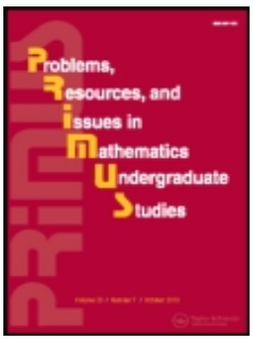

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Math Mistakes That Make the News

Heather A. Lewis

Abstract: Teachers often promote care in doing calculations, but for most students a single mistake rarely has major consequences. This article presents several real-life events in which relatively minor mathematical errors led to situations that ranged from public embarrassment to the loss of millions of dollars' worth of equipment. The stories here are appropriate to share in middle school through undergraduate classrooms.

Keywords: Gimli glider, Mars climate orbiter, Katrina, mistakes, errors, accuracy, measurement.

1. INTRODUCTION

Pounds are used instead of kilograms. A plus and minus sign are reversed. Errors like this are commonplace in classrooms, but when they happen in the workplace they can cause an airplane to fall out of the sky, a parking ticket to be issued incorrectly, or a submarine to sink. The stories in this collection provide real-life examples that can be shared with students to illustrate that sometimes small mathematical mistakes can have large consequences.

In my own teaching, I tell one or two stories at a time, spreading them out over a semester. For example, if I notice that students have left off units on a homework assignment — a common occurrence in my classes — then as I return the homework I tell the story of the Gimli Glider, drawing it out and having people guess what the mistake was that caused the plane to run out of fuel. If I am writing an equation and I myself mix up addition and subtraction, then I might mention how a similar difficulty led to a bridge in Europe being built at two different heights. If I notice that some students have computed incorrectly on an exam, reading $3 \times 2 - 1$ as $3 \times (2 - 1)$, then at the start of the next class I will show them the mathematical equation that was printed on

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the back of a box of cocoa and have them figure out the intended answer; often the students themselves raise the issue of order of operations, but if not then I will point out the printed answer and explain why it differs from what they had expected. For the students who make mistakes, the fact that a company could do likewise seems to make them feel better even as it reminds them to be careful.

In several cases, too, the fact that many of the mistakes in the stories below were expensive to fix resonates with the students: they cringe at the thought of building a spacecraft or a submarine only to discover that one tiny error meant that so much time and money was wasted. By hearing first one, and then another, and then yet another similar example, students end up with a much firmer grasp of why it is important to be attentive not only in the overall processes, but also in the finest details.

2. UNIT MISTAKES

2.1. The Gimli Glider: Metric and English Units

23 July 1983. Air Canada Flight 143. Captain Bob Pearson and First Officer Maurice Quintal were scheduled to fly a Boeing 767 across Canada, but due to a fault in the Fuel Quantity Information System Processor, the fuel gauges were not working. The determination was made that, as long as the amount of fuel was calculated manually, it would still be safe and legal to fly.

A test using a drip stick revealed that there were 7682 liters of fuel in the tank. It was known that the plane needed 22,300 kilograms of fuel to fly from Montreal to its destination in Edmonton, and so the flight crew and maintenance personnel multiplied the 7682 liters by the conversion factor of 1.77 and determined that there were 13,597 kilograms of fuel onboard. This meant they needed to add 8703 kilograms of fuel; dividing by 1.77 translated this into 4916 liters, and at the suggestion of the refueler they rounded up and added 5000 liters for a total of 12,682 liters of fuel on the aircraft. A recheck during a layover in nearby Ottawa indicated that the computations were correct and all was well.

And it was, at least for the first half of the trip. But then a fuel pressure warning light came on, followed quickly by beeps and another set of warning lights. Because the fuel gauges were not working it was not clear what the exact problem was, and no one realized the airplane had run out of fuel until the engines stopped. With limited emergency resources, there were few options. The plane was near Winnipeg, but not near enough to land there safely; the best option was to fly to the small town of Gimli, which housed a decommissioned Royal Canadian Air Force base where First Officer Quintal had previously served. What the pilots did not know was that the Winnipeg Sports Car Club was using the base to celebrate "Family Day," and the runway that Captain Pearson neared was at that moment being used for drag races.

The plane approached, but too quickly and at too steep an angle. Captain Pearson, who was an experienced glider pilot, was able to put the plane into a maneuver called a sideslip to reduce the altitude quickly and land on the runway. As he recalled in an interview with the *National Post* in April 2013, he only felt scared after landing, when he looked up and saw three boys on bicycles a short distance ahead.

The plane had landed at an angle and the nose caught on fire, but no one on the plane or on the ground was killed or even seriously injured. The plane itself was able to fly out just a few days later.

So why did the plane run out of fuel halfway through its flight? The problem was the conversion factor of 1.77 that was used. Canada was in the process of switching from the English system (miles, gallons, etc.) to the metric system (kilometers, liters, etc.), and although liters had been used for fueling for several years, the Boeing 767 was the first Air Canada aircraft to use kilograms instead of pounds for fuel loads. The conversion factor of 1.77 was the conversion from liters to pounds, not kilograms. This incorrect computation meant that the 12,682 liters of fuel the plane had in Montreal was not 22,447 kilograms, but 22,447 pounds, or roughly 10,200 kilograms. Enough to get halfway across the country.

The Gimli Glider, as the plane came to be called, flew for another 25 years before being retired in 2008. At the invitation of Air Canada officials, both Bob Pearson and Maurice Quintal were onboard its final flight.

(For more information on the Gimli Glider, see [7, 16, 20, 26, 29].)

2.2. The Mars Climate Orbiter: Metric and English Units (Again)

The Gimli Glider was a dramatic example of the perils of having multiple forms of measurement in the same country, and also of the necessity of having a system in place to double-check results. It was not, however, the most recent example. Fifteen years after that incident, on 11 December 1998, the Mars Climate Orbiter was launched from Cape Canaveral, Florida to serve as a weather satellite for Mars. Nine months later, on 23 September 1999, NASA lost touch with the spacecraft just as it was approaching the planet. They never regained communication, and the $125,000,000 orbiter was considered a complete loss. The root problem, once again, was with units.

NASA had been using the metric system for several years. The primary contractor, however, was Lockheed Martin Astronautics, and some of the software was written with English units instead of metric. One spacecraft procedure used thruster firings to reduce excess angular momentum in onboard flywheels, and data from that was recorded in a file and used to model the trajectory of the Mars Climate Orbiter. This data was supposed to be in Newton-seconds, but it was actually recorded in pound-seconds.

This mixture of units meant that there were small errors in the Mars Climate Orbiter's trajectory that built up during the trip to Mars, but the scope of the problem was not clear because of limitations in the line of sight from Earth. The spacecraft was designed so that, as it entered into orbit around Mars, it would initially be at least 226 kilometers above the planet. There was some flexibility for how close the orbiter could be, but it had to remain at least 80 kilometers above the planet to stay in orbit. Due to the accumulated errors in its trajectory, the Mars Climate Orbiter approached Mars from only 57 kilometers above the surface. Although NASA was not able to determine exactly what happened at that point, they concluded that the spacecraft either burned up on entry to Mars' atmosphere, or left the orbit entirely and continued into space.

(For more information on the Mars Climate Orbiter, see [21].)

2.3. Cases of Sporks: Non-standard Units

The two examples above show what can go wrong when there is a mix-up between metric and English units. However, it turns out that even nonstandard units can cause trouble.

Back in 2005, a large number of house supplies (cots, camp stoves, toilet paper, etc.) were donated or purchased for people who had lost their homes in Hurricanes Katrina and Rita. The items were stored in a warehouse in Louisiana, and then moved to Texas, and then . . . nothing. They sat in Fort Worth, and the Federal Emergency Management Agency (FEMA) paid a million dollars each year to keep them stored. A few years later, when the warehouse was due to be torn down, the items were declared to be federal surplus and given away. This is where the controversy began: although the materials were donated to several agencies, including schools and food banks, they had originally been intended for the hurricane victims and despite the amount of time that had passed, some of the people who suffered from the storms were still in need of the materials. Community groups said they had told FEMA that they needed provisions for people who were still recovering, whereas FEMA claimed that no one from Louisiana had indicated that they wanted the items. And during all this arguing, the General Services Administration reported the value of the goods as $85,000,000.

This story originally made the news in 2008 because of concerns about the decision to give away the supplies, and indeed as a result of the media scrutiny some of the items were returned to Louisiana. However, a follow-up a month later revealed that the total worth was not $85,000,000 after all, but only $18,500,000. The problem was in how objects were counted: the appraisal error happened because some items were priced by the case but others were priced individually, and some of the individual items were then assigned the monetary value of an entire case. For example, each individual spork was assessed as if it

were a case of 1000 sporks, causing the value of donated sporks to be reported as $36,000,000 instead of $36,000. Likewise, each roll of toilet paper was initially recorded as though it were an entire package, so that the $18,000 worth of toilet paper ended up being reported as being worth $1,500,000. Similar mix-ups between individual items and groups of items accounted for the rest of the $66,500,000 overestimation.

(For more information on the supplies, see [1, 2].)

3. COMPUTATION MISTAKES

3.1. Flood Control: Addition and Subtraction

Counting sporks was not the only math mistake that occurred in the aftermath of Hurricane Katrina. After the storm, the Army Corps of Engineers in New Orleans built a system of flood gates and pumps. Maps released on 20 June 2007 showed that in areas around the Lakeview neighborhood, where floodwaters had reached 10 feet during the hurricane, the new flood control system would reduce water levels by 66 inches in the event of a major storm.

Unfortunately, that number turned out to be more than a little bit off: a table in one of the appendices to a report released on 7 November 2007 showed that in fact scientists predicted that in the areas around Lakeview the system would only reduce floodwaters by six inches.

The reason for the numbers on the map being off by 1000%? In one calculation used for the maps, a plus sign was inadvertently replaced with a minus sign. The mistake was corrected in the reports, and the lower number made public when local television station WWL-TV brought up the discrepancy with an engineer. Residents who had already begun rebuilding in Lakeview, however, were particularly unhappy at learning that so much of the predicted floodwater reduction was based on a miscalculation, and nothing they could count on in future storms.

(For more information on the map error, see [3, 12, 27].)

3.2. The Laufenburg Bridge: Addition and Subtraction (Again)

The maps above were not the first time in the 21st century that addition versus subtraction made the news. A few years earlier, in 2003, a bridge was built across the Rhine River between Laufenburg, Germany and Laufenburg, Switzerland. This High Rhine Bridge was built simultaneously from the two countries, and was supposed to connect in the middle of the river.

This project had a special complication, however: the bridge design referenced sea level, and sea level is not the same everywhere. (Indeed, this is one of the reasons that the Panama Canal has a system of locks between the Atlantic and Pacific Oceans.) In this case, the two countries each used a

different reference point for sea level: Germany used the North Sea, whereas Switzerland used the Mediterranean Sea, and the two measurements differ by 27 centimeters.

The fact that there were two different sea levels being used was known, and fortunately there was a computation to correct for that difference. Unfortunately, the computation added the error to itself instead of eliminating it, and as the bridge was built it became clear that the German side of the bridge was 54 centimeters higher than the Swiss side. The German side had to be lowered before the two parts of the bridge could be joined, resulting in additional time, additional money, and certainly additional frustration.

(For more information on the bridge error, see [4, 8, 22].)

3.3. Swiss Miss Calculations: Order of Operations

The computation errors above had significant impact for a lot of people; fortunately, the consequences of math mistakes are not always so dire. In 2010 students at Bay State Middle School in Massachusetts saw something odd on a box of Swiss Miss®Marshmallow Madness™Hot Cocoa Mix. On the back of the box was the question "On average, how many mini mallows are in one serving?" with the equation $3 + 2 \times 4 \div 2 - 3 \times 7 - 4 + 47 =$?? for finding the answer (see Figure 1). This computation simplifies to $3 + 4 - 21 - 4 + 47$, which is 29, but the answer on the bottom of the box was actually 92.

At first this would seem to be a simple transcription error, but it was actually more complicated than that: the average number of mini mallows really is 92, but in coming up with a mathematical expression the company had forgotten to take order of operations into account, where multiplication and division are computed before addition and subtraction, and had expected people to work left to right one step at a time (getting $3 + 2 = 5$, then $5 \times 4 = 20$, etc.). Using this incorrect left-to-right method the expression gives the intended 92.

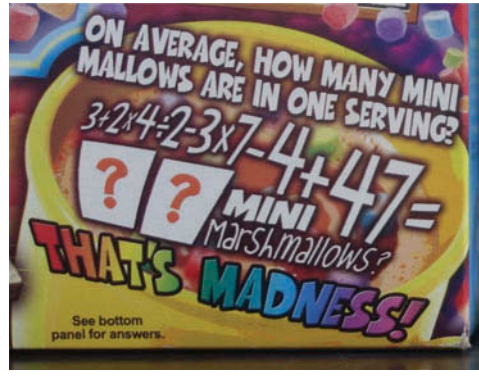

Figure 1. The original equation.

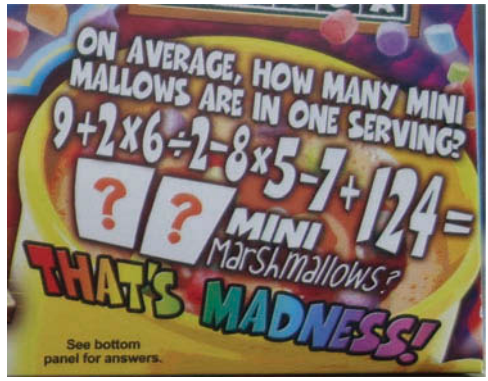

Figure 2. The revised equation.

The students wrote to the company and received a response within a month: the company would fix the error. Sure enough, later boxes of the cocoa had a new equation $9 + 2 \times 6 \div 2 - 8 \times 5 - 7 + 124 =$?? that simplifies correctly (see Figure 2).

On a related note, order of operations has given other people trouble as well: only two years earlier on the British television show *Big Brother* (UK Series 9) contestants had to simplify three math expressions in order to find the combination for a safe. The expressions were:

- $3 \times 17 - 24 + 78 \times 9 \div 5 - \left(13^2\right) + (65 - 29) \div 4 + \left(4^2\right) - (7 \times 3) + \left(3^2\right) + 99 - \left(7^2\right) - 49$
- $1396 \times 2 \div 4 - \left(12^2\right) + 46 \times 2 \div 40 \times \left(5^2\right) - (7 \times 99) \times 3 - \left(11^2\right) \times 5 - 219$
- $100 - 33 \times 5 + 655 \div \left(5^2\right) \times 17 - 248 \times 3 \div \left(4^2\right) + 52 \div 7 + (273 - 217)$

These expressions simplify to $12\frac{2}{5}, -2291\frac{1}{2}$, and $404\frac{9}{70}$ respectively, which could not open the safe. Had the computations been done left-to-right without using the standard order of operations, the results would have been the intended 19, 31, and 75.

(For more information on the Swiss Miss story, see [28]; for more information on the Big Brother episode, see [5, 23].)

4. DECIMAL MISTAKES

4.1. Parking Garage Tickets: Decimals and Time

A calculator can be quite useful for simplifying expressions like those above, as long as users understand what they are doing. This is particularly important

for problems involving time, as a traffic warden new to the job discovered in 2008 when he incorrectly ticketed several cars at a parking lot in Devon, England.

In this particular parking lot, drivers would pay in advance for a certain number of minutes and would then put a ticket in the windshield showing the time they had entered the lot and how many minutes of parking they had paid for. One driver, Dave Alsop, entered at 2:49 pm and paid for 75 minutes. This meant that the car was covered until 4:04 pm.

The traffic warden, however, determined the expiration time by entering 14.49 into his calculator (for 1449 in 24-hour time, which corresponds to 2:49 pm) and adding on 0.75 (for the 75 minutes). The traffic warden got 15.24 as the sum, and he interpreted that number to mean that the car was only covered until 3:24 pm. It was just past that time, so the warden issued a penalty. When Mr Alsop returned to the car at 3:41 pm, he saw the £50 fine and found the traffic warden. Mr Alsop said that he tried to explain the error — that hours have 60 minutes, not 100, so standard decimal addition does not apply — but the warden did not see any problem. Three cars incorrectly received fines due to this error.

The story had a happy ending, though: Mr Alsop appealed, and the local council not only repealed the penalties, but sent a letter of apology and offered additional training to the traffic warden.

(For more information on the time error, see [6].)

4.2. Parlier Water Bills and the Isaac Peral Submarine: Misplaced Decimals

In the situation above, the decimal error was due to a misunderstanding of how to translate and interpret fractions of time. A different kind of error, which is not computational but can have outcomes that are just as serious, is simply recording the wrong number. This can happen with any kind of numbers — in May 2013 the wrong person was initially crowned Miss Universe Canada because some of the judges' handwritten scores were incorrectly entered into a computer — but in the following two examples the miswritten symbol was as small as a decimal point.

In the first example, an error caused business owners in Parlier, California to receive inaccurate water bills for five years. In 2007 the city council had approved an increase of approximately 90% in water fees; however, a city worker put a decimal point in the wrong place in the formula used to compute the water bills for commercial and industrial businesses, resulting in much lower water bills than intended. The error was discovered in 2012, and the corrected rates went into effect on 1 July 2013, although businesses were not informed until a letter sent on 25 July 2013. In this case, although the city determined that legally it could bill the increase for up to three years back, it

has so far decided against any retroactive collection. Rather, the difficulty for the businesses was that the new rates were so steep and took effect so many years after the city council vote that owners were unprepared to suddenly pay bills that in some cases amounted to thousands of additional dollars each year.

In the second example, the repercussions were more severe. In 2004, after years of review, the Ministry of Defense in Spain signed contracts for the building of four S-80 submarines, advanced non-nuclear submarines that could stay submerged and undetected for weeks rather than days. At the time the four submarines were projected to be completed between 2011 and 2014, and cost 1.756 billion euros (over 2 billion dollars). There were some delays and some cost increases, but the first ship — the Isaac Peral, named for the Spanish sailor and engineer who invented an electric submarine in the late 19th century — was well on its way to completion until the second half of 2012, when a flaw was discovered.

The error itself was relatively simple: a decimal point was misplaced. According to the Defense News, Rafael Bardaji, head of the Madrid-based Strategic Studies Group and former director of the Office of Strategic Assessment at Spain's Defense Ministry, said "I have been told it was a simple matter of someone writing in one zero when they should have written three."

The consequences were more dramatic. The misplaced decimal meant that when the submarine was built, it weighed more than 70 tons more than expected. While that was less than 5% of the sub's total weight, it made a huge difference in its buoyancy, which impacts how submarines maneuver in the water.

Navantia, the company building the S-80 submarines, announced in June 2013 that it will now be working with Electric Boat, a contractor for the US Navy, to redesign and build the ships. The current plan is to increase the size-to-weight ratio by increasing the length of the submarines by 3 to 6 meters, but the costs are high. There is a delay of several years (with the longest delay for the Isaac Peral itself, which was the closest to completion) and the additional cost is measured in tens of millions of dollars: one approximation was that the redesign would cost roughly €14,000,000 (over $18,000,000), plus additional expenditures for current submarine repairs now that the existing fleet will need to remain in service longer than expected. And finally, while not a monetary disadvantage per se, the partnership with the US Navy turns a national project that was a source of pride for many into an international one.

(For more information on the crowning of Miss Universe Canada, see [17]; for more information on the Parlier water bills, see [9, 15]; for more information on the S-80 submarines, see [10, 11, 18, 24, 25].)

5. CONCLUSIONS

When students are learning mathematics, it is common for them to make mistakes. And sometimes, as the mathematics becomes more complicated, they

may discount the importance of errors they perceive as minor. In a sense I agree: if a student has solved a complicated problem with only a single misstep, I will praise the work they did well. What these examples show, however, is that there are times outside of the classroom when the (in)correctness of the final answer is all that matters.

Many of these examples I found through luck: occasionally while reading the news I will notice an article about an error; people who know of my interest in math mistakes will also send me links. Just recently, for example, reports have surfaced about brand-new trains in France that were built to fit in modern train stations, which have a standardized distance between tracks and platforms, but due to a lack of communication between the train company and the rail operators, the trains turned out to be too wide to fit in more than one thousand of the older train stations. This measurement confusion will cost millions of euros to fix. (See [13, 14, 19] for more details.)

Other examples I found by doing a search every few months for phrases such as "math mistake news" or "arithmetic error news" and seeing if any new reports appeared. My reaction was a mixture of delight and dismay if one did. And yet, the fact that I accumulate one or two new examples each year means that I am able to share current information with my classes as an ongoing illustration of why I remind them to be careful in their units, their notation, and their computations, and to double check their work whenever possible.

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BIOGRAPHICAL SKETCH

Heather A. Lewis is a Professor at Nazareth College, and has an office filled with mathematical curiosities. She has been collecting stories about math errors for several years to share with her students; some of them have been included in the unofficial department blog at http://threesixty360.wordpress.com.