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Science

Grade Three

Building with a Variety of Materials

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Building with a Variety of Materials

Before You Begin

After investigating the strength and stability of a variety of materials and designs in Testing Materials and Designs, children are challenged to investigate the process of designing and building structures. Children examine the relationship that exists between the design of a structure and its function.

Topic B: Building with a Variety of Materials

(Suggested time: 8 weeks)

It is recommended that Building with a Variety of Materials be **taught after completing the topic Testing Building Materials**, as it provides students with an understanding of the characteristics of different materials used in building. Consider exploring this topic several times during the year, as each season provides access to different natural building materials, for example, in spring mud and dried grasses can be used to build birds' nests, and in winter snow can be used to build igloos and snow caves.

Provide children opportunities to walk through the neighbourhood and observe the structures around them, to compare them to natural structures and to see how society uses technology to create structures. Plan to invite guests, such as architects, planners, contractors or engineers, to speak to the class.

The building materials and student constructions will require adequate storage space. Building materials should be stored in labelled boxes, tubs or plastic bags for easy access. Open shelving or counter space is ideal for displaying projects. Structures can be suspended from the ceiling if counter space or shelving is unavailable. Students can assist in collecting, sorting and organizing the building materials.

The two topics Building with a Variety of Materials and Testing Materials and Designs are closely related. In Building with a Variety of Materials, the focus is on construction tasks: learning to build objects using a variety of materials and techniques, working as individual students and as part of a team. In Testing Materials and Designs, the focus is on choices between different materials and designs—using the skills of science to test things and evaluate them.

Either topic can be taught first. The topics can also be combined and taught as a single unit. If Building with a Variety of Materials is taught first, students will have the opportunity to experience construction activities before formal investigation of different materials and design. If Testing Materials and Designs is taught first, students will gain knowledge of materials and the effect of different designs that can later be applied in construction activities.

No matter which unit is taught first, its initial activities should provide an opportunity for exploration of materials. The key activity tables for these two units begin with a sequence of exploratory activities. The exploratory activities for the unit that is taught second may be abbreviated as most of the exploration will have been covered in the unit taught first.

Background Information

The basic principles of good engineering design and the physical properties that distinguish certain materials as being suitable for specific applications are explored in this unit. It follows from the grade 1 unit Building Things that looked at the important relationship between the intended function of an artifact and the nature of the components and materials incorporated in the artifact's design. This unit also builds on knowledge of materials gained in the grade 2 unit Buoyancy and Boats.

The variety of building materials at our disposal has grown considerably over the course of history and continues expanding today. The following paragraphs outline some interesting properties of several common materials.

Materials

Wood

Wood is a remarkable and versatile material. Its properties vary with the kind of wood and the direction of grain in the wood. The denser a variety of wood, the greater hardness and strength it possesses. Spruce is the light, low-density wood commonly used in house construction. Oak is much heavier, denser and harder. It is easy to drive a nail into soft spruce, but oak is so hard it often splits when nailed. Oak is used for furniture due to its strength and durability.

Each type of wood also has a unique grain pattern, produced by the cellular structure of the tree it comes from. It is far more difficult to break or split wood across the grain than with the grain. Plywood consists of thin layers of wood adhered together, with the grain running at right angles in each layer so it is equally strong in every direction.

Wood's durability can be enhanced by painting, varnishing or coating with various plastics. In addition to preserving the finished surface of the wood, these applications prevent the wood from absorbing moisture. Extremely dry wood is a good electrical and thermal insulator, whereas saturated wood conducts electricity nearly as well as water.

Today wood is used in combination with other materials, giving it new properties and new uses. For example, much low-cost furniture is made from particle board (sawdust glued together and pressed into panels) coated with a thin film of melamine plastic. The melamine coating is smooth, water-resistant and can be made any colour, even a fairly convincing wood-grain.

Wood's main problem as a material is defects such as knots and uneven grain. Wood building materials are graded according to the number of defects they display. High-quality defect-free hardwoods are typically quite expensive.

Paper

Paper can vary in thickness, weight, texture, absorbency and colour depending on the fibres used and the type of coating applied to the finished surface. Rags, straw, wood and recycled paper products are a few of the most common sources of fibre for paper-making. Fibres are tightly interwoven but typically quite short, leaving paper prone to tearing.

Paper is not usually considered to be a structural material. It has a reputation for being easily damaged and flimsy. However, the thinness and flexibility of paper make it easy to fold and crease, a process that can lend stiffness to a paper construction. Just think of the strength of corrugated cardboard. A stiff piece of corrugate is really just three thin sheets of craft paper glued together. The inner sheet is folded in little ripples (note their resemblance to triangles) and this gives the resulting panel strength far beyond that of the components alone. Corrugated cardboard bends more easily in one direction than the other. One strategy for making it equally strong each way is to glue two layers together with the corrugations at right angles to each other.

Corrugated cardboard has limited applications because it isn't very resistant to moisture. A new plastic corrugated material that is available at building supply stores has the same structure as corrugated cardboard but provides greater strength and weather resistance. Tenplast is one of the trade names for this product. Students might find it interesting to compare the plastic and paper corrugates for both strength and water resistance.

Glass

Glass is weak and brittle, right? Wrong! In spite of what everyday experience might suggest, glass is extremely strong and elastic in nature (sometimes it is referred to as being a very slow flowing liquid rather than a solid). When glass does break, it is usually due to minute surface flaws, which seriously compromise the material's *tensile strength* (resistance to being pulled apart). Newly produced glass fibres devoid of such flaws are amazingly strong. They have a tensile strength in the neighbourhood of 70,000 kilograms per square centimetre. That's five times the tensile strength of the best available steel! Glass fibres are so thin they flex easily. When embedded in plastic resin, the resulting fibreglass composite material exhibits many of the best properties of glass and plastic. Fibreglass in resin makes exceptionally strong, light panelling. It can also be moulded into complex shapes.

Sheet glass bonded to thin layers of plastic is very resistant to impact. This is how automotive windshields are made. Multiple layers of glass and plastic create an even stronger material that is used to make bullet-proof windows.

In addition to being strong, glass is a relatively poor conductor of heat. You can comfortably grab the handle of a glass frying pan to remove it from the stovetop but you will burn your hand if you try doing the same thing with a metal frying pan handle.

Recently invented glasses have almost no thermal coefficient of expansion—they don't change shape or size as the temperature changes. Ordinary glass breaks easily if it is exposed to sudden, uneven changes in temperature, as anyone who has poured ice-cold pop into a glass tumbler still hot from the dishwasher knows. The new specialty glasses used in cookware barely change shape as temperature varies, and won't break when rapidly heated or chilled.

Clay

Clay is a marvelously versatile material that has been used extensively for more than 10,000 years. Wet clay can be shaped into just about any form, from bricks and pottery to statuary and paving tiles. When allowed to air dry, clay objects hold their shape well but are susceptible to damage from blows and re-absorption of water. Fired clay, on the other hand, is extremely resilient. Archaeologists have recovered 4,000-year-old fired clay tablets from ancient Mesopotamia that are perfectly intact and so hard they can be dropped on the floor and not break.

Fired clay materials like brick, pottery and tile are preferable to glass in certain situations. Tile can be made quite durable to surface wear, making it a good candidate for flooring. Glass tends to melt and flow at high temperatures, so fired clays are used in situations where glass would melt. Glazed tile or pottery has a thin layer of glass applied to its surface, combining the ease of working clay with the smoothness and moisture-resistance of glass.

Metal

Steel and aluminum are the most commonly used metals today. Steel is inexpensive, strong and easier to weld, so it is the more widely used structural material of the two. A particularly useful steel structural component is the I-beam, a length of steel with a cross-sectional profile shaped like the letter I. A given length of I-beam is much lighter than an equal length of a solid steel beam, yet just as strong due to its thicker cross-section. (See grade 3 unit Testing Materials and Designs for the relationship between cross-section and strength.)

Aluminum is easily cast into complex shapes, so it is frequently found in domestic products (cans, camera bodies, lighting fixtures), power tools (electric drills, circular saws), and some auto parts (engine components and housings for mechanical components). Its light weight also makes it indispensable in aircraft construction.

Plastic

The first "plastic" was actually rubber, the flexible, black, water-resistant material that Charles Goodyear discovered when he heated the sap of the rubber plant with sulphur. Later, the hard, glassy material Bakelite was invented, and today we have numerous other types of plastic materials with a wide variety of properties. Most of these newer plastics are petroleum by-products.

Styrene is the hard, smooth plastic used in model kits. When foamed with air or nitrogen, it makes the common material Styrofoam. *Acrylic plastics* are the clear or coloured sheet materials we often see used to make signs. *Polyester resins* can be purchased in liquid form. The liquid resin comes in two parts, which, when combined, harden into a durable solid. Ornaments that have coins or bugs moulded into a clear block are made with polyester resins. *Nylon* in large pieces is a translucent, white, solid material. It is durable and very slippery, so it is often used to make bearings. As a fibre, it makes an excellent clothing material due to its durability. *Mylar* is a clear, incredibly tough plastic. A thin strip of Mylar is amazingly difficult to break. Mylar is the material used to make audio and video tape and some motion picture film. Mylar film is so strong that, if it is accidentally pulled tight in the projector, it will sometimes tear a projector apart before it snaps. Mylar is also commonly used to form novelty balloons, the kind that come in specialized shapes and have visible seams where panels of the material are joined.

Structures

Once the properties of materials are understood, they can be combined and joined to form *structures*. Each new material and combination of materials offers the designer an extended range of physical capabilities, making it feasible to build in ways never before possible.

Perhaps the most basic structural challenge—how to span a gap—was met in extreme antiquity by the innovation of the *lintel*, a horizontal piece of timber or stone laid across a gap to form the top of a door, or as one span of a bridge. Stonehenge is an example of stone pillar and lintel construction. In Roman time, the masonry arch, made of wedge-shaped blocks with a keystone at the top, added remarkable versatility to the designer's repertoire. The arch more effectively transfers the force of heavy loads to the pillars, making much wider spans possible than with the lintel.

Today, wide spans are often handled with either an I-beam (mentioned earlier under Metal) or *truss*. A truss is a support structure made up of a spidery series of triangles that give it great strength with relatively little weight. Using triangles, amazingly large, strong structures can be made. Materials usually thought of as being weak or flimsy (like drinking straws) if joined in connecting triangles can be used to form surprisingly large, stiff structures. The roofs in many modern, box-like stores are spanned by long steel trusses incorporating triangles.

In addition to spanning gaps, another basic design challenge is providing structural support. How do you build a structure that will not collapse, crush under its own weight or topple over?

One consideration is the **type of material used**. Brick, stone and concrete, for example, have good *compressive strength*. They can support a reasonable weight before they crush. While these materials will sustain a significant downward force, they are very *brittle*—a thin column of masonry will break very easily. To compensate, walls of tall structures must be quite thick to carry the weight of the material above without crushing. This is one reason why European buildings constructed before the end of the last century tend to have only five or six stories, the limit imposed by the characteristics of the materials available up to that time.

The use of steel reinforcing rods inside a concrete column (ferroconcrete) greatly reduce its brittleness, making it possible to build with much narrower, lighter concrete columns. Many skyscrapers and other structures are built of ferroconcrete. The Calgary Tower and Toronto's CN Tower are two very tall ferroconcrete buildings. The great height of these structures means they must be wider at the base to distribute the great compressive forces (weight) of the material above. Forces like wind loading (forces perpendicular to one side of the structure) also dictate wider bases so the towers do not tip over.

To be stable a structure must be constructed of material that is strong enough to withstand the forces imposed on the structure (weight, wind, etc.), and the geometry of the structure must direct these forces to the parts of the structure most capable of withstanding the forces (usually the parts with greatest cross-section). Triangular building components are particularly good at distributing weight over large areas. Not only is the amount of weight in the structure a consideration, but also where the weight is borne. A top-heavy structure (a structure with a high centre of gravity) is more likely to fall over when subjected to sideways forces than a structure with most of its weight carried low. **Another critical stability factor is the way structural components are joined**.

Fasteners and Joining Methods

The main *fastening* materials used in construction are nails, glue, mortar, screws, welds and rivets. These are sometimes used in combination, depending on the materials to be joined and the forces the joint will experience.

The way materials are joined together makes a great difference in their strength and usefulness. The success of the triangular truss mentioned earlier depends upon our ability to securely join the ends of short, narrow pieces of wood, iron, plastic or other materials.

Houses in earthquake and hurricane areas need more than nails to hold the roof and walls together. The use of *hurricane ties* is common in California and Florida. These thin steel straps nailed across key joints in the house have much greater flexibility and strength than wood and nails alone. A house built with hurricane ties withstands much stronger wind or earthquake forces than one simply nailed together.

Factors Affecting Design Decisions

An engineer or a builder needs to consider **the environment in which the structure will be used, and select materials and construction techniques accordingly**. If fire is a risk, non-flammable materials like concrete, glass or metal are required. Areas that get wet need water-resistant materials. Floor coverings should resist abrasive wear, the grinding away that occurs when sand and dirt are tramped underfoot. The design of machines and electrical equipment must take into account the electrical and thermal conductivity of materials, and architects who design apartment buildings and theatres need to find materials that have just the right ability to resist the transmission of sound.

Cost is another major factor in deciding **how a structure will be built**. Since cost increases (in part) with the amount of material used, an architect or engineer is often faced with finding the minimum-materials solution to a design problem. Durability considerations of the addition of amenities and design features may increase project costs. Labour is another major cost in construction. To hold costs down, designers choose materials, joints and fasteners that go together in the least time. Sometimes it is economical to use more expensive materials if the speed of assembly reduces the overall cost.

Once built, how likely is a construction to hold together? The grade 3 unit Testing Building Materials and Designs provides information regarding standard tests that are applied to determine structural integrity.

Elementary Science Program of Studies

General and Specific Learner Expectations

The following general and specific learner expectations have been taken directly from the 1996 Elementary Science Program of Studies. The specific learner expectations (SLEs) are referred to by number in the second column of the activities table.

General Learner Expectations

Students will be able to:

- Safely use a variety of tools, techniques and materials in construction activities.
- Construct structures using a variety of materials and designs, and compare the effectiveness of the various materials and designs for their intended purposes.

Specific Learner Expectations

Students will be able to:

1. Using a variety of materials and techniques, design, construct and test structures that are intended to:
   - support objects;
   - span gaps;
   - serve as containers; and
   - serve as models of particular living things, objects or buildings.
2. Select appropriate materials for use in construction tasks, and explain the choice of materials. Students should demonstrate familiarity with a variety of materials such as paper, wood, plastic, clay and metal.
3. Select tools that are suitable to particular tasks and materials, and use them safely and effectively.
4. Understand and use a variety of methods to join or fasten materials.
5. Identify the intended purpose and use of structures to be built, and explain how knowing the intended purpose and use helps guide decisions regarding materials and design.
6. Understand that simple designs are often as effective as more complex ones, as well as being easier and cheaper to build, and illustrate this understanding with a particular example.
7. Recognize the importance of good workmanship, and demonstrate growth toward good workmanship.
8. Maintain and store materials and tools safely and properly.
9. Apply skills of listening, speaking and cooperative decision-making in working with other students on a construction project.

Cross-curricular Connections

Language Arts

- Complete a glossary of bridge terminology.
- Research bridges, for example, types of bridges, the history of famous bridges, protecting bridges from corrosion and wear, bridge failures, or finding out about recent failures during or after the construction of other structures.
- Create "how-to" books such as "Creating Miniature Furniture," "Homemade Toys," "Model Buildings," etc.

Mathematics

- Solve word problems related to building, building materials and fasteners, for example, "John bought a box of 12 paper clips for $1.20. How much did each paper clip cost?" Or "It took Lee 5 bundles of logs to build his garden box. There were 6 logs in each bundle. How many logs in all?"

Art

- Make pencil sketches of local buildings or bridges, highlighting arches and supports with coloured pencil.
- Draw blueprints to represent the classroom, school or house.
- Sketch inventions for testing the strength of their structures.
- Collect pictures of concrete structures and make a class collage or mural.

Social Studies

- Discuss a local bridge from the point of view of how it affects the environment, the people nearby, the purpose that it serves and how things might change if it were moved.
- Examine the building techniques and tools used by other cultures or civilizations.
- Report on the building techniques and tools used by their family for home repairs, renovation and additions.

Children's Alternative Frameworks

Children often have misconceptions concerning the relationships that exist between the physical dimensions of structures and their strength and stability. It is advisable to start this topic with an open-ended activity to determine what alternative frameworks your students possess.

Some possible misconceptions regarding Building with a Variety of Materials include the following.

- The more material used in a structure the stronger and more stable it is.
- The larger a structure the stronger and more stable it is.
- The heavier a structure the stronger and more stable it is.

Activities

Classroom teachers have identified the following activities that address the Specific Learner Expectations (SLEs) in the Program of Studies. The list is not prescriptive and teachers may select activities that are most appropriate for their students.

Activities have been listed under two headings. Key Activities and Extension Activities. Key activities are supported by authorized resources and identify "powerful and practical" means for achieving learner expectations. Extension activities represent alternative ways of achieving or supporting learner expectations.

Key Activities

Key Activity	SLE	Print Resources	Essential Materials	Comments
Free exploration using simple construction materials	1, 2, 3, 4	*Explorations in Science, Level 3, Super Structures (Free Exploration), p. 6*	toothpicks, marshmallows, straws, modelling clay, pipe cleaners, Popsicle sticks, tongue depressors, file cards, paper plates, paper, cardboard pieces, hole punch, paper fasteners, paper clips, spaghetti	This open-ended activity allows students to explore ways that familiar materials can be used in construction. It provides an opportunity to assess students' interest in construction tasks and their skills in selecting and using materials. It can also provide an opportunity to initiate student thinking about purposes for building and design. Encourage students to think about how their structures could be used and to identify different techniques used in construction.

Key Activity	SLE	Print Resources	Essential Materials	Comments
Building towers	1, 2, 3, 4, 5, 6, 7, 8, 9	*Explorations in Science, Level 3, Super Structures (Tower Power), p. 14*	straws, pipe cleaners, scissors	Invite students in small groups to design and build the tallest free-standing straw towers possible.
		Challenging Artstraws (NES Arnold) (Towers), p. 4	straws, tape, scissors	
		Towers and Bridges (Fitzpatrick) *(Building Towers), p. 5*	variety of construction materials such as plastic containers, small cardboard boxes, egg cartons, tape measure	
		Towers and Bridges (Fitzpatrick) *(Design and Make a Tower), p. 16*		
		Design and Technology System (Moore) *(Tower Power), p. 39*	straws, scissors, cardboard, glue, marbles	
Observing and constructing different types of bridges	1, 2, 3, 4, 5, 6, 7, 8, 9	*Innovations in Science, Level 3, Bridgeworks (Bridging the Gap), p. 8*	black line master 2, cardboard, rulers, elastics, string, other classroom building materials, washers, nuts, bolts, blocks to use as loads	Organize students into small groups and give them freedom to explore in their first attempt to build a bridge. Then encourage students to use designs in their building. Test the bridge's capacity to bear a load.
		Innovations in Science, Level 3, Bridgeworks (Now You See It), p. 35	toothpicks, wooden splint, paper clips, spools, straws, string, glue, toy cars, boats, commercial building toys	
		Innovations in Science, Level 3, Bridgeworks (Spanning the Gap), p. 38	rope, twine or string, rocks, bricks or wooden blocks, thin planks or large pieces of stiff paper or cardboard, scissors, chairs or high-jump standards	Organize the students into working groups and explain that each group is going to become a small "engineering company."
		Innovations in Science, Level 3, Bridgeworks (Fantastic Bridges), p. 42	newspapers, tape, plastic drinking straws, pins, masses such as wooden blocks, bricks, pencils, toothpicks, glue, soap-bubble solution, spaghetti, string, materials that will float such as wood, plastic supports such as blocks, chairs, tables	Have students sketch drawings of their proposed bridges, then list all the steps they will take to build their bridges and the materials they will need before engaging in the construction of their bridges.

Key Activity	SLE	Print Resources	Essential Materials	Comments
Observing and constructing different types of bridges *(cont'd)*		*Explorations in Science, Level 3, Super Structures (Bridging the Gap), p. 20*	pictures of many different types of bridges: beam, cantilever, suspension, swinging, arch, covered, moveable section, concrete/steel	
		Challenging Artstraws (NES Arnold) *(Bridges), p. 8*	straws, tape, scissors	
Creating a model school playground	1, 2, 3, 4, 5, 6, 7, 8, 9	*Explorations in Science, Level 3, Super Structures (Playground Design), p. 22*	paper, cardboard, paper rolls, toothpicks, straws, Plasticine, art materials	Allow the students to choose to work individually or in pairs or small groups. Discuss the size of the whole playground, the size of the playground equipment and the materials needed.
		Design and Technology System (Moore) *(Ride and Slide), p. 75*	straws, scissors, cardboard tubes, glue, string, paper clips, wood	
Designing and making furniture	1, 2, 3, 4, 5, 6, 7, 8, 9	*Explorations in Science, Level 3, Designs that Work (Furniture Warehouse), p. 32*	wood, nails, screws, glue, tape, tools, safety goggles, materials as requested	Challenge students to use simple materials to make a chair that is strong enough to sit on.
		Explorations in Science, Level 3, Super Structures (Strong Enough to Sit On?), p. 18	newspaper (or other kind of paper), tape	
		Design and Technology System (Moore) *(Furniture for Sale), p. 33*	straws, scissors, cardboard, wood, glue	
Building models using wood	1, 2, 3, 4, 5, 6, 7, 8, 9	*Explorations in Science, Level 3, Design, Test, Build! (Wood Working), p. 23*	wood scraps, hammers, nails, sandpaper, workbench with vise or C-clamp	
		Explorations in Science, Level 3, Designs that Work (Wooden Encounters), p. 20	hammers, screwdrivers, screws, nails, safety goggles, pieces of wood, line masters 2 and 3	
Observing and comparing the structure and design of manufactured objects	5, 6, 7	*Explorations in Science, Level 3, Super Structures (Structures All Around Us), p. 10*	classroom objects, chart paper, pens	Go for a neighbourhood walk to look at structures. By focusing on the similarities and differences among the structures observed, teachers will get insight into children's initial ideas about structures.

Key Activity	SLE	Print Resources	Essential Materials	Comments
Building model houses	1, 2, 3, 4, 5, 6, 7, 8, 9	*Explorations in Science, Level 3, Super Structures (The House that Will Not Blow Down), p. 23* *Challenging Artstraws* (NES Arnold) *(Shelters), p. 26* *Design and Technology* (Newton and Newton) *(Build a Two-storey House), p. 110*	a variety of construction materials straws, tape, scissors, paper large box, small box, thin card, thick card, sheet of poly, decorating materials, card tube, fabric pieces, straws, paper fasteners, string, tape	After reading *The Three Little Pigs*, have the students build a house that will not blow down. To be a fair test, the houses need to be the same size. Brainstorm ways the students can test the stability of their structures.
Designing a package for something	1, 2, 3, 4, 5, 6, 7, 8, 9	*Explorations in Science, Level 3, Designs that Work (Design and Create), p. 29*	variety of packaging materials, paper, different types of cloth, variety of fasteners	Encourage students to form groups and make a plan that includes sketches of their design.

Extension Activities

Extension Activity	SLE	Print Resources	Essential Materials	Comments
Using blueprints in bridge construction	1, 5, 6	*Innovations in Science, Level 3, Bridgeworks (Blueprint Bridges), p. 21*	black line master 3, straws, string, stir sticks, blocks, glue, tape, paper clips, newspaper, cardboard, sticks, commercial building toys	
Building structures at sand and water tables	1, 2, 5, 6, 9	*Explorations in Science, Level 3, Super Structure (Water World, Sand World), p. 24*	sand table, water table, building materials from bins	Discuss the challenges of building structures on sand and water compared to building on a solid surface. Brainstorm ways of making a suitable foundation.
Building a support for a weight	1, 2, 5, 6, 9	*Challenging Artstraws* (NES Arnold) *(Support a Weight), p. 6*	straws, tape, scissors	
Building ramps for marbles, toy cars or model bobsleighs	1, 2, 5, 6, 9	*Challenging Artstraws* (NES Arnold) *(Propel the Marble), p. 14* *Challenging Artstraws* (NES Arnold) *(Bobsleigh Courses), p. 16*	straws, tape, scissors, paper	

Assessment

For a broader discussion of science classroom assessment techniques see *Assessing Student Learning* in the introduction of this publication on p. 15. Good places to begin looking for the unit-related ideas are *Explorations in Science* assessment handbooks, *Innovations in Science* teaching notes, Unit tests and Portfolio ideas, Alberta Education sample tests at **www.education.gov.ab.ca** and Alberta Assessment Consortium at **www.aac.ab.ca**

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