Assignment 6: GLMs (Linear Regressios, ANOVA, & t-tests)

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OVERVIEW

This exercise accompanies the lessons in Environmental Data Analytics on generalized linear models.

Directions

1. Rename this file `<FirstLast>_A06_GLMs.Rmd` (replacing `<FirstLast>` with your first and last name).
2. Change "Student Name" on line 3 (above) with your name.
3. Work through the steps, **creating code and output** that fulfill each instruction.
4. Be sure to **answer the questions** in this assignment document.
5. When you have completed the assignment, **Knit** the text and code into a single PDF file.

Set up your session

1. Set up your session. Check your working directory. Load the tidyverse, agricolae and other needed packages. Import the *raw* NTL-LTER raw data file for chemistry/physics (`NTL-LTER_Lake_ChemistryPhysics_Raw.csv`). Set date columns to date objects.

2. Build a ggplot theme and set it as your default theme.

```
# 1. Setting up my session
getwd()  #checking working directory
```

```
## [1] "/home/guest/EDA-Fall2022/EDA-Fall2022"
```

```
library(tidyverse)  #loading tidyverse
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.2 --
## v ggplot2 3.3.6      v purrr   0.3.4
## v tibble  3.1.8      v dplyr   1.0.10
## v tidyr   1.2.0      v stringr 1.4.1
## v readr   2.1.2      v forcats 0.5.2
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```
library(lubridate)  #loading lubridate
```

```
##
## Attaching package: 'lubridate'
##
## The following objects are masked from 'package:base':
##
##     date, intersect, setdiff, union
```

```
library(agricolae)  #loading agricolae
```

```r
Lake.Chemistry.raw <- read.csv("./Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv",
    stringsAsFactors = TRUE)  #importing and naming the raw data set

Lake.Chemistry.raw$sampledate <- as.Date(Lake.Chemistry.raw$sampledate, format = "%m/%d/%y")
# setting the sampledate column as a date object

# 2. Building a ggplot theme & setting it as my default theme
A06_theme <- theme_classic(base_size = 14) + theme(axis.text = element_text(color = "dark gray"),
    legend.position = "right")
theme_set(A06_theme)
```

Simple regression

Our first research question is: Does mean lake temperature recorded during July change with depth across all lakes?

3. State the null and alternative hypotheses for this question: > Answer: H0: During the month of July, there is no correlation or relationship between mean lake temperature and depth across all lakes. In other words, the intercept and slope are equal to zero. Ha: During the month of July, there is a relationship between mean lake temperature and depth across all lakes. Further, the intercept and slope are not equal to zero.

4. Wrangle your NTL-LTER dataset with a pipe function so that the records meet the following criteria:

- Only dates in July.
- Only the columns: `lakename`, `year4`, `daynum`, `depth`, `temperature_C`
- Only complete cases (i.e., remove NAs)

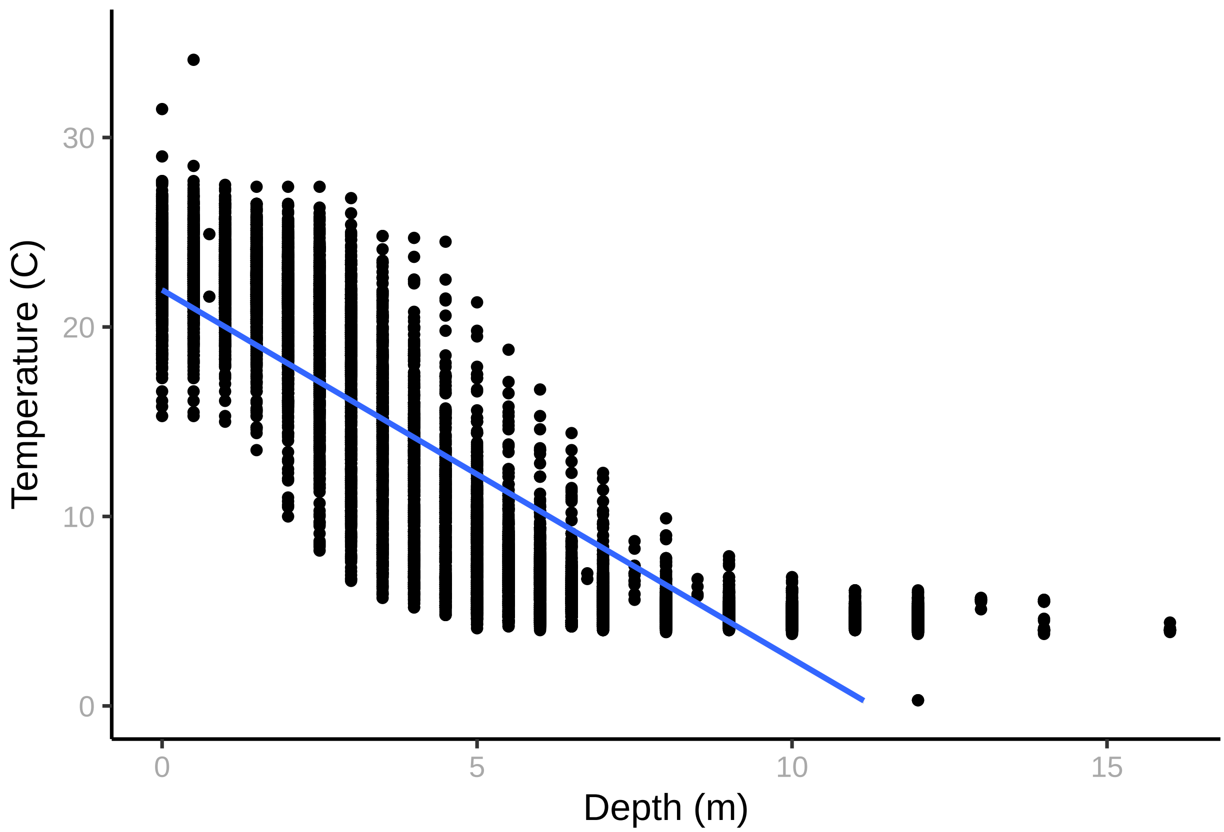
5. Visualize the relationship among the two continuous variables with a scatter plot of temperature by depth. Add a smoothed line showing the linear model, and limit temperature values from 0 to 35 °C. Make this plot look pretty and easy to read.

```r
#4. Wrangling the raw data set with a pipe function
Lake.Chemistry.raw.wrangled <-
  Lake.Chemistry.raw %>%
    mutate(month = month(sampledate)) %>%  #creating a new month column from the sampledate column
      filter(month == 7) %>%  #filtering to only include the month of July
        select(lakename:daynum, depth:temperature_C) %>%  #selecting specific columns as
                                                           #specified above
          na.omit() #omitting na's to ensure the data set only includes complete cases

#5. Plotting the wrangled data set using ggplot
tempbydepthplot <-
  ggplot(Lake.Chemistry.raw.wrangled, aes(x = depth, y = temperature_C)) + #assigning x & y values
  geom_point() + #creating a scatterplot
  geom_smooth(method = "lm") + #adding a line of best fit
  ylim(0,35) + #setting the limits of temperature along the y-axis
  ylab(expression("Temperature (C)")) + #renaming the y-axis
  xlab(expression("Depth (m)")) #renaming the x-axis
print(tempbydepthplot)
```

```
## `geom_smooth()` using formula 'y ~ x'
```

```
## Warning: Removed 24 rows containing missing values (geom_smooth).
```



6. Interpret the figure. What does it suggest with regards to the response of temperature to depth? Do the distribution of points suggest about anything about the linearity of this trend?

   Answer: The scatterplot of temperature by depth implies that there is a negative correlation between temperature and depth during the month of July. As depth increases, temperature decreases. In addition, the relatively equal distrubtion of points on either side of the line emphasizes the linearity of the negative correlation between temperature and depth.

7. Perform a linear regression to test the relationship and display the results

```
# 7. Performing a linear regression to test the relationship between
# temperature & depth
tempbydepth.regression <- lm(data = Lake.Chemistry.raw.wrangled, temperature_C ~
    depth)
summary(tempbydepth.regression)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = Lake.Chemistry.raw.wrangled)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -9.5173 -3.0192  0.0633  2.9365 13.5834
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 21.95597    0.06792   323.3   <2e-16 ***
## depth       -1.94621    0.01174  -165.8   <2e-16 ***
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.835 on 9726 degrees of freedom
## Multiple R-squared:  0.7387, Adjusted R-squared:  0.7387
## F-statistic: 2.75e+04 on 1 and 9726 DF,  p-value: < 2.2e-16
```

8. Interpret your model results in words. Include how much of the variability in temperature is explained by changes in depth, the degrees of freedom on which this finding is based, and the statistical significance of the result. Also mention how much temperature is predicted to change for every 1m change in depth.

   Answer: From running the linear regression, you can see that there is in fact a relationship between temperature and depth. The p-value (2.2e^-16) indicates whether the relationship between the two variables is statistically significant. This regression is based on 9726 observations, as described by the degrees of freedom. In this scenario, the p-value is very small so we reject the null hypothesis that states there is no relationship or correlation between temperature and depth. The R-squared value of 0.7387 indicates that ~73.87% of the variability in temperature is explained by depth. Lastly, temperature is predicted to change -1.95 degrees celsuis for every 1 meter change in depth.

Multiple regression

Let's tackle a similar question from a different approach. Here, we want to explore what might the best set of predictors for lake temperature in July across the monitoring period at the North Temperate Lakes LTER.

9. Run an AIC to determine what set of explanatory variables (year4, daynum, depth) is best suited to predict temperature.

10. Run a multiple regression on the recommended set of variables.

```
# 9. Running an AIC to determine what explanatory variables (year4, daynum, &
# depth) are best suited to predict temperature
AIC.lake.chemistry <- lm(data = Lake.Chemistry.raw.wrangled, temperature_C ~ year4 +
    daynum + depth)
step(AIC.lake.chemistry)
```

```
## Start:  AIC=26065.53
## temperature_C ~ year4 + daynum + depth
##
##          Df Sum of Sq    RSS   AIC
## <none>                141687 26066
## - year4   1       101 141788 26070
## - daynum  1      1237 142924 26148
## - depth   1    404475 546161 39189

##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = Lake.Chemistry.raw.wrangled)
##
## Coefficients:
## (Intercept)        year4       daynum        depth
##    -8.57556      0.01134      0.03978     -1.94644
```

```
# 10. Running a multiple regression on the recommended set of variables (year4,
# daynum, & depth) to predict temperature
multiple.regression <- lm(data = Lake.Chemistry.raw.wrangled, temperature_C ~ year4 +
```

```
    daynum + depth)
summary(multiple.regression)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = Lake.Chemistry.raw.wrangled)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -9.6536 -3.0000  0.0902  2.9658 13.6123
##
## Coefficients:
##              Estimate Std. Error  t value Pr(>|t|)
## (Intercept) -8.575564   8.630715   -0.994  0.32044
## year4        0.011345   0.004299    2.639  0.00833 **
## daynum       0.039780   0.004317    9.215  < 2e-16 ***
## depth       -1.946437   0.011683 -166.611  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.817 on 9724 degrees of freedom
## Multiple R-squared:  0.7412, Adjusted R-squared:  0.7411
## F-statistic:  9283 on 3 and 9724 DF,  p-value: < 2.2e-16
```

11. What is the final set of explanatory variables that the AIC method suggests we use to predict temperature in our multiple regression? How much of the observed variance does this model explain? Is this an improvement over the model using only depth as the explanatory variable?

    Answer: The AIC method suggests we use year4, daynum, and depth as explanatory variables to predict temperature. The multiple regression model now explains ~74.12% (R-squared value = 0.7412) of the variability in temperature, which is a slight improvement over the linear model used in #7. In summary, more of the variability in temperature is explained by year4, daynum, and depth than just depth alone.

Analysis of Variance

12. Now we want to see whether the different lakes have, on average, different temperatures in the month of July. Run an ANOVA test to complete this analysis. (No need to test assumptions of normality or similar variances.) Create two sets of models: one expressed as an ANOVA models and another expressed as a linear model (as done in our lessons).

```
# 12. Running an ANOVA test
Lake.Chemistry.anova <- aov(data = Lake.Chemistry.raw.wrangled, temperature_C ~ lakename)
summary(Lake.Chemistry.anova)
```

```
##               Df Sum Sq Mean Sq F value Pr(>F)
## lakename       8  21642  2705.2      50 <2e-16 ***
## Residuals   9719 525813    54.1
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# Running a linear regression
Lake.Chemistry.lm <- lm(data = Lake.Chemistry.raw.wrangled, temperature_C ~ lakename)
summary(Lake.Chemistry.lm)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = Lake.Chemistry.raw.wrangled)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -10.769  -6.614  -2.679   7.684  23.832
##
## Coefficients:
##                            Estimate Std. Error t value Pr(>|t|)
## (Intercept)                 17.6664     0.6501  27.174  < 2e-16 ***
## lakenameCrampton Lake       -2.3145     0.7699  -3.006 0.002653 **
## lakenameEast Long Lake      -7.3987     0.6918 -10.695  < 2e-16 ***
## lakenameHummingbird Lake  -6.8931     0.9429  -7.311 2.87e-13 ***
## lakenamePaul Lake           -3.8522     0.6656  -5.788 7.36e-09 ***
## lakenamePeter Lake          -4.3501     0.6645  -6.547 6.17e-11 ***
## lakenameTuesday Lake        -6.5972     0.6769  -9.746  < 2e-16 ***
## lakenameWard Lake           -3.2078     0.9429  -3.402 0.000672 ***
## lakenameWest Long Lake      -6.0878     0.6895  -8.829  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 7.355 on 9719 degrees of freedom
## Multiple R-squared:  0.03953,    Adjusted R-squared:  0.03874
## F-statistic:    50 on 8 and 9719 DF,  p-value: < 2.2e-16
```

13. Is there a significant difference in mean temperature among the lakes? Report your findings.

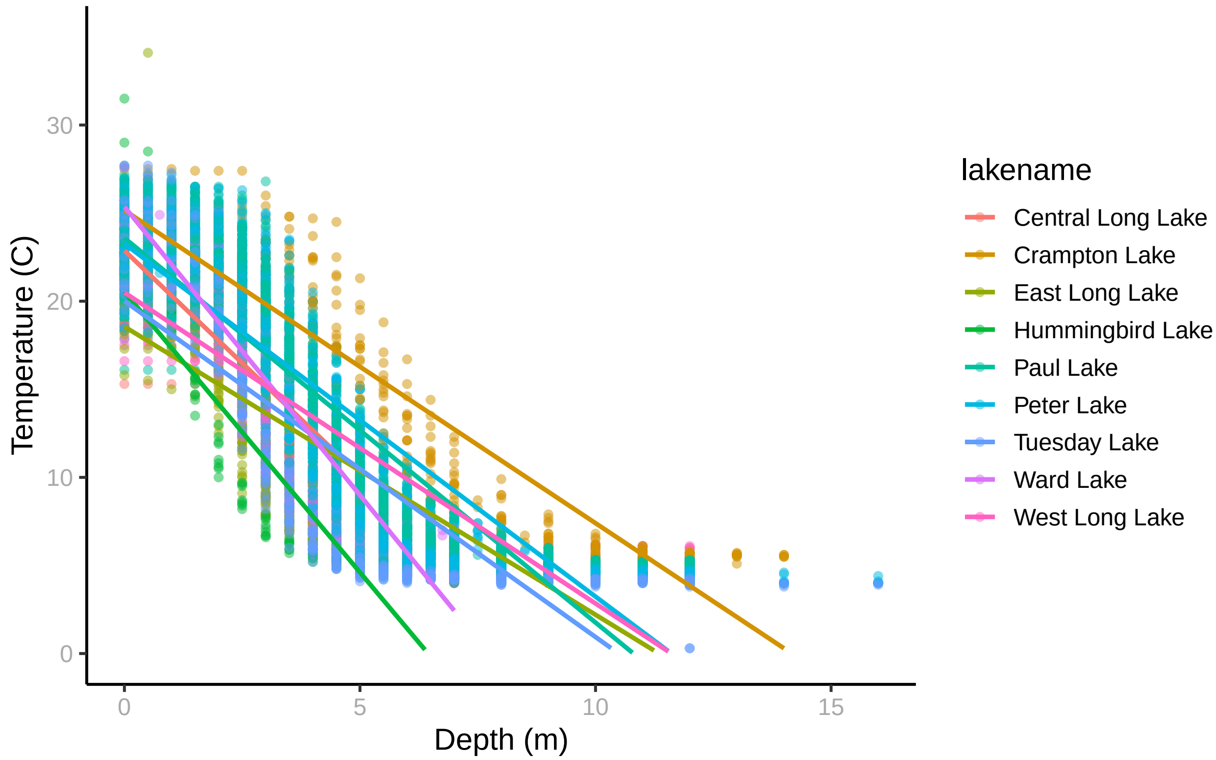
    Answer: Yes, there is a significant difference in mean temperature among the lakes. The results of the ANOVA test and linear regression indicate that the p-value (2.2e^-16) is much less than 0.05, so we must reject the null hypothesis that states there is no difference in the mean temperatures across all lakes. In addition, the R-squared value of 0.03953 indicates that only ~4% of the variability in temperature is explained by the lake name.

14. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a geom_smooth (method = "lm", se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```r
#14. Plotting temperature by depth with separate colors for each lake
tempbydepthplot2 <-
  ggplot(Lake.Chemistry.raw.wrangled, aes(x = depth, y = temperature_C, color = lakename)) +
  #assigning x & y values and different colors for each lakename
  geom_point(alpha = 0.5) + #making the points of the scatterplot 50% transparent
  geom_smooth(method = "lm", se = FALSE) + #creating a line of best fit for each lakename
  xlab("Depth (m)") + #renaming x-axis
  ylab("Temperature (C)") + #renaming y-axis
  ylim(0, 35) #setting y-axis limits
print(tempbydepthplot2)
```

```
## `geom_smooth()` using formula 'y ~ x'
```

```
## Warning: Removed 73 rows containing missing values (geom_smooth).
```



15. Use the Tukey's HSD test to determine which lakes have different means.

```r
# 15. Running the Tukey HSD test
TukeyHSD(Lake.Chemistry.anova)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = Lake.Chemistry.raw.wrangled)
##
## $lakename
##                                      diff        lwr        upr     p adj
## Crampton Lake-Central Long Lake    -2.3145195 -4.7031913  0.0741524 0.0661566
## East Long Lake-Central Long Lake   -7.3987410 -9.5449411 -5.2525408 0.0000000
## Hummingbird Lake-Central Long Lake -6.8931304 -9.8184178 -3.9678430 0.0000000
## Paul Lake-Central Long Lake        -3.8521506 -5.9170942 -1.7872070 0.0000003
## Peter Lake-Central Long Lake       -4.3501458 -6.4115874 -2.2887042 0.0000000
## Tuesday Lake-Central Long Lake     -6.5971805 -8.6971605 -4.4972005 0.0000000
## Ward Lake-Central Long Lake        -3.2077856 -6.1330730 -0.2824982 0.0193405
## West Long Lake-Central Long Lake   -6.0877513 -8.2268550 -3.9486475 0.0000000
## East Long Lake-Crampton Lake       -5.0842215 -6.5591700 -3.6092730 0.0000000
## Hummingbird Lake-Crampton Lake     -4.5786109 -7.0538088 -2.1034131 0.0000004
## Paul Lake-Crampton Lake            -1.5376312 -2.8916215 -0.1836408 0.0127491
## Peter Lake-Crampton Lake           -2.0356263 -3.3842699 -0.6869828 0.0000999
## Tuesday Lake-Crampton Lake         -4.2826611 -5.6895065 -2.8758157 0.0000000
## Ward Lake-Crampton Lake            -0.8932661 -3.3684639  1.5819317 0.9714459
## West Long Lake-Crampton Lake       -3.7732318 -5.2378351 -2.3086285 0.0000000
## Hummingbird Lake-East Long Lake     0.5056106 -1.7364925  2.7477137 0.9988050
## Paul Lake-East Long Lake            3.5465903  2.6900206  4.4031601 0.0000000
## Peter Lake-East Long Lake           3.0485952  2.2005025  3.8966879 0.0000000
```

```
## Tuesday Lake-East Long Lake         0.8015604 -0.1363286  1.7394495 0.1657485
## Ward Lake-East Long Lake            4.1909554  1.9488523  6.4330585 0.0000002
## West Long Lake-East Long Lake       1.3109897  0.2885003  2.3334791 0.0022805
## Paul Lake-Hummingbird Lake          3.0409798  0.8765299  5.2054296 0.0004495
## Peter Lake-Hummingbird Lake         2.5429846  0.3818755  4.7040937 0.0080666
## Tuesday Lake-Hummingbird Lake       0.2959499 -1.9019508  2.4938505 0.9999752
## Ward Lake-Hummingbird Lake          3.6853448  0.6889874  6.6817022 0.0043297
## West Long Lake-Hummingbird Lake     0.8053791 -1.4299320  3.0406903 0.9717297
## Peter Lake-Paul Lake               -0.4979952 -1.1120620  0.1160717 0.2241586
## Tuesday Lake-Paul Lake             -2.7450299 -3.4781416 -2.0119182 0.0000000
## Ward Lake-Paul Lake                 0.6443651 -1.5200848  2.8088149 0.9916978
## West Long Lake-Paul Lake           -2.2356007 -3.0742314 -1.3969699 0.0000000
## Tuesday Lake-Peter Lake            -2.2470347 -2.9702236 -1.5238458 0.0000000
## Ward Lake-Peter Lake                1.1423602 -1.0187489  3.3034693 0.7827037
## West Long Lake-Peter Lake          -1.7376055 -2.5675759 -0.9076350 0.0000000
## Ward Lake-Tuesday Lake              3.3893950  1.1914943  5.5872956 0.0000609
## West Long Lake-Tuesday Lake         0.5094292 -0.4121051  1.4309636 0.7374387
## West Long Lake-Ward Lake           -2.8799657 -5.1152769 -0.6446546 0.0021080
```

16.From the findings above, which lakes have the same mean temperature, statistically speaking, as Peter Lake? Does any lake have a mean temperature that is statistically distinct from all the other lakes?

> Answer: Ward Lake and Paul Lake have the same mean temperature, statstically speaking, as Peter Lake. When comparing the mean temperatures of these lakes to Peter Lake, they have a p-value greater than 0.05 which indicates they have the same mean temperature. No one lake has a mean temperature that is statistically distinct from all other lakes, the difference of means between lakes is not greater than 8 (degrees C) in any pairwise comparison.

17. If we were just looking at Peter Lake and Paul Lake. What's another test we might explore to see whether they have distinct mean temperatures?

> Answer: If we were just looking at Peter Lake and Paul Lake, we could utilze a two-sample t-test in order to determine whether their mean temperatures are the same or different.

18. Wrangle the July data to include only records for Crampton Lake and Ward Lake. Run the two-sample T-test on these data to determine whether their July temperature are same or different. What does the test say? Are the mean temperatures for the lakes equal? Does that match you answer for part 16?

```r
# 18. Wrangling the July data set
Lake.Chemistry.Crampton.Ward <- Lake.Chemistry.raw.wrangled %>%
    filter(lakename == "Crampton Lake" | lakename == "Ward Lake")
# filtering to only include records for Crampton and Ward Lakes

# Running a two-sample t-test to determine if their mean temperatures are the
# same or different
Crampton.Ward.two_sample <- t.test(Lake.Chemistry.Crampton.Ward$temperature_C ~ Lake.Chemistry.Crampton
Crampton.Ward.two_sample
```

```
##
##  Welch Two Sample t-test
##
## data:  Lake.Chemistry.Crampton.Ward$temperature_C by Lake.Chemistry.Crampton.Ward$lakename
## t = 1.1181, df = 200.37, p-value = 0.2649
## alternative hypothesis: true difference in means between group Crampton Lake and group Ward Lake is n
## 95 percent confidence interval:
##  -0.6821129  2.4686451
## sample estimates:
```

```
## mean in group Crampton Lake     mean in group Ward Lake
##                    15.35189                   14.45862
```

Answer: The results of the two-sample t-test indicate that the means are similar, with the mean temperature of Crampton Lake being 15.35 (degrees C) and Ward Lake being 14.46 (degrees C). The p-value (0.2649) is greater than 0.05, so we fail to reject the null hypothesis. Thus, the mean temperatures of Crampton Lake and Ward Lake are equal, statsitically speaking. This matches my answer to question 16.