtaining the wattage of the kettle, the heat added can more accurately be found. This would increase the accuracy and validity of the formed conclusions. Though, being a constant through all specific heat values calculated, this likely would not have any significant effect on the formed trends.

Commented [A35]: Evaluation, second strand: This is unclear because the wattage is reported.

By calculating the true heat added, heat loss to the environment must be minimized and considered in any calculations to find accurate specific heat capacity values. Heat loss can be minimized by increasing insulation, such as polystyrene, around the heating vessel. Heat loss can also be factored, if significant, into calculations by monitoring the change in air temperature around the heating vessel and, using the specific heat capacity of air, estimating the heat lost to the environment. This would provide more accurate values for the added heat.

Commented [A36]: Evaluation, first strand: The candidate should have considered insulation during the design.

Commented [A37]: Evaluation, first strand: The temperature of the surroundings should have been monitored.

Evaluation, second strand: This is a valid improvement, but one that should have been considered during the design.

References

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