Developing an Experimental Project:
The Need to Knead - Part 2
Collecting and Analyzing Data

by Wendy Topic

In a scientific investigation, the data collected should be handled with increasing sophistication as the researcher matures. With essentially the same procedure, we will show data collection and analysis at an Intermediate (Grades 6 & 7) and Senior level (Grades 10-12).

Procedure - Dough Preparation

1. Make the bread using the following ingredient amounts
   - 475 ml warm water (110 degrees F/45 degrees C)
   - 135 g white sugar
   - 20 g active dry yeast
   - 9 g salt
   - 60 ml vegetable oil
   - 820 g bread flour

2. Follow the directions for making the dough at
   http://allrecipes.com/recipe/amish-white-bread/detail.aspx
   (or use the local link - Amish Bread Recipe - if the above URL does not work)

3. Begin kneading the dough. Remove an approximately 100 g portion after 2 minutes of kneading. Shape into a ball, contacting the dough as little as possible. Place on an oiled cookie sheet.

4. Repeat step 3 every 2 minutes until 7 or 8 dough balls are formed.

5. Cut any leftover dough into approximately 100 g portions. Shape into balls on a second oiled cookie sheet. Use this dough as a control to ensure rising and oven baking conditions are consistent in the oven.

6. Let the dough rise uncovered for 60 minutes in an oven preheated to 170oF (77oC). Oven was turned off with 37 minutes of rising time remaining.

7. Remove dough from oven and preheat oven to 350oF. Bake for 20 minutes. Put the tray with the variable knead times on the top rack and the control buns on the middle rack. Remove from oven and allow to cool before touching the buns.

8. Weigh each bun, then wrap in cling film. Submerge each bun in water to measure the volume of water displaced.

9. Replace the flour in step 1 with whole wheat. Continue with steps 2 - 8

Senior level:

10. Repeat steps 1-9 twice, for a total of three trials with white flour and three trials with whole wheat.

On the second and third trials of the white flour dough, make buns every minute for the first 4 minutes. Continue kneading and making buns every 2 minutes until all the dough is used (approximately 26 minutes).On the second and third trials of the whole wheat dough, continue kneading and making buns every 2 minutes until all the dough is used (approximately 26 minutes). This will allow more data points at the beginning of the experiment (for the white flour) and at the end (for the whole wheat flour).

Observations of white dough buns (Intermediate Level)

Table 1. Observations of the control white dough buns. Each bun was kneaded for 16 minutes. Buns rose and were baked in the following positions on the middle rack.

Oven location	Mass (+ 0.1 g)	Volume (+ 10 mL)	Density (g/mL)
Back left	82.2	240	0.343
Back right	72.2	210	0.344
Front left	75.6	220	0.344
Front right	67.1	200	0.336

Table 2. Observations of white dough buns, each bun was kneaded for different amounts of time.

Knead time of bun	Mass (+ 0.1 g)	Volume (+ 10 mL)	Density (g/mL)
2 minutes	88.9	195	0.456
4 minutes	105.4	265	0.398
6 minutes	106.7	280	0.381
8 minutes	99.0	260	0.381
10 minutes	91.1	250	0.364
12 minutes	104.6	280	0.374
14 minutes	105.2	295	0.357
16 minutes	93.7	275	0.341
18 minutes	94.8	270	0.351

Analysis and Interpretation of Data (at an Intermediate Level)

The control buns had an average density of 0.342 g/mL, all the control buns were within 1.7% of the average value. This suggests that the location of the buns in the oven during rising and baking has a negligible impact on the final density.

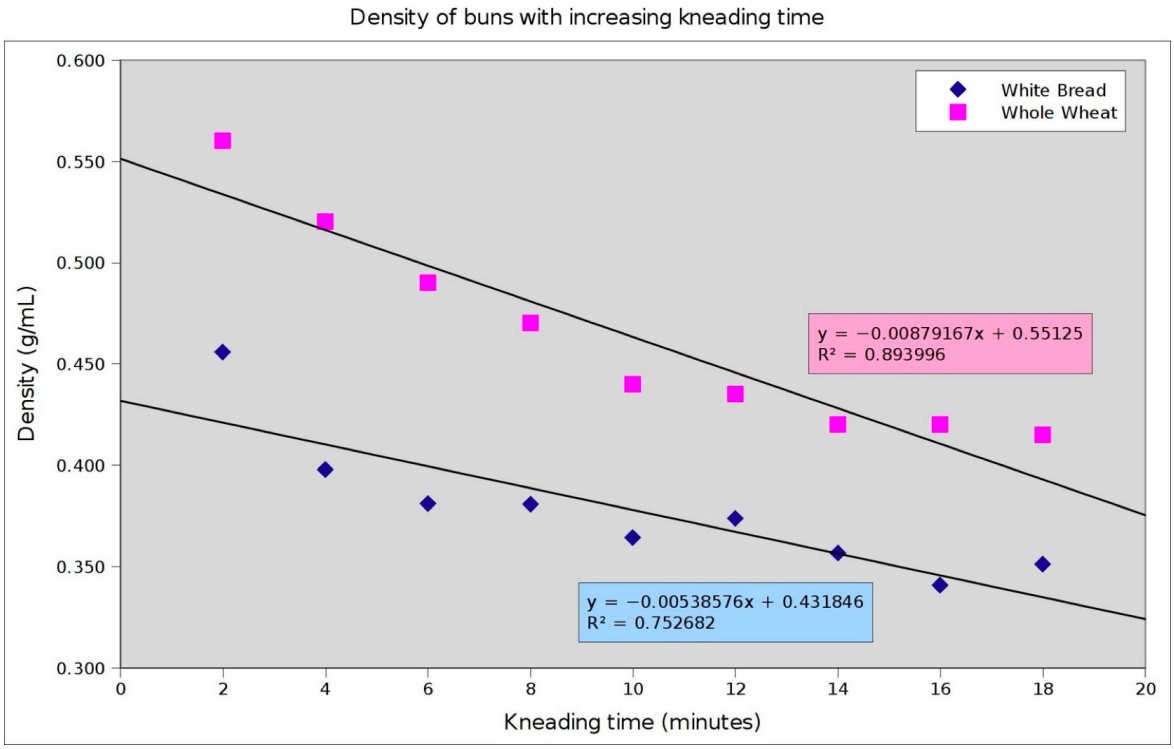

Figure 1. The densities of white flour and whole wheat buns with increased kneading time.

From figure 1, it can be seen that the density of both white flour buns and whole wheat buns decreases as the length of kneading increases. The whole wheat buns are more dense than the white buns. The slope of the line for the whole wheat buns is steeper than the white flour buns. The steeper line suggests that the density is decreasing more quickly in the whole wheat buns. This is odd because gluten, a protein found in wheat, develops more slowly in whole wheat flour than in white flour. The trend line for the whole wheat dough should be less steep than for the white flour.

How long must the bread be kneaded? While kneading the bread does decrease the density, kneading the bread for a long time is hard work. With the white flour, the densities at 6 minutes and 8 minutes were the same. This suggests that kneading the white flour dough for 8 minutes does not cause much more gluten to develop than kneading it for 6 minutes. In the whole wheat dough, the same density was found at 14 and 16 minutes. Again, this suggests that 16 minutes of kneading the whole wheat flour is enough to see most of the gluten react.

Conclusion

White flour dough should be kneaded for 6 to 8 minutes, while whole wheat flour dough should be kneaded for 14 to 16 minutes. While some further decreases in density could be observed after this, these times provide a good compromise between effort and lightness of the bread.

Analysis and Interpretation of Data (at a Senior Level)

The control buns had an average density of 0.342 g/mL, all the control buns were within 1.7% of the average value. This suggests that the location of the buns in the oven during rising and baking has a negligible impact on

the final density.

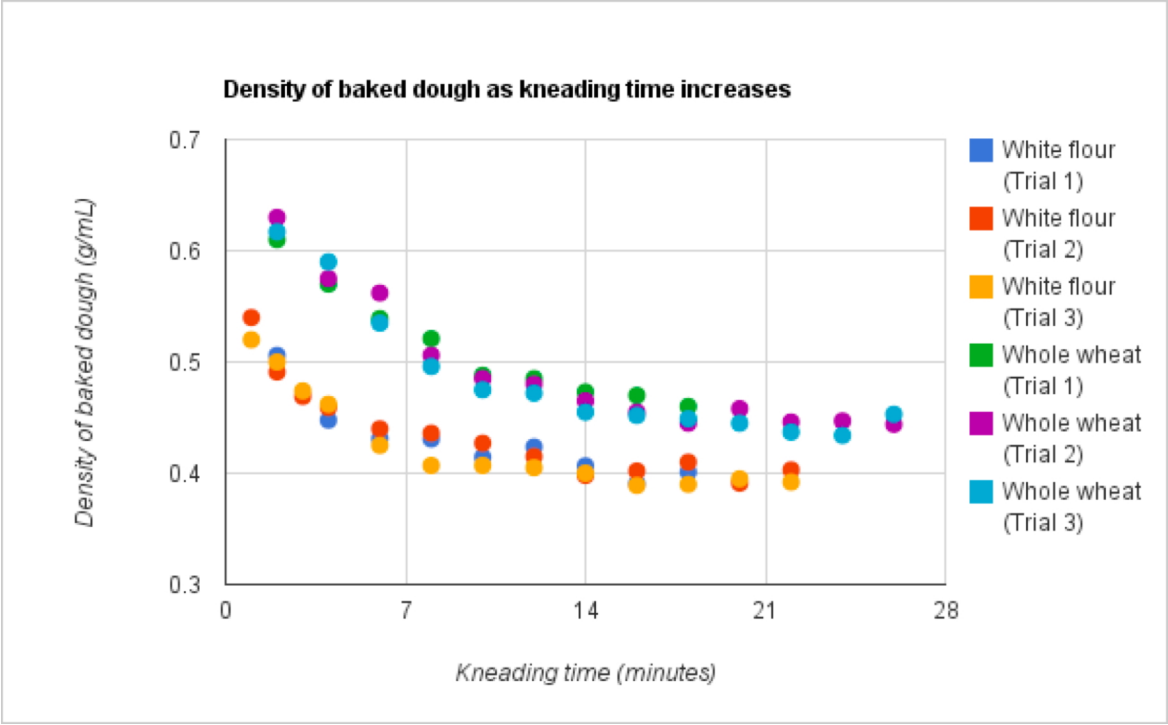

Figure 2. Plot of all the densities determined for three trials of white flour buns and three trials of whole wheat buns.

As the kneading time increases for both the white flour and the whole wheat dough the density of the resulting buns generally decreases (see figure 2). The whole wheat buns are considerably more dense than the white flour buns. The densities of both types of buns have the general shape of an exponential decay. The rate of decay is slower in the whole wheat buns compared to the white flour buns. This suggests that gluten, a protein found in wheat, takes longer to develop in whole wheat flour when kneaded, compared to white flour.

In chemical reactions, the initial rate of a reaction can be determined by fitting the linear portion of a measurable observable versus time. In this experiment, the decrease in density with kneading time can be used to compare how quickly gluten develops in both white and whole wheat flour.

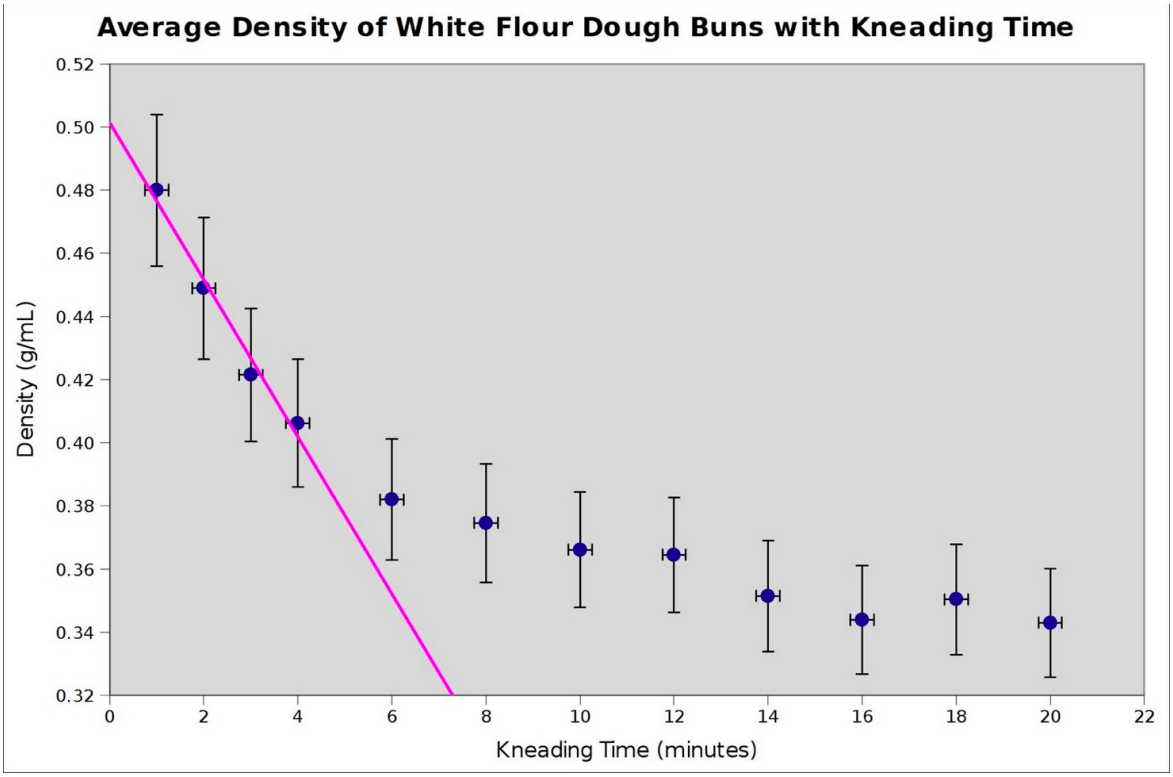

Figure 3. Average of the calculated densities of three trials of white flour buns.
The pink line indicated the linear regression of the first four data points (deemed linear).
The equation of this line of best fit is y = _0.0249 x + 0.501, with an R-squared of 0.9791.

As shown in figure 3, the equation of the best fit line for the linear data is y = _0.0249 x + 0.501, with an R-squared of 0.9791 for the white flour buns. This means that the density of the white flour was initially decreasing at a rate of 0.0249 g/(mL min) (grams per milliliter per minute). As the gluten is reacted, the rate of the reaction slows. This is why the density of buns begins to decrease more slowly after 4 minutes. The y-intercept of the equation suggests that without any kneading, the density of the white flour bun would be 0.501 g/mL.

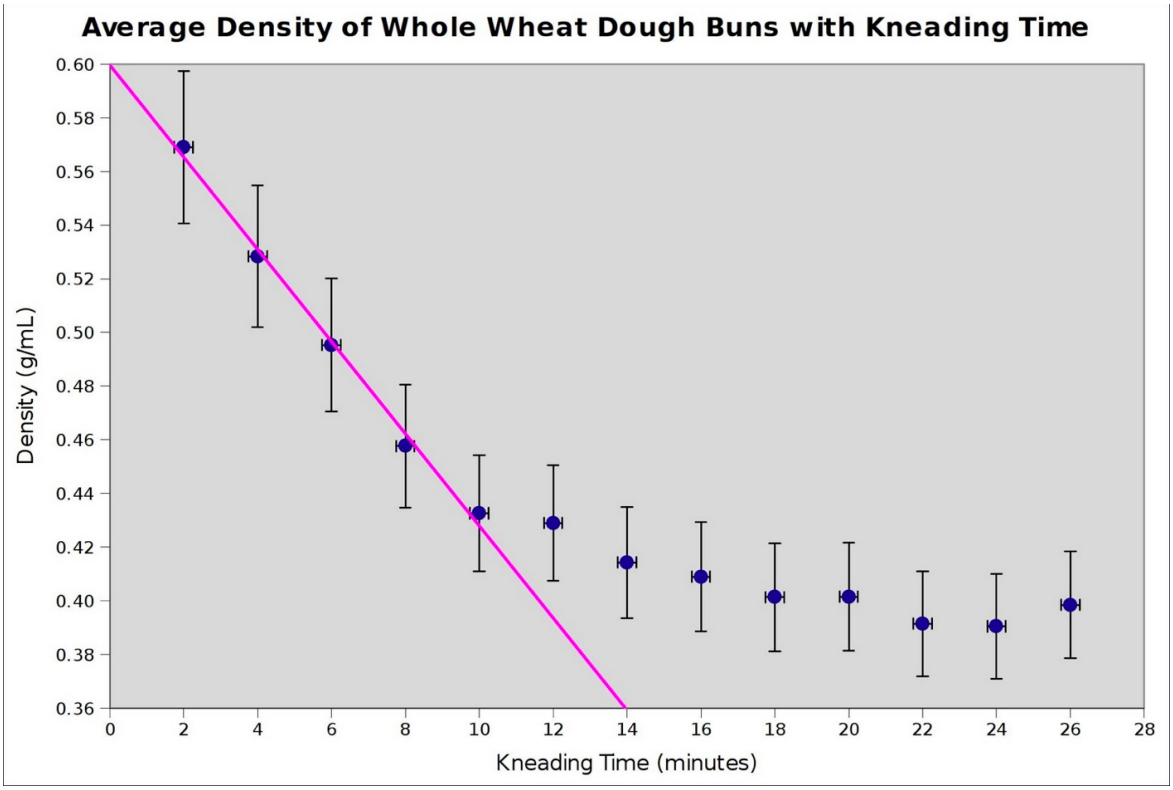

Figure 4. Average of the calculated densities of three trials of whole wheat buns.
The pink line indicated the linear regression of the first five data points (deemed to linear).
The equation of this line of best fit is y = _0.0172 x + 0.600, with an R-squared of 0.9944.

As shown in figure 4, the equation of the best fit line for the linear data is y = _0.0172 x + 0.600, with an R-squared of 0.9944 for the whole wheat buns. This means that the density of the whole wheat flour was decreasing more slowly, at a rate of 0.0172 g/(mL min). This is approximately _ the rate of the white flour. The density decrease deviates from the linear regression after 10 minutes of kneading time. The y-intercept of the equation suggests that without any kneading, the density of the whole wheat bun would be 0.600 g/mL.

How much kneading is required? The data collected does not provide a clear answer. As stated above, steady decreases in the density of the bread are only seen in the first 4 and 10 minutes of kneading for the white and whole wheat dough, respectively. If the goal is the lightest (least dense) buns possible, small returns may be seen when the dough is needed for longer than the duration of my experiment.The actual decreases in density, however, become unreliably small after a while. In the six trials conducted for this experiment, kneading the bread longer continued to provide small decreases in density until an average of 8.7 minutes for white flour and 17.3 minutes for whole wheat flour (see table 3).

Table 3. First time at which the bun density decreased by less than 0.01 g/mL .

	White Flour			Whole Wheat		
Trial	1	2	3	1	2	3
Time (in minutes) when density decrease was less than 0.01 g/mL	8	8	10	12	20	20

Average time (in minutes)	8.7	17.3

Conclusion

When trying to make light and fluffy bread kneading 4 to 9 minutes for white flour and 10 to 17 minutes for whole wheat flour is a good compromise between effort and impact of kneading.

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Wendy Topic is a science teacher at Glenlyon Norfolk School.
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