Design & Innovation

Thomas Heatherwick / Heatherwick Studio

Teaching Resource

Nasher Sculpture Center

2001 Flora Street Dallas, TX 75201 Tel 214.242.5100 Fax 214.242.5155 NasherSculptureCenter.org

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ABOUT THIS RESOURCE

Developed in conjunction with Nasher Sculpture Center's *Provocations: The Architecture and Design of Heatherwick Studio*, the first exhibition in North America to present the work of Heatherwick and his studio, this guide offers both classroom- and gallery-based teaching strategies for learners of all ages.

Some information in this guide has been adapted from *Thomas Heatherwick: Making*, a retrospective publication that details the process and "provocations" behind Heatherwick's many innovative projects. You can find more information on *Making* and other Thomas Heatherwick resources in the bibliography section of this guide.

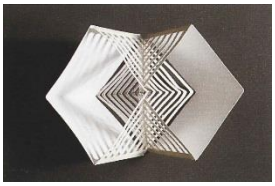
Provocations will be on view at the Nasher Sculpture Center from September 13, 2014 – January 4, 2015, before travelling to the Hammer Museum in Los Angeles and Cooper-Hewitt, National Design Museum in New York.

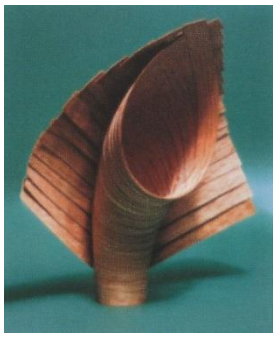
Thomas Heatherwick

Thomas Heatherwick

"When I was younger, sometimes I'd worry: maybe I'll never have a good idea again. And then I'd stop, walk out into the world and see things that could be better."
–Thomas Heatherwick

British designer Thomas Heatherwick has been hailed as a genius, and praised by esteemed designer Sir Terence Conran as "the next Leonardo da Vinci" for the uniquely inventive nature of his work. Heatherwick's practice encompasses projects ranging in scale from very small to monumental, from products to public sculpture to architecture.





"Test pieces" from Thomas Heatherwick's time as a student

Heatherwick's interest in design grew out of a childhood curiosity about "ideas, structures and problems being solved." Growing up in what he described as "an old, shambly, rambling house," Heatherwick turned his bedroom into a workshop, taking apart old electronic and mechanical objects such as typewriters, television sets, cameras and calculators to learn what they were made of and how they functioned. He read books about architecture and engineering and pored over drawings of whimsical contraptions dreamed up by comic artist Heath Robinson.

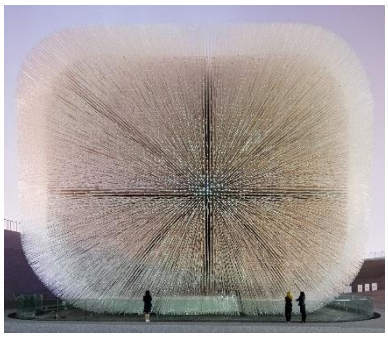
Heatherwick went on to study design at London's Royal College of Arts. While there, he developed an approach to problem solving that he described as "thinking through making," letting experimentation with materials determine his final product rather than working towards a preconceived idea.

Heatherwick Studio

PROVOCATIONS

In 1994, Thomas Heatherwick set up a studio in order to take on larger projects. Today, Heatherwick Studio employs a team of140 people with expertise in fields including engineering, architecture, sculpture, photography and product design. The studio's approach to projects stems from the open-ended design philosophy Thomas Heatherwick developed as a student. Rather than imagining a finished concept, the team generates a key question, or "provocation," that encourages them to break the project down to its essence and experiment with different ideas.

"Thinking and experimenting together, we have found that we tend to guide ourselves towards ideas by finding a few key questions."
– Thomas Heatherwick



Seed Cathedral, exterior and interior

NOTABLE PROJECTS

- Seed Cathedral – Built as the UK Pavilion for the 2010 World Expo in Shanghai, this structure showcased the Millennium Seed Bank of Kew Gardens. The pavilion was made up of 60,000 acrylic rods, each tipped with one or more seeds, that extended from the "hairy" exterior surface to an interior visitor space.
- Olympic Cauldron – For the 2012 London Olympics, the studio designed a cauldron made of 204 "petals" laid out in a circular pattern on the ground. When lit by the Olympic Torch, the petals ignited and came together to form a single flame, symbolizing the unifying power of the Olympic Games.
- Spun Chair – Inspired by the industrial process of metal spinning, used to make lampshades and drums, the studio created a rocking chair with perfect rotational symmetry.

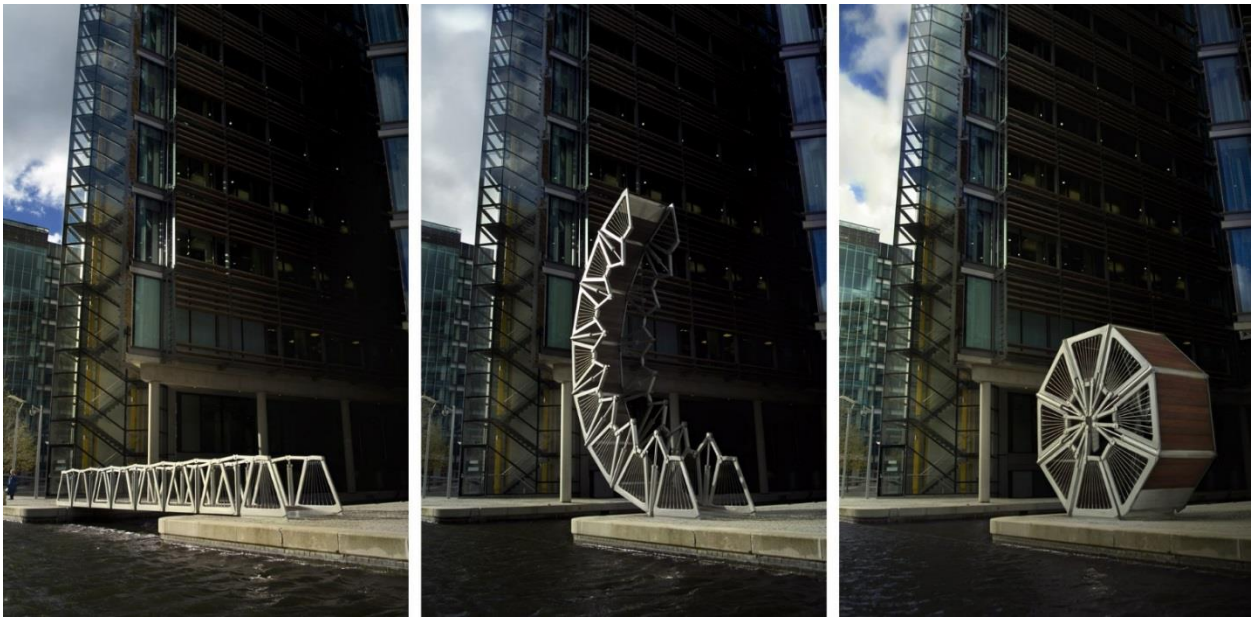


Olympic Cauldron, open and closed


Spun chair

Case Study: Rolling Bridge

Provocation: Can an opening bridge open without breaking?

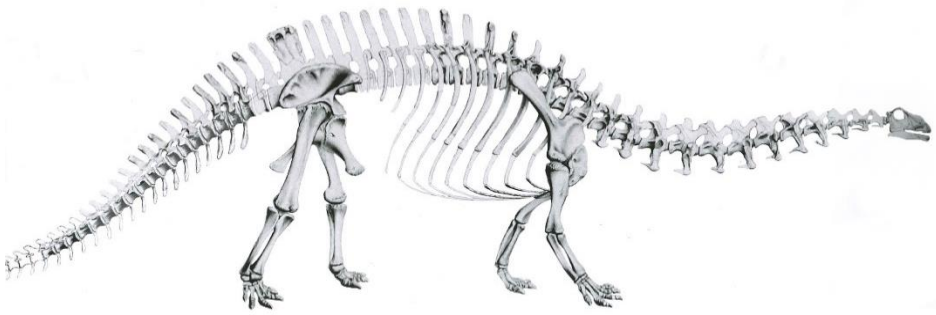


Rolling Bridge in action

Property developers from Paddington Basin in London commissioned Heatherwick Studio to design a pedestrian bridge that would span an inlet in the neighborhood. This bridge would need to be safe for pedestrians to walk on, but also allow boats to pass through.

Tower Bridge, London, opening by "breaking"

Most opening bridges "break" in the middle to allow boats through. (This reminded Heatherwick of a bone fracture – ouch!) Heatherwick Studio considered how the bridge might "get out of the way" rather than splitting in the middle.



"I suppose the question is, Is my studio's work playful or is everyone else's work too serious?"
–Thomas Heatherwick

Heatherwick's team wanted to make a bridge that would impress people with its theatrical opening and closing rather than what it looked like when standing still. They ultimately designed a structure inspired by the tail of an animatronic dinosaur from the film *Jurassic Park*, which used a steel mechanism to bend fluidly.

The bridge is made up of eight sections. Hydraulic rams between each section push upwards on the handrail, causing it to fold. As the handrail folds, the sections roll into a freestanding sculptural object that looks nothing like a bridge.

Rolling Bridge with exposed hydraulics

DESIGN CHALLENGE

Can you recreate the Rolling Bridge just by looking at its final form?

- Using cardstock, scissors, and measuring tools, try to create a model of Rolling Bridge.
- Consider: How many sections make up the bridge? How can you find the correct angle for the wedge-shaped handrails?

How could you span a canal twice as wide without enlarging the sections of the Rolling Bridge?

- To see how Heatherwick Studio solved this problem, look for the "large span rolling bridge" on the last page of this guide.

Case Study: Extrusions

Provocation: Can you squeeze a chair out of a machine, the way you squeeze toothpaste out of a tube?

Extrusion is a process used to create objects that may vary in length, but will always have the same shape if cut into a cross-section. To create an extrusion, a material is pushed or drawn through a **die**, a type of cut-out template.

When watching aluminum being extruded at a factory, Thomas Heatherwick was surprised that the process did not produce perfect results every time. He became interested in the sculptural qualities of the warped and imperfect extruded metal.

Later, Heatherwick became interested in creating furniture using this process. He found an aerospace company with a large extruding machine built for making rocket parts and created a die to be used with this machine that would create benches instead.

In theory, with unlimited materials and power, Heatherwick could use this machine to create a bench that wrapped around the entire world!

Extrusion machine with die for bench

Extruded aluminum bench with warped end, Heatherwick Studio

"We've extruded lengths specifically for different clients—and I really like the stopping-and-starting bits, where you see how 10,000 tons of pressure forces the aluminum to contort" – Thomas Heatherwick

Extruded aluminum bench, Heatherwick Studio

DESIGN CHALLENGE

Can you create your own extrusion machine out of materials found in your home or classroom?

- Your machine should have two parts: a die that will shape the material and a press to guide the material as you push it through the die.
- Consider using cardboard, wood or plastic to create a die. For your press, you might use a plastic baggie or a cardboard tube.
- Experiment with pushing the material through your extrusion machine. What happens when you twist or turn the machine as you go?
- Using frosting, clay or dough, try to re-create the shape of Heatherwick's extruded bench (pictured on page 8).
- Imagine a piece of furniture you would like in your room. Use your extrusion machine to create a model of this item.

EVERYDAY EXTRUSIONS

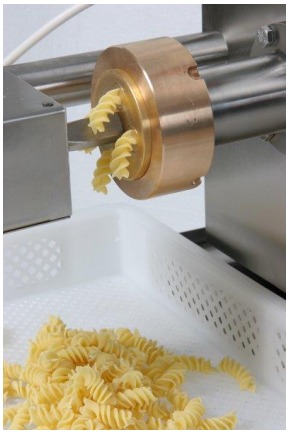
Many things you see every day are created using the process of extrusion. For each of the items below, draw the shape of the die that was used to create it.

Aluminum window frame

Drinking straw

Windshield wiper

PVC pipe



Fusilli pasta

Cupcake icing

Case Study: London Bus

Provocation: Can a London bus be better and use 40 per cent less fuel?

Along with Big Ben and Buckingham Palace, the red double-decker bus is one of the most internationally recognized symbols for the city of London. The last bus designed specifically for London was the Routemaster, developed between 1947 and 56, which had an open platform that allowed passengers to jump on and off when it was stuck in traffic.

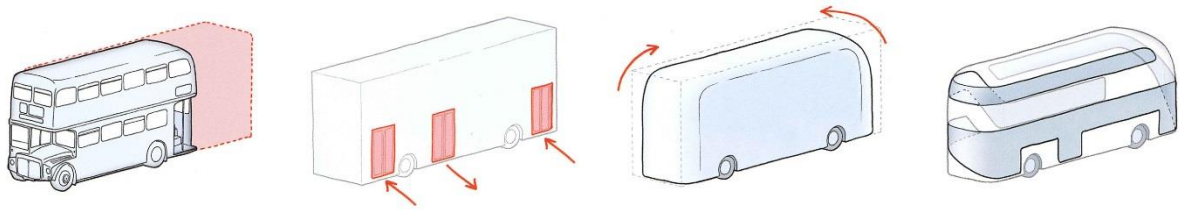
After production of the Routemaster ceased in 1968, London's bus routes were contracted out to private operating companies. As a result, various models of buses less suited to passengers' needs were put into use.

In 2010, the Mayor of London decided to commission the first new bus for the city in fifty years, and Heatherwick Studio was asked to collaborate with the manufacturer on the design.

East London Routemaster


New Bus for London, Heatherwick Studio

"It's amazing: when you type "London" into Google, the first image that comes up is a red double-decker bus on Westminster Bridge. The bus is London and its qualities should be particular to it, to London's little streets." –Thomas Heatherwick



The new bus needed to be completely wheelchair accessible and minimize the time it would take at each stop to load and unload passengers. To accomplish this, the bus would need three doors and two staircases, making it longer than the Routemaster, but it would also need to be more fuel efficient. Heatherwick Studio made the new bus a hybrid vehicle to reduce fuel use and chose to round the edges to compensate for the larger size.

The design team placed all three doors on one side of the new bus, and played up the resulting asymmetry by wrapping a "ribbon" of window around the bus, forming a windshield and opening a view of the street from the staircases.

To unify the interior of the bus with the bright red exterior, the studio used a simplified palette of colors on the stairs, hand rails and seats

DESIGN CHALLENGE

How can a school bus meet the needs of modern students?

- What type of bus does your school use for field trips and day-to-day transportation? Write a brief description of this bus and its current design.
- Now, imagine your ideal bus. Make a list of features that would improve the experience for passengers, then list the features that would be important to the bus driver.
- Sketch a design for your new bus. Consider where this bus will travel and how it will keep passengers and pedestrians safe.

New London bus stairway

New London bus seat with contour pattern

Think Like a Designer

QUESTION

When approaching a problem, break it down to an essential question. What are you really trying to accomplish?

"We pare a project back in successive rounds of discussions, through analysis, questioning, testing, experimentation, looking for the logic that will lead to an idea." –Thomas Heatherwick

ZOOM IN, ZOOM OUT

Think about how your design as a whole relates to the details of how it will function.

"Our role is to pull right back and see something in its biggest context, but then zoom in until you're analysing the close detail, then pull back again. To never let one thing get disconnected from context and meaning." –Thomas Heatherwick

ELIMINATE

Take a step back from your design. What aspects are unnecessary?

"Finding a design solution is like solving a crime. We're a bit like an investigative team. We analyse. We explore lines of inquiry. Then we eliminate things until we're left with the solution." –Thomas Heatherwick

Heatherwick Studio offices, Kings Cross, London

"At the root of everything I do is a fascination with ideas – what ideas are for, what jobs they do. An interest in ideas is a sign of human life. People are fascinated by what the future is going to be – and the future is going to be an accumulation of ideas." –Thomas Heatherwick

Design Challenges

How can you send a work of art through the mail?

Thomas Heatherwick's grandfather, Miles Tomalin, wrote poems every year which he sent out as Christmas Cards. Inspired by this, Heatherwick Studio made a tradition of sending innovative cards to clients and friends each year.

- Create your own mailable artwork to send to a friend. First, study the requirements set out by the US Postal Service and consider how you might stretch your imagination within these constraints. How large or small could you make your artwork? How can you incorporate the stamp or stamps into your design?
- How could your friend interact with the artwork once it arrives? Could it open, expand or unfold?

Heatherwick Studio Christmas cards

"Identity Crisis," 1999

How far can you stretch a budget by using a material that is virtually free?

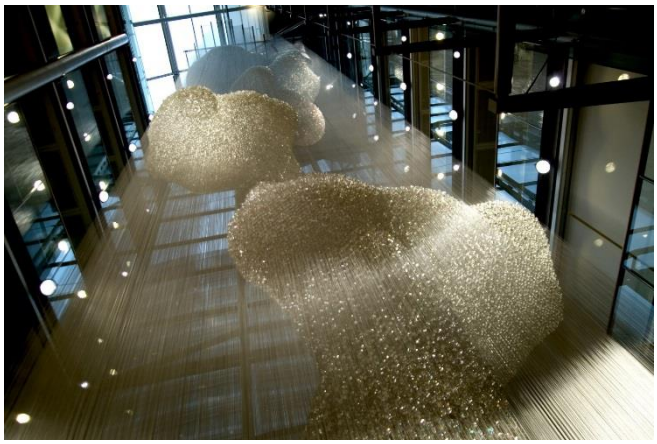
For a 1999 exhibition on architecture and design, Heatherwick Studio created an enormous hanging display using plastic wrap.

- How could you create a display for artwork in your classroom using this or another inexpensive material?

Can a giant sculpture fit through a letterbox?

In 2002, Heatherwick Studio was asked to create a sculpture that would fill the space of a seven-story atrium, but could be brought in through the building's small front door. To accomplish this, the studio created a form made of 150,000 glass beads hung on wires.

- Choose a small opening like a paper towel tube or the finger grip of a pair of scissors. What materials could you use to make a sculpture that would fit through this opening but still be as large as your desk?



"Bleigiessen," 2002

MORE PROVOCATIONS FOR STUDENTS

Use these questions, drawn from Heatherwick Studio projects, as inspiration for your own designs. To see how Heatherwick approached them, see the corresponding pages in the book *Thomas Heatherwick: Making*.

How can inanimate objects change shape? (p. 330)

What different forms can link together and articulate to form a chain? (p. 20)

How much three-dimensionality can you give to a repeating ceramic tile? (p. 21)

Can friction alone hold the pieces of an object together? (p. 27)

How can a student make a real building? (p. 33)

Can furniture upholstery have the qualities of an animal's skin? (p. 40)

Can you make a building using only two components? (p. 59)

How might people interact with a monument? (p. 402)

Can a strong structure look delicate? (p. 460)

Further Resources

BOOKS

Heatherwick, Thomas. *Thomas Heatherwick: Making*. New York: Monacelli, 2012. Print.

ONLINE RESOURCES

Heatherwick Studio

Heatherwick Studio website: http://www.heatherwick.com/

Interview with designer Neil Hubbard of Heatherwick Studio:
http://www.youtube.com/watch?v=jTHfHXNnT7M

Seed Cathedral

TED Talk, Thomas Heatherwick on Building the Seed Cathedral:
http://www.ted.com/talks/thomas_heatherwick?language=en

Millenium Seed Bank:
http://www.kew.org/visit-wakehurst/explore/attractions/millennium-seed-bank-exhibition

Rolling Bridge

Rolling Bridge in action: https://www.youtube.com/watch?v=x0Dj7XA77hw

London Bus

Thomas Heatherwick on designing a new bus for London: http://vimeo.com/43543589

Spun Chair

Students take the Spun Chair for a spin: https://www.youtube.com/watch?v=dkndyTopGNM

Olympic Cauldron

Lighting the Olympic Cauldron: https://www.youtube.com/watch?v=Ei54TO1VBIM

Manufacturing and testing the Olympic Cauldron:
https://www.youtube.com/watch?v=-fuH6mM-c8w

Thomas Heatherwick discusses the concept for the Olympic Cauldron:
https://www.youtube.com/watch?v=gLUu53ShM9Y

EXHIBITION INFORMATION

http://www.nashersculpturecenter.org/art/exhibitions/exhibition?id=136

TEKS

The following TEKS may apply when completing projects in this resource or touring the exhibition.

Chapter 117. Texas Essential Knowledge and Skills for Fine Arts

§117.5. Art, Grade 1.

(b) Knowledge and skills.

(1) Perception. The student develops and organizes ideas from the environment. The student is expected to:

(A) identify similarities, differences, and variations among subjects, using the senses; and

(B) identify color, texture, form, line, and emphasis in nature and in the human-made environment.

(3) Historical/cultural heritage. The student demonstrates an understanding of art history and culture as records of human achievement. The student is expected to:

(A) identify simple ideas expressed in artworks through different media;

(4) Response/evaluation. The student makes informed judgments about personal artworks and the works of others. The student is expected to:

(A) express ideas about personal artworks; and

(B) identify simple ideas about original artworks, portfolios, and exhibitions by peers and others.

§117.8. Art, Grade 2.

(b) Knowledge and skills.

(1) Perception. The student develops and organizes ideas from the environment. The student is expected to:

(A) identify variations in objects and subjects from the environment, using the senses

(B) identify art elements such as color, texture, form, line, and space and art principles such as emphasis, pattern, and rhythm.

(3) Historical/cultural heritage. The student demonstrates an understanding of art history and culture as records of human achievement. The student is expected to:

(C) identify different kinds of jobs in art.

(4) Response/evaluation. The student makes informed judgments about personal artworks and the artworks of others. The student is expected to:

(A) define reasons for preferences in personal artworks; and

(B) identify ideas in original artworks, portfolios, and exhibitions by peers and artists.

§117.11. Art, Grade 3.

(b) Knowledge and skills.

(1) Perception. The student develops and organizes ideas from the environment. The student is expected to:

(A) identify sensory knowledge and life experiences as sources for ideas about visual symbols, self, and life events; and

(B) identify art elements such as color, texture, form, line, space, and value and art principles such as emphasis, pattern, rhythm, balance, proportion, and unity in artworks.

(3) Historical/cultural heritage. The student demonstrates an understanding of art history and culture as records of human achievement. The student is expected to:

(C) relate art to different kinds of jobs in everyday life.

(4) Response/evaluation. The student makes informed judgments about personal artworks and the artworks of others. The student is expected to:

(A) identify general intent and expressive qualities in personal artworks; and

(B) apply simple criteria to identify main ideas in original artworks, portfolios, and exhibitions by peers and major artists.

§117.14. Art, Grade 4.

(b) Knowledge and skills.

(1) Perception. The student develops and organizes ideas from the environment. The student is expected to:

(B) choose appropriate vocabulary to discuss the use of art elements such as color, texture, form, line, space, and value and art principles such as emphasis, pattern, rhythm, balance, proportion, and unity.

(2) Creative expression/performance. The student expresses ideas through original artworks, using a variety of media with appropriate skill. The student is expected to:

(B) design original artworks

(3) Historical/cultural heritage. The student demonstrates an understanding of art history and culture as records of human achievement. The student is expected to:

(A) identify simple main ideas expressed in art;

(B) compare and contrast selected artworks from a variety of cultural settings; and

(C) identify the roles of art in American society.

(4) Response/evaluation. The student makes informed judgments about personal artworks and the artworks of others. The student is expected to:

(A) describe intent and form conclusions about personal artworks; and

(B) interpret ideas and moods in original artworks, portfolios, and exhibitions by peers and others.

§117.17. Art, Grade 5.

(b) Knowledge and skills.

(1) Perception. The student develops and organizes ideas from the environment. The student is expected to:

(B) identify in artworks that color, texture, form, line, space, and value are basic art elements and that the principles such as emphasis, pattern, rhythm, balance, proportion, and unity serve as organizers.

(2) Creative expression/performance. The student expresses ideas through original artworks, using a variety of media with appropriate skill. The student is expected to:

(B) compare relationships between design and everyday life; and

(3) Historical/cultural heritage. The student demonstrates an understanding of art history and culture as records of human achievement. The student is expected to:

(C) identify the use of art skills in a variety of jobs.

(4) Response/evaluation. The student makes informed judgments about personal artworks and the artworks of others. The student is expected to:

(A) analyze personal artworks to interpret meaning; and

(B) analyze original artworks, portfolios, and exhibitions by peers and others to form conclusions about properties.

§117.32. Art, Grade 6.

(c) Knowledge and skills.

(1) Perception. The student develops and organizes ideas from the environment. The student is expected to:

(B) analyze and form generalizations about the interdependence of the art elements such as color, texture, form, line, space, and value and principles such as emphasis, pattern, rhythm, balance, proportion, and unity, using art vocabulary appropriately.

(2) Creative expression/performance. The student expresses ideas through original artworks, using a variety of media with appropriate skill. The student is expected to:

(B) describe in detail a variety of practical applications for design ideas; and

(3) Historical/cultural heritage. The student demonstrates an understanding of art history and culture as records of human achievement. The student is expected to:

(A) identify in artworks the influence of historical and political events;

(C) compare career and avocational opportunities in art.

(4) Response/evaluation. The student makes informed judgments about personal artworks and the artworks of others. The student is expected to:

(A) conduct in-progress analyses and critiques of personal artworks; and

(B) analyze original artworks, portfolios, and exhibitions of peers to form conclusions about formal properties and historical and cultural contexts.

§117.35. Art, Grade 7.

(c) Knowledge and skills.

(1) Perception. The student develops and organizes ideas from the environment. The student is expected to:

(B) compare and contrast the use of art elements and principles, using vocabulary accurately.

(2) Creative expression/performance. The student expresses ideas through original artworks, using a variety of media with appropriate skill. The student is expected to:

(B) incorporate design into artworks for use in everyday life; and

(3) Historical/cultural heritage. The student demonstrates an understanding of art history and culture as records of human achievement. The student is expected to:

(A) analyze ways that international, historical, and political issues influence artworks;

(B) analyze selected artworks to determine cultural contexts; and

(C) identify career and avocational choices in art.

(4) Response/evaluation. The student makes informed judgments about personal artworks and the artworks of others. The student is expected to:

(A) analyze and compare relationships, such as function and meaning, in personal artworks; and

(B) analyze original artworks, portfolios, and exhibitions by peers and others to form conclusions about formal properties, historical and cultural contexts, and intent.

§117.38. Art, Grade 8.

(c) Knowledge and skills.

(1) Perception. The student develops and organizes ideas from the environment. The student is expected to:

(A) illustrate ideas from direct observation, imagination, and personal experience and from experiences at school and community events; and

(B) define a variety of concepts directly related to the art elements and principles, using vocabulary accurately.

(2) Creative expression/performance. The student expresses ideas through original artworks, using a variety of media with appropriate skill. The student is expected to:

(B) apply design skills to communicate effectively ideas and thoughts in everyday life; and

(3) Historical/cultural heritage. The student demonstrates an understanding of art history and culture as records of human achievement. The student is expected to:

(A) analyze ways in which electronic media/technologies have influenced art;

(B) identify cultural ideas expressed in artworks relating to social, political, and environmental themes; and

(C) survey career and avocational opportunities in art.

(4) Response/evaluation. The student makes informed judgments about personal artworks and the artworks of others. The student is expected to:

(B) analyze original artworks, portfolios, and exhibitions by peers and others to form conclusions about formal

properties, historical and cultural contexts, intents, and meanings.

§117.52. Art, Level I.

(c) Knowledge and skills.

(1) Perception. The student develops and organizes ideas from the environment. The student is expected to:

(A) illustrate ideas for artworks from direct observation, experiences, and imagination; and

(B) compare and contrast the use of art elements (color, texture, form, line, space, value) and art principles (emphasis, pattern, rhythm, balance, proportion, unity) in personal artworks and those of others, using vocabulary accurately.

(2) Creative expression/performance. The student expresses ideas through original artworks, using a variety of media with appropriate skill. The student is expected to:

(B) create designs for practical applications; and

(3) Historical/cultural heritage. The student demonstrates an understanding of art history and culture as records of human achievement. The student is expected to:

(A) compare and contrast historical and contemporary styles, identifying general themes and trends;

(C) compare and contrast career and avocational opportunities in art.

(4) Response/evaluation. The student makes informed judgments about personal artworks and the artworks of others. The student is expected to:

(A) interpret, evaluate, and justify artistic decisions in personal artworks; and

(B) select and analyze original artworks, portfolios, and exhibitions by peers and others to form precise conclusions about formal qualities, historical and cultural contexts, intents, and meanings.

§117.53. Art, Level II.

(c) Knowledge and skills.

(1) Perception. The student develops and organizes ideas from the environment. The student is expected to:

(A) interpret visual parallels between the structures of natural and human-made environments; and

(B) compare suitability of art materials and processes to express specific ideas relating to visual themes, using precise art vocabulary.

(2) Creative expression/performance. The student expresses ideas through original artworks, using a variety of media with appropriate skill. The student is expected to:

(B) apply design skills in creating practical applications, clarifying presentations, and defining choices made by consumers; and

(3) Historical/cultural heritage. The student demonstrates an understanding of art history and culture as records of human achievement. The student is expected to:

(C) select and research career and avocational choices in art.

(4) Response/evaluation. The student makes informed judgments about personal artworks and the artworks of others. The student is expected to:

(B) select and critique original artworks, portfolios, and exhibitions by peers or others.

§117.54. Art, Level III.

(c) Knowledge and skills.

(1) Perception. The student develops and organizes ideas from the environment. The student is expected to:

(A) analyze visual characteristics of natural and human-made subjects in a variety of ways, illustrating flexibility in solving problems, creating multiple solutions, and thinking imaginatively; and

(2) Creative expression/performance. The student expresses ideas through original artworks, using a variety of media with appropriate skill. The student is expected to:

(A) solve visual problems by planning and attempting a variety of solutions;

(B) solve visual problems and develop multiple solutions for designing ideas, clarifying presentations, and evaluating consumer choices, using design skills; and

(3) Historical/cultural heritage. The student demonstrates an understanding of art history and culture as records of human achievement. The student is expected to:

(B) trace influences of various cultures on contemporary artworks; and

(C) analyze a selected career opportunity in art, identifying the training, skills, and plan of action necessary for realizing such a goal.

(4) Response/evaluation. The student makes informed judgments about personal artworks and the artworks of others. The student is expected to:

(B) analyze original artworks, portfolios, and exhibitions to form conclusions about formal qualities, historical and cultural contexts, intents, and meanings and to show innovation and provide examples of in-depth exploration of one or more themes.

§117.55. Art, Level IV.

(c) Knowledge and skills.

(1) Perception. The student develops and organizes ideas from the environment. The student is expected to:

(B) make subtle discriminations in analyzing complex visual relationships and content, using precise art vocabulary.

(3) Historical/cultural heritage. The student demonstrates an understanding of art history and culture as records of human achievement. The student is expected to:

(B) analyze and evaluate the influence of contemporary cultures on artworks; and

(C) evaluate a selected career in art, justifying the choice.

(4) Response/evaluation. The student makes informed judgments about personal artworks and the artworks of others. The student is expected to:

(B) analyze a wide range of artworks to form conclusions about formal qualities, historical and cultural contexts, intents, and meanings.

Chapter 112. Texas Essential Knowledge and Skills for Science

§112.12. Science, Grade 1

(b) Knowledge and skills.

(2) Scientific investigation and reasoning. The student develops abilities to ask questions and seek answers in classroom and outdoor investigations. The student is expected to:

(A) ask questions about organisms, objects, and events observed in the natural world;

(B) plan and conduct simple descriptive investigations such as ways objects move;

(5) Matter and energy. The student knows that objects have properties and patterns. The student is expected to:

(A) classify objects by observable properties of the materials from which they are made such as larger and smaller, heavier and lighter, shape, color, and texture; and

(6) Force, motion, and energy. The student knows that force, motion, and energy are related and are a part of everyday life. The student is expected to:

(D) demonstrate and record the ways that objects can move such as in a straight line, zig zag, up and down, back and forth, round and round, and fast and slow.

§112.13. Science, Grade 2

(b) Knowledge and skills.

(3) Scientific investigation and reasoning. The student knows that information and critical thinking, scientific problem solving, and the contributions of scientists are used in making decisions. The student is expected to:

(A) identify and explain a problem in his/her own words and propose a task and solution for the problem such as lack of water in a habitat;

(5) Matter and energy. The student knows that matter has physical properties and those properties determine how it is described, classified, changed, and used. The student is expected to:

(C) demonstrate that things can be done to materials to change their physical properties such as cutting, folding, sanding, and melting; and

(D) combine materials that when put together can do things that they cannot do by themselves such as building a tower or a bridge and justify the selection of those materials based on their physical properties.

(6) Force, motion, and energy. The student knows that forces cause change and energy exists in many forms. The student is expected to:

(D) compare patterns of movement of objects such as sliding, rolling, and spinning.

§112.14. Science, Grade 3

(b) Knowledge and skills.

(3) Scientific investigation and reasoning. The student knows that information, critical thinking, scientific problem solving, and the contributions of scientists are used in making decisions. The student is expected to:

(A) in all fields of science, analyze, evaluate, and critique scientific explanations by using empirical evidence, logical reasoning, and experimental and observational testing, including examining all sides of scientific evidence of those scientific explanations, so as to encourage critical thinking by the student;

(D) connect grade-level appropriate science concepts with the history of science, science careers, and contributions of scientists.

§112.15. Science, Grade 4

(b) Knowledge and skills.

(2) Scientific investigation and reasoning. The student uses scientific inquiry methods during laboratory and outdoor investigations. The student is expected to:

(A) plan and implement descriptive investigations, including asking well-defined questions, making inferences, and selecting and using appropriate equipment or technology to answer his/her questions;

§112.16. Science, Grade 5

(b) Knowledge and skills.

(3) Scientific investigation and reasoning. The student uses critical thinking and scientific problem solving to make informed decisions. The student is expected to

(A) in all fields of science, analyze, evaluate, and critique scientific explanations by using empirical evidence, logical reasoning, and experimental and observational testing, including examining all sides of scientific evidence of those scientific explanations, so as to encourage critical thinking by the student;

(C) draw or develop a model that represents how something works or looks that cannot be seen such as how a soda dispensing machine works; and

(D) connect grade-level appropriate science concepts with the history of science, science careers, and contributions of scientists.

(6) Force, motion, and energy. The student knows that energy occurs in many forms and can be observed in cycles, patterns, and systems. The student is expected to:

(A) explore the uses of energy, including mechanical, light, thermal, electrical, and sound energy;

§112.18. Science, Grade 6

(b) Knowledge and skills.

(3) Scientific investigation and reasoning. The student uses critical thinking, scientific reasoning, and problem solving to make informed decisions and knows the contributions of relevant scientists. The student is expected to:

(A) in all fields of science, analyze, evaluate, and critique scientific explanations by using empirical evidence, logical reasoning, and experimental and observational testing, including examining all sides of scientific evidence of those scientific explanations, so as to encourage critical thinking by the student;

(D) relate the impact of research on scientific thought and society, including the history of science and contributions of scientists as related to the content.

(8) Force, motion, and energy. The student knows force and motion are related to potential and kinetic energy. The student is expected to:

(A) compare and contrast potential and kinetic energy;

§112.19. Science, Grade 7,

(b) Knowledge and skills.

(3) Scientific investigation and reasoning. The student uses critical thinking, scientific reasoning, and problem solving to make informed decisions and knows the contributions of relevant scientists. The student is expected to:

(D) relate the impact of research on scientific thought and society, including the history of science and contributions of scientists as related to the content.

§112.20. Science, Grade 8,

(b) Knowledge and skills.

(3) Scientific investigation and reasoning. The student uses critical thinking, scientific reasoning, and problem solving to make informed decisions and knows the contributions of relevant scientists. The student is expected to:

(A) in all fields of science, analyze, evaluate, and critique scientific explanations by using empirical evidence, logical reasoning, and experimental and observational testing, including examining all sides of scientific evidence of those scientific explanations, so as to encourage critical thinking by the student;

Chapter 111. Texas Essential Knowledge and Skills for Mathematics

§111.3. Grade 1

(b) Knowledge and skills.

(6) Geometry and measurement. The student applies mathematical process standards to analyze attributes of two-dimensional shapes and three-dimensional solids to develop generalizations about their properties. The student is expected to:

(A) classify and sort regular and irregular two-dimensional shapes based on attributes using informal geometric language;

(B) distinguish between attributes that define a two-dimensional or three-dimensional figure and attributes that do not define the shape;

(C) create two-dimensional figures, including circles, triangles, rectangles, and squares, as special rectangles, rhombuses, and hexagons;

(D) identify two-dimensional shapes, including circles, triangles, rectangles, and squares, as special rectangles, rhombuses, and hexagons and describe their attributes using formal geometric language;

(E) identify three-dimensional solids, including spheres, cones, cylinders, rectangular prisms (including cubes), and triangular prisms, and describe their attributes using formal geometric language;

(F) compose two-dimensional shapes by joining two, three, or four figures to produce a target shape in more than one way if possible;

(7) Geometry and measurement. The student applies mathematical process standards to select and use units to describe length and time. The student is expected to:

(B) illustrate that the length of an object is the number of same-size units of length that, when laid end-to-end with no gaps or overlaps, reach from one end of the object to the other;

§111.4. Grade 2

(b) Knowledge and skills.

(8) Geometry and measurement. The student applies mathematical process standards to analyze attributes of two-dimensional shapes and three-dimensional solids to develop generalizations about their properties. The student is expected to:

(A) create two-dimensional shapes based on given attributes, including number of sides and vertices;

(B) classify and sort three-dimensional solids, including spheres, cones, cylinders, rectangular prisms (including cubes as special rectangular prisms), and triangular prisms, based on attributes using formal geometric language;

(C) classify and sort polygons with 12 or fewer sides according to attributes, including identifying the number of sides and number of vertices;

(E) decompose two-dimensional shapes such as cutting out a square from a rectangle, dividing a shape in half, or partitioning a rectangle into identical triangles and identify the resulting geometric parts.

(9) Geometry and measurement. The student applies mathematical process standards to select and use units to describe length, area, and time. The student is expected to:

(E) determine a solution to a problem involving length, including estimating lengths;

§111.5. Grade 3,

(b) Knowledge and skills.

(6) Geometry and measurement. The student applies mathematical process standards to analyze attributes of two-dimensional geometric figures to develop generalizations about their properties. The student is expected to:

(A) classify and sort two- and three-dimensional figures, including cones, cylinders, spheres, triangular and rectangular prisms, and cubes, based on attributes using formal geometric language;

(B) use attributes to recognize rhombuses, parallelograms, trapezoids, rectangles, and squares as examples of quadrilaterals and draw examples of quadrilaterals that do not belong to any of these subcategories;

(E) decompose two congruent two-dimensional figures into parts with equal areas and express the area of each part as a unit fraction of the whole and recognize that equal shares of identical wholes need not have the same shape.

§111.6. Grade 4

(b) Knowledge and skills.

(6) Geometry and measurement. The student applies mathematical process standards to analyze geometric attributes in order to develop generalizations about their properties. The student is expected to

(A) identify points, lines, line segments, rays, angles, and perpendicular and parallel lines;

(B) identify and draw one or more lines of symmetry, if they exist, for a two-dimensional figure;

(C) apply knowledge of right angles to identify acute, right, and obtuse triangles; and

(D) classify two-dimensional figures based on the presence or absence of parallel or perpendicular lines or the presence or absence of angles of a specified size.

(7) Geometry and measurement. The student applies mathematical process standards to solve problems involving angles less than or equal to 180 degrees. The student is expected to:

(A) illustrate the measure of an angle as the part of a circle whose center is at the vertex of the angle that is "cut out" by the rays of the angle. Angle measures are limited to whole numbers;

(B) illustrate degrees as the units used to measure an angle, where 1/360 of any circle is one degree and an angle that "cuts" *n*/360 out of any circle whose center is at the angle's vertex has a measure of *n* degrees. Angle measures are limited to whole numbers;

(C) determine the approximate measures of angles in degrees to the nearest whole number using a protractor;

(D) draw an angle with a given measure

§111.7. Grade 5

(b) Knowledge and skills.

(7) Geometry and measurement. The student applies mathematical process standards to select appropriate units, strategies, and tools to solve problems involving measurement. The student is expected to solve problems by calculating conversions within a measurement system, customary or metric.

§111.22. Mathematics, Grade 6.

(b) Knowledge and skills.

(6) Geometry and spatial reasoning. The student uses geometric vocabulary to describe angles, polygons, and circles. The student is expected to:

(A) use angle measurements to classify angles as acute, obtuse, or right;

(B) identify relationships involving angles in triangles and quadrilaterals; and

(C) describe the relationship between radius, diameter, and circumference of a circle.

§111.23. Mathematics, Grade 7

(b) Knowledge and skills.

(6) Geometry and spatial reasoning. The student compares and classifies two- and three-dimensional figures using geometric vocabulary and properties. The student is expected to:

(B) use properties to classify triangles and quadrilaterals;

(C) use properties to classify three-dimensional figures, including pyramids, cones, prisms, and cylinders; and

(8) Geometry and spatial reasoning. The student uses geometry to model and describe the physical world. The student is expected to:

(A) sketch three-dimensional figures when given the top, side, and front views;

(C) use geometric concepts and properties to solve problems in fields such as art and architecture.

§111.24. Mathematics, Grade 8

(b) Knowledge and skills.

(6) Geometry and spatial reasoning. The student uses transformational geometry to develop spatial sense. The student is expected to:

(A) generate similar figures using dilations including enlargements and reductions; and

(7) Geometry and spatial reasoning. The student uses geometry to model and describe the physical world. The student is expected to:

(A) draw three-dimensional figures from different perspectives;

Concept for large span rolling bridge