Scientific Problem Solving

Case Study

Read to Learn

The Minneapolis Bridge Failure

On August 1, 2007, the center section of the Interstate-35W (I-35W) bridge in Minneapolis, Minnesota, suddenly collapsed. A major portion of the bridge fell more than 30 m into the Mississippi River. There were more than 100 cars and trucks on the bridge at the time, including a school bus carrying over 50 students. Several people were killed and many more were injured.

The failure of this 8-lane, 581-m long interstate bridge came as a surprise to almost everyone. Drivers do not expect a bridge to drop out from underneath them. The design and engineering processes that bridges undergo are supposed to ensure that bridge failures do not happen.

Controlled Experiments

After the 2007 bridge collapse, investigators had to determine why the bridge failed. To do this, they used a process of scientific inquiry similar to the one you read about in Lesson 1. The investigators designed controlled experiments to help them answer questions and test their hypotheses. A controlled experiment is a scientific investigation that tests how one factor affects another. You might conduct controlled experiments to help discover answers to questions, to test hypotheses, or to collect data.

Identifying Variables and Constants

When conducting an experiment, you must identify factors that can affect the experiment's outcome. *A* **variable** *is any factor that can have more than one value*.

Types of Variables In controlled experiments, there are two kinds of variables. *The* **independent variable** *is the factor that you want to test. It is changed by the investigator to observe how it affects a dependent variable*. *The* **dependent variable** *is the factor you observe or measure during an experiment*.

Key Concepts

- Why are evaluation and testing important in the design process?
- How is scientific inquiry used in a real-life scientific investigation?

Study Coach

Preview Headings Before you read the lesson, preview all the headings. Make a chart and write a question for each heading beginning with *What* or *How*. As you read, write the answers to your questions.

Reading Check

1. Identify What does a controlled experiment test?

Factors that Do Not Vary Constants *are the factors in an experiment that do not change.* You can change the independent variable to observe how it affects the dependent variable. Without constants, two independent variables could change at the same time, and you would not know which variable affected the dependent variable.

Experimental Groups

A controlled experiment usually has at least two groups. *The* **experimental group** *is used to study how a change in the independent variable changes the dependent variable. The* **control group** *contains the same factors as the experimental group, but the independent variable is not changed.* Without a control, it is impossible to know if your observations result from the variable you are testing or some other factor.

Reading Check

2. State What is the purpose of a control group in an experiment?

This case study will explore how the investigators used scientific inquiry to determine why the bridge collapsed. The tables like the one on the next page provide additional information and show what a scientist might write in a science journal.

Simple Beam Bridges

Before you read about the bridge-collapse investigation, think about the structure of bridges. The simplest type of bridge is a beam bridge. This type of bridge has one horizontal beam across two supports. A beam bridge might be constructed across a small creek. A disadvantage of beam bridges is that they tend to sag in the middle if they are too long.

Reading Check

3. Explain Why are trusses often used for bridges that span long distances?

Truss Bridges

A truss bridge often spans long distances. This type of bridge is supported only at its two ends, but a series of interconnected triangles, or trusses, strengthens it. The I-35W bridge was a truss bridge designed in the early 1960s. Straight beams connected to triangular and vertical supports held up the deck. These supports held deck of the bridge, or the roadway. The beams in the bridge's deck and the supports came together at structures known as gusset plates.

The steel gusset plates joined the triangular and vertical trusses to the overhead roadway beams. These beams ran along the deck of the bridge. This area, where the truss structure connects to the roadway at a gusset plate, is called a node. The gusset plates at each node are critical pieces that hold the bridge together.

Reading Check

4. Describe What are the gusset plates of a bridge?

Bridge Failure Observations

After the bridge collapsed, the local sheriff's department handled the initial recovery of the collapsed bridge. Finding, freeing, and identifying victims was a higher priority than preserving evidence about why the bridge collapsed. Emergency rescue workers also damaged the collapsed structure. The unintentional damage to the bridge made evaluating why the collapse occurred more difficult.

However, investigators eventually recovered the entire structure. The investigators labeled each part with the location where it was found. They also noted the date when they removed each piece. Investigators then moved the pieces to a nearby park. There, they placed the pieces in their relative original positions. Examining the reassembled structure, investigators found physical evidence they needed to determine where the breaks in each section occurred.

The investigators had an additional source of information about the collapse. A motion-activated security camera recorded the bridge collapse. The video showed about 10 seconds of the collapse. This revealed the sequence of events that destroyed the bridge. Investigators used this video to help pinpoint where the collapse began. This video gave investigators additional clues as to how and why the bridge failed.

Observe and Gather Information
Scientists often observe and gather information about an object or an event before proposing a hypothesis. This information is recorded or filed before the investigation.
Observations: • Recovered parts of the collapsed bridge • A video showing the sequence of events as the bridge fails and falls into the river

Asking Questions

Asking questions and seeking answers to those questions is a way that scientists formulate hypotheses. One or more factors could have caused the bridge to fail. Was the original bridge design faulty? Were bridge maintenance and repair poor or lacking? Was there too much weight on the bridge at the time of the collapse? Each of these questions was studied to determine why the bridge collapsed. Did one or a combination of these factors cause the bridge to fail?

Reading Check

5. Consider How did investigators go about studying the bridge?

Reading Check

6. Identify What important information did investigators gain from the surveillance video?

Interpreting Tables

7. Point Out How do scientists use information about an object or event?

Gathering Information and Data

Investigators reviewed the modifications made to the bridge since it opened in 1967. In 1977, engineers noticed that salt used to deice the bridge during winter weather was causing the reinforcement rods in the roadway to weaken. To protect the rods, engineers applied a thicker layer of concrete to the surface of the bridge roadway.

Analysis after the collapse revealed that this extra concrete increased the dead load on the bridge by about 13.4 percent. A load can be a force applied to the structure from the structure itself (dead load) or from temporary loads such as traffic, wind gusts, or earthquakes (live load).

Investigators recorded this qualitative and quantitative data. **Qualitative data** *uses words to describe what is observed*. **Quantitative data** *uses numbers to describe what is observed*.

More modifications were made to the bridge in 1998. The bridge that was built in the 1960s did not meet current safety standards. Analysis showed that the changes made to the bridge during this renovation further increased the dead load on the bridge by about 6.1 percent.

Reading Check

8. Contrast What is the difference between the dead load and the live load on a bridge?

Reading Check

9. Distinguish How do qualitative data and quantitative data differ?

An Early Hypothesis

At the time of the bridge collapse in 2007, the bridge was undergoing additional renovations. Piles of sand and gravel, a water tanker filled with over 11,000 L of water, a cement tanker, a concrete mixer, and other equipment, supplies, and workers were assembled on the bridge. In addition to these renovation materials, normal vehicle traffic was on the bridge. Did these renovations, materials, and traffic overload the bridge, causing the center section to collapse? Only a thorough analysis could answer this question.

Collect and Process Data

When gathering information or collecting data, scientists might perform an experiment, create a model, gather and evaluate evidence, or make calculations.

Qualitative Data: A thicker layer of concrete was added to the bridge to reinforce rods.

Quantitative Data:
- The concrete increased the load on the bridge by 13.4 percent.
- The modifications in 1998 increased the load on the bridge by 6.1 percent.
- At the time of the collapse in 2007, the load on the bridge increased by another 20 percent.

Interpreting Tables

10. Identify Circle the increase in the dead load due to the addition of concrete to the road deck.

Hypothesis
A hypothesis is a possible explanation for an observation that can be tested by scientific investigations.
Hypothesis: The bridge failed because it was overloaded.

Computer Modeling

Engineers used computer models to analyze the structure and loads on the bridge. Using computer-modeling software, investigators entered data from the Minnesota bridge into a computer. The computer performed numerous mathematical calculations. After thorough modeling and analysis, it was determined that the bridge was not overloaded.

Revising the Hypothesis

Evaluations conducted in 1999 and 2003 provided additional clues as to why the bridge might have failed. As part of the study, investigators took numerous pictures of the bridge structure. The photos revealed bowing of the gusset plates at the eleventh node from the south end of the bridge. Investigators labeled this node *U10*.

Gusset plates are designed to be stronger than the structural parts they connect. It is possible that the bowing of the plates indicated a problem with the gusset plate design. Previous inspectors and engineers missed this warning sign.

The accident investigators found that some recovered gusset plates were fractured, while others were not damaged. If the bridge had been properly constructed, none of the plates should have failed. But inspection showed that some of the plates failed very early in the collapse.

After evaluating the evidence, the accident investigators formulated the hypothesis that the gusset plates failed, which lead to the bridge collapse. Now investigators had to test this hypothesis.

Hypothesis
~~**1.** The bridge failed because it was overloaded.~~
2. The gusset plates failed, which lead to the bridge collapse.

Think it Over

11. Name one advantage of using computer modeling software.

Reading Check

12. Describe What evidence caused investigators to be concerned about the U10 node?

Interpreting Tables

13. Identify Highlight the investigators' new hypothesis.

Testing the Hypothesis

The investigators knew the load limits of the bridge. To calculate the load on the bridge when it collapsed, they estimated the combined weight of the bridge and the traffic on the bridge. The investigators divided the load on the bridge when it collapsed by the load limits of the bridge to find the demand-to-capacity ratio. The demand-to-capacity ratio provides a measure of a structure's safety.

Interpreting Tables

14. Recognize What is the demand-to-capacity ratio?

Test the Hypothesis
• Compare the load on the bridge when it collapsed with the load limits of the bridge at each of the main gusset plates. • Determine the demand-to-capacity ratios for the main gusset plates. • Calculate the appropriate thicknesses of the U10 gusset plates.
Independent Variables: actual load on bridge and load bridge was designed to handle.
Dependent Variable: demand-to-capacity ratio

Analyzing Results

As investigators calculated the demand-to-capacity ratios for each of the main gusset plates, they found that the ratios were particularly high for the U10 node. The U10 plate failed earliest in the bridge collapse. The table below shows the demand-to-capacity ratios for a few of the gusset plates at some nodes. A value greater than 1 means the structure is unsafe. Notice how high the ratios are for the U10 gusset plate compared to the other plates.

Interpreting Tables

15. Explain Why does this data suggest that the U10 gusset plate was unsafe?

Node-Gusset Plate Analysis

Gusset Plate	Thickness (cm)	*Demand-to-Capacity Ratios for the Upper-Node Gusset Plates					
		Horizontal loads			Vertical loads		
U8	3.5	0.05	0.03	0.07	0.31	0.46	0.20
U10	**1.3**	**1.81**	**1.54**	**1.83**	**1.70**	**1.46**	**1.69**
U12	2.5	0.11	0.11	0.10	0.71	0.37	1.15

*A value greater than 1 indicates the plates are unsafe.

Key Concept Check

16. Analyze Why are evaluation and testing important in the design process?

Further calculations showed that the U10 plates were not thick enough to support the loads they were supposed to handle. They were about half the required thickness.

Analyzing Results
The U10 gusset plates should have been twice as thick as they were to support the bridge.

Drawing Conclusions

Over the years, modifications to the I-35W bridge added more load to the bridge. On the day of the accident, traffic and the concentration of construction vehicles and materials added still more load. Investigators concluded that if the U10 gusset plates were properly designed, they would have supported the added load.

When investigators examined the original records for the bridge, they were unable to find any detailed gusset plate specifications. They could not determine whether undersized plates were used because of a mistaken calculation or some other error in the design process. The only thing that they could conclude with certainty was that undersized gusset plates could not reliably hold up the bridge.

The Federal Highway Administration and the National Transportation Safety Board published the results of their investigations. These published reports now provide scientists and engineers with valuable information they can use in future bridge designs. These reports are good examples of why it is important for scientists and engineers to publish their results and to share information.

Conclusions
The bridge failed because the gusset plates were not properly designed and they could not carry the load that they were supposed to carry.

Key Concept Check

17. Identify Give three examples of the scientific inquiry process that was used in this investigation.

Mini Glossary

constant: factors in an experiment that a scientist does not change

control group: the part of an experiment that contains the same factors as the experimental group, but the independent variable is not changed

dependent variable: the factor a scientist observes or measures during an experiment

experimental group: used to study how a change in the independent variable changes the dependent variable

independent variable: the factor in an experiment that a scientist wants to test that is changed to see how it affects a dependent variable

qualitative data: observations in an experiment described in words

quantitative data: observations in an experiment described in numbers

variable: any factor that can have more than one value

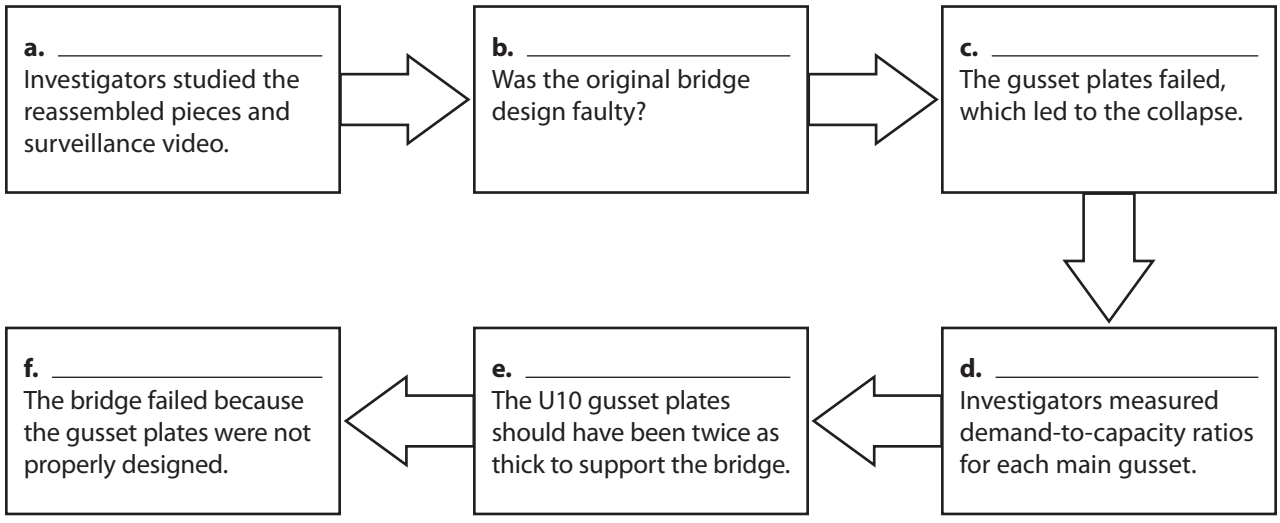
1. Review the terms and their definitions in the Mini Glossary. Write a sentence that gives an example of qualitative data gathered by investigators of the bridge collapse.

_____

_____

2. Identify the steps in the investigation of the bridge collapse by writing the following phrases in the correct sequence in the flow chart.

analyzing results **testing a hypothesis** **asking questions**
gathering information **drawing conclusions** **making a hypothesis**



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