Honeycomb Structures: Teacher Notes

Overview/Introduction

This activity has its genesis in the materials science research conducted at Deakin University's Institute of Frontier Materials. http://www.deakin.edu.au/research/ifm/.

This Laboratory Learning Activity (LLA) addresses some of the principles that are currently being investigated through research and design at the Institute.

A common aim of materials scientists and engineers is to create materials with the greatest strength and the minimum weight and minimum amount of materials (minimum cost). Honeycomb sandwich structures are often used to achieve these outcomes and are used in aerospace, automotive, housing, packaging, sports-equipment and other industries.

Being strong as well as light makes honeycomb materials ideal for the manufacture of crash helmets for racing car drivers, motor cyclists and even bicyclists.

A honeycomb structured material is produced using an array of hollow tubes or cells (usually) sandwiched between two solid walls. At the Institute of Frontier Materials scientists have produced and tested a honeycomb sandwich structure made from two layers of carbon fibre composite separated by a honeycomb layer of Kevlar.

While the hexagonal shape of true honeycomb is usually the strongest shape. The cells could be tubular, triangular or square shaped.

This is an open-ended inquiry activity in which students can devise their own question to test; devise a method, conduct tests, collect and analyse date and report their findings

Students might test different cell sizes, different shapes, different thicknesses of the honeycomb sandwich and so on.

Curriculum Outcomes: Australian Curriculum - Science F-10

[Footnote [4]]

Years 5 and 6

Science as a human endeavour: Use and influence of science

- Scientific knowledge is used to solve problems and inform personal and community decisions (ACSHE083 & ACSHE100)

Year 7

Science as a human endeavour

- People use science understanding and skills in their occupations and these have influenced the development of practices in areas of human activity (ACSHE121)

Science Understanding: Physical Sciences

- Change to an object's motion is caused by unbalanced forces, including Earth's gravitational attraction, acting on the object (ACSSU117)

Year 8

Science as a human endeavour

- People use science understanding and skills in their occupations and these have influenced the development of practices in areas of human activity (ACSHE136)

Science Understanding: Chemical Sciences

- Properties of the different states of matter can be explained in terms of the motion and arrangement of particles (ACSSU151)

[4] http://www.australiancurriculum.edu.au/science/curriculum/f-10?layout=1#level5

Curriculum Outcomes: Australian Curriculum - Design Technologies

Years 5 and 6

Design Technologies

- Explore the characteristics and properties of materials and components that are used to produce designed solutions (ACTDEK004)

Curriculum Outcomes: Victorian Curriculum F-10

[Footnote [5]]

Levels 5 and 6

Science Understanding: Science as a human endeavour

- Scientific understandings, discoveries and inventions are used to inform personal and community decisions and to solve problems that directly affect people's lives(VCSSU073)

Science Understanding: Chemical sciences

- Solids, liquids and gases behave in different ways and have observable properties that help to classify them (VCSSU076)

Levels 7 and 8

Science Understanding: Science as a human endeavour

- Scientific knowledge and understanding of the world changes as new evidence becomes available; science knowledge can develop through collaboration and connecting ideas across the disciplines and practice of science (VCSSU089)
- Science and technology contribute to finding solutions to a range of contemporary issues; these solutions may impact on other areas of society and involve ethical considerations (VCSSU090)

[5] http://victoriancurriculum.vcaa.vic.edu.au/Print

Science Understanding: Chemical Sciences

- The properties of the different states of matter can be explained in terms of the motion and arrangement of particles (VCSSU096)
    - modelling the arrangement of particles in solids, liquids and gases.

Science Understanding: Physical sciences

- Change to an object's motion is caused by unbalanced forces acting on the object; Earth's gravity pulls objects towards the centre of Earth (VCSSU103)
    - investigating the effects of applying different forces to familiar objects.

Curriculum Outcomes: Victorian Curriculum – Technologies F-10 [Footnote [6]]

Design and Technologies: Technologies Contexts

- **Engineering principles and systems**. Analyse how motion, force and energy are used to manipulate and control electromechanical systems when designing simple, engineered solutions (VCDSTC045)
    - experimenting to select the most appropriate principles and systems on which to base design ideas, for example structural components to be tested for strength
- **Materials and technologies specialisation**. Analyse ways to produce designed solutions through selecting and combining characteristics and properties of materials, systems, components, tools and equipment (VCDSTC048)

Key Knowledge and Skills

In completing this activity, students explore and apply a range of concepts and terms. Some of these terms and concepts are described, defined and explained below.

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[6] http://victoriancurriculum.vcaa.vic.edu.au/level8?layout=1&d=DE

Force - A force is a push or a pull. A force can cause movement in an object or cause compression, tension or torsion within the object.

Impact - Impact or impact force is a shock or large force applied for a very short time.

Compression force – a push that squeezes an object to try to make it smaller or shorter.

Tension force – a pull stretches an object to try to make it bigger or longer.

Strength – The ability of a material to resist breaking when a force is applied.

Strength to mass ratio - This is a measure of the strength of a material compared to its mass.

Investigation - A scientific process of answering a question, exploring an idea or solving a problem that requires activities such as planning a course of action, collecting data, interpreting data, reaching a conclusion and communicating these activities

Variable - Something that can change.

Dependent variable - Variable that changes in response to changes in the independent variable and that is observed or measured.

Independent variable - Variable that is deliberately changed.

Controlled variables - Variables that are kept constant.

Fair test - When testing different materials all the variables except the one being tested need to be kept the same.

Key Science Inquiry Skills

In conducting these activities, students need to:

- identify a question and formulate a hypothesis
- identify variables relevant in the test
- determine the independent, dependent and control variables
- take steps to ensure accuracy in measurement
- plan and conduct an investigation
- record data systematically

- analyse data
- draw conclusions based on evidence

Background information

Honeycomb structures generally have two major types of design.

One type of honeycomb structure uses an arrangement of tubes sandwiched between two walls. Corrugated cardboard is often made by sandwiching a sheet of wavy paper between two sheets of thick paper. The waves, or corrugations, form channels that run parallel to the walls.

Forces applied at right angles to the honeycomb channels will cause the structure to deform.

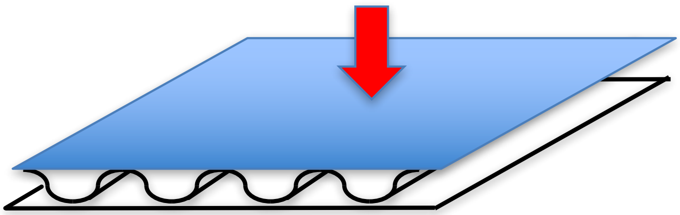
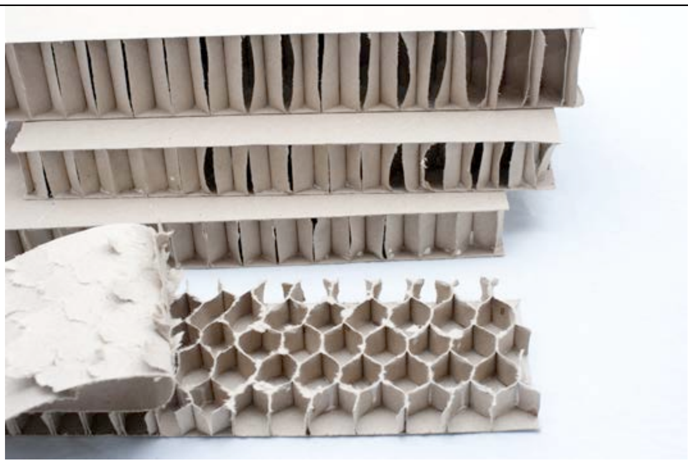


Diagram of corrugated cardboard.
Diagram by Kieran F Lim.

This type of honeycomb structure will deform to absorb forces that are applied at right angles to the honeycomb channels.

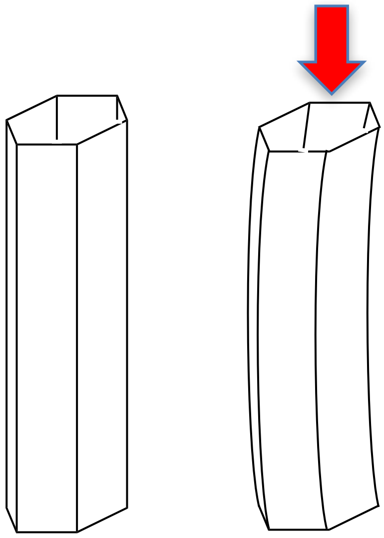
Honeycomb crash absorption structure made of injection moulded thermoplastic polymer on a BMW i3.
Photograph by AutomobilePassion, and used under a Creative Commons (CC BY 2.0) licence.
<https://en.wikipedia.org/wiki/File:2013_IAA_BMW_i3_Honeycomb_structure.jpg>

In other honeycomb structures the open tubes are arranged at right angles to the walls. These tubes can be different shapes in cross section. They could be circles, squares, triangles or hexagons (like honeycomb).



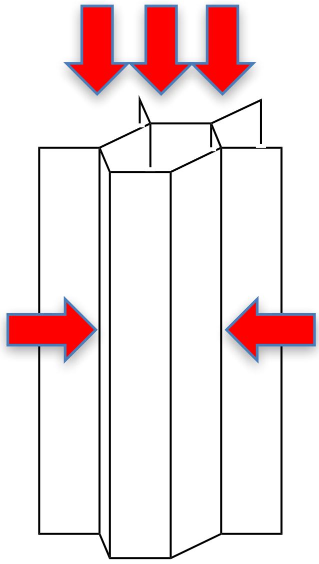
Honeycomb pattern for strength in cardboard. Image by sciencestockphotos.com.
<http://sciencestockphotos.com/free/engineering/slides/cardboard_strength.html>

Forces applied along a single honeycomb channel will cause the structure to deform.



A single honeycomb tube or channel will deform and collapse.
Diagram by Kieran F Lim.

Compression forces applied along the honeycomb channel(s).



Walls of adjacent honeycomb channel(s) exert forces to keep each honeycomb channel rigid and undeformed.

The walls of adjacent honeycomb tubes or channels act to prevent central honeycomb tube deforming.
Diagram by Kieran F Lim.

A single tube structure will deform (change shape) when compression forces are applied parallel to the tube or channel. As soon as the structure deforms, the forces are now not parallel to the tube or channel, which then collapses.

A honeycomb structure consists of adjacent tubes which share joined walls. The walls of adjacent tubes provide sideways forces to maintain the shape of every other adjacent tube or channel. This means that a honeycomb structure is very strong under compression forces applied parallel to the honeycomb channels.

Honeycomb tires

Resilient Technologies and Wisconsin-Madison's Polymer Engineering Center have developed a **honeycomb tire**. This is a variation of the first type of honeycomb structure, in which the forces are applied at right angles to the channels of the honeycomb structure.

We do not have permission to include pictures of the honeycomb tire; more information can be found at:

- Airless Tires (2015). Airless Tires. Retrieved 9 October 2017 from <http://airlesstiresonline.com/>.
- Corky's Pest Control (2016). Architects and engineers; bio-inspired to design and create by nature's finest builders, insects! Retrieved 9 October 2017 from <http://blog.corkyspest.com/?p=853>.
- David Russell Schilling (2015). New airless tires improve battlefield and off-road performance. Retrieved 9 October 2017 from <http://www.industrytap.com/new-airless-tires-improve-battlefield-off-road-performance/24703>.

The air in normal tires provide structure and rigidity when the air is compressed. When stretched in one direction, the honeycombs collapse in the direction at right angles to the tension forces. When stretched in multiple directions, the honeycombs in these tires are strong under tension (stretching). The thick tire outsides (the surface in contact with the road) provide structure and rigidity – the vehicle axle is actually hanging from the top edge of the tire and the forces are distributed around the tire and onto the road surface by the honeycomb structure.

Pedagogy

Inquiry Skills

This is an inquiry activity that can be adjusted by the teacher to be as guided or as open-ended as desired. Since this activity occurs towards the end of the IFM/ReMSTEP sequence of activities, the student notes are designed to be at more independent investigation end of the range. The teacher may, however, decide to provide closer guidance and direction throughout the activity.

Teachers may use the inquiry scaffolding tool[7] to assist decision making about the degree of support to provide students for each phase of the inquiry process.

[7] Inquiry scaffolding tool. National Research Council (2000); Bruck, L.B., Bretz, S.L., & Towns, M. H.,2008. Adapted for the Victorian Curriculum by Lim, K. F. (2016), unpublished.)

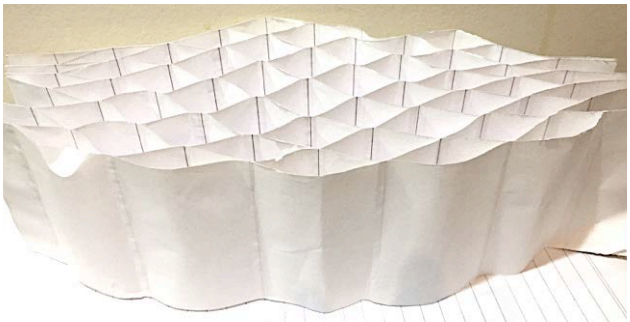
Curriculum outcome (slightly paraphrased)	Prescription	Confirmation	Structured Inquiry	Guided Inquiry	Open Inquiry	Curriculum outcome (slightly paraphrased)
Identify questions (VCSIS107)	No question	Student engages in a question provided by teacher, or other source	Student sharpens or clarifies a question provided by teacher, or other source	Student selects among questions, poses new questions	Student poses a question	Identify questions (VCSIS107)
Plan and conduct investigation (VCSIS108)	Student is given plan of investigation	Student uses a plan provided by teacher	Student sharpens or clarifies a plan provided by teacher	Student selects among plans	Student plans and conducts investigation	Plan and conduct investigation (VCSIS108)
In fair tests, select equipment to collect data (VCSIS109)	Student is given data	Student is told how to use equipment to collect data	Student is told how to select equipment for a fair test	Student selects among equipment	Student selects equipment	In fair tests, select equipment to collect data (VCSIS109)
Construct and use representations, to record and summarise data (VCSIS110)	Student is given representations and summaries of data	Student told how to represent and summarise data	Student is guided to represent and summarise data	Student selects among representations and summaries	Student determines and uses representations and summaries	Construct and use representations, to record and summarise data (VCSIS110)
Identify relationships, evaluate claims and draw conclusions (VCSIS111)	Student is given conclusions	Student is given relationships and evaluations, and told how to draw conclusions	Student is given relationships and evaluations, and guided towards conclusions	Student is directed to evaluate claims and selects among possible conclusions	Student evaluates claims and draws conclusions	Identify relationships, evaluate claims and draw conclusions (VCSIS111)
Reflect on the method used and evaluate data (VCSIS112)	Student is given evaluation	Student is given reflection and told how to evaluate	Student told how to reflect and evaluate	Student is guided toward reflection and evaluation	Student reflects on the method and evaluates data	Reflect on the method used and evaluate data (VCSIS112)
Communicate ideas, findings and solutions to problems , using scientific language (VCSIS113)	No communication	Student is given steps and procedures for communication	Student is provided broad guidelines to use to sharpen communication	Student is coached in development of communication	Student communicates ideas, findings and solutions	Communicate ideas, findings and solutions to problems , using scientific language (VCSIS113)

Conceptual Development

While this is in an open-ended inquiry, students are still likely to need some assistance formulating a question. Leading questions may also be required to ensure that the students design a fair test of their question and collect accurate and reliable data.

Students may need some guidance regarding materials they could use. Circular, square and triangular shape tubes could be made from paper and then the tubes glued together. Alternatively, students could use straws (preferably paper to save the environment).

Another alternative is to stick sheets of paper together to make an expanded structure as shown in the picture. Using this approach students can vary the size of the cells.



Paper honeycomb structure.
Photograph by Ian Bentley.

If students are required to complete a report in accordance with the "Communicate ideas, findings and solutions using scientific language" outcome, teachers will need to specify the nature of the report and the intended audience.

Representation construction approach

Using a representation construction approach (Tytler, Prain, Hubber and Waldrip 2013) can help. The teacher can encourage the students to represent a honeycomb structure. The representation could show the forces involved and shape changes as loads are added to the various structures.

The representations will most likely to be drawings (annotated diagrams), but they could also be models or role plays. Such representations provide insight into students' conceptions. Whatever form the representations take they afford an opportunity to engage with the students in dialogue about their conceptions with the purpose of developing and refining their representations and hence their conceptualisation of composite materials and their components.

Possible designs for honeycomb structures

This is intended as a non-exhaustive list of ideas.

Hexagonal honeycomb structure

Fold paper in parallel folds: two folds up, two folds down, and repeating this pattern. Small folds about 1 cm apart work best.

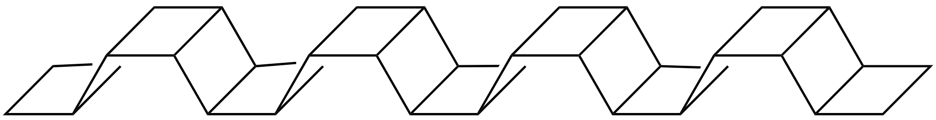


Diagram by Kieran F Lim.

Make some more of these folded strips and glue the touching surfaces together as indicated by the arrows.

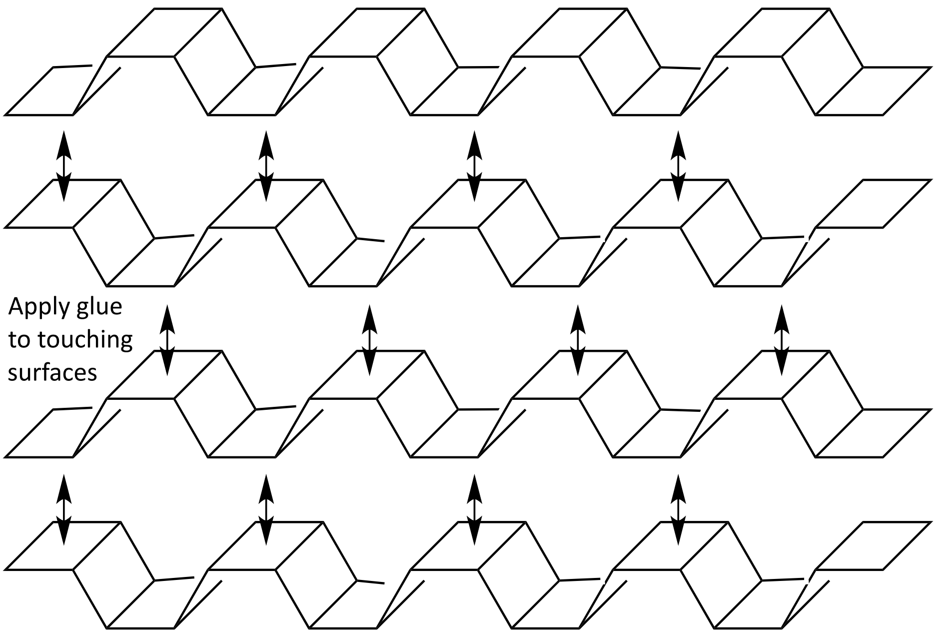


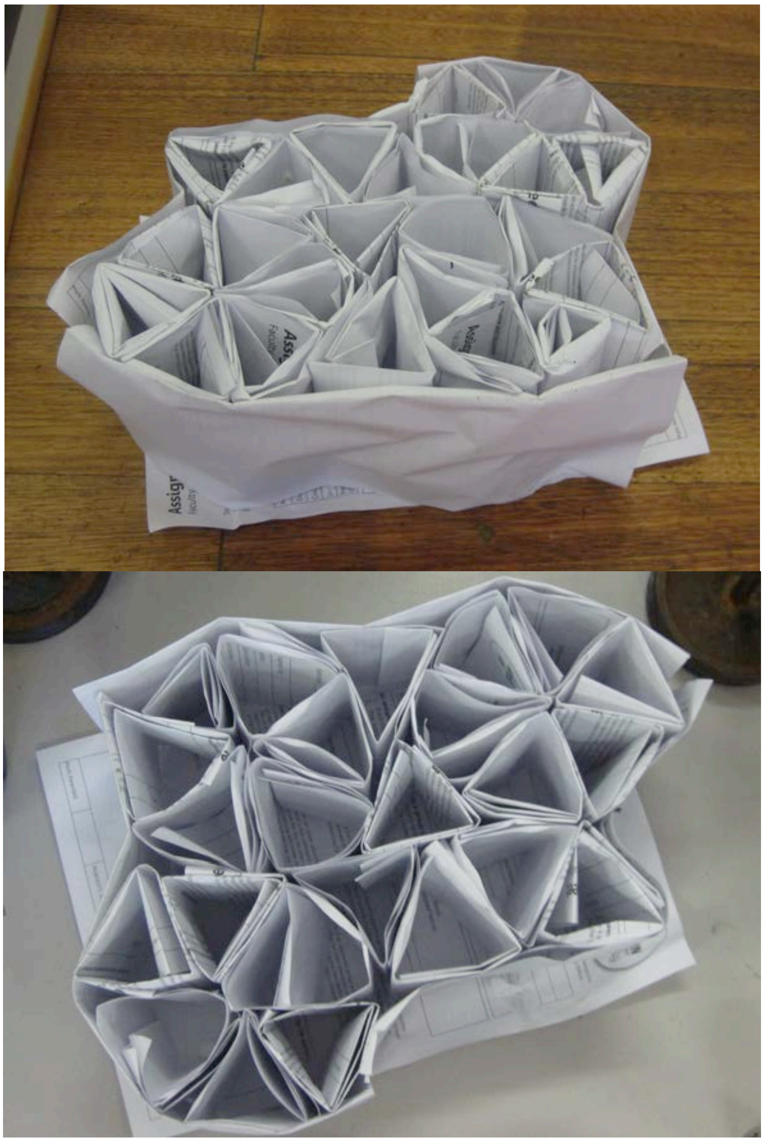
Diagram by Kieran F Lim.

Extension: is the honeycomb stronger if a strip of paper is glued to the around the outside of the honeycomb?

Extension: is the honeycomb stronger if the openings are smaller or bigger (as the spacing of the folds is varied)?

Trigonal honeycomb structure

Fold and glue paper into a triangular "roll" or tube. A quick-drying glue works best. Bundle the "rolls" or tubes together and stick a strip of paper around the outside.



Photographs by Kieran F Lim and Esther Wan.

Extension: what is the purpose of the strip of paper around the outside of the bundle of tubes?

Extension: is the honeycomb stronger if the tubes are glued to each other?

Extension: is the honeycomb stronger if the tubes smaller or bigger?

Extension: Does the strength of the honeycomb depend on having all the tubes of the same size?

Tubular honeycomb structure

Roll paper into small tubes with ca. 2-cm diameter. A quick-drying glue works best. Bundle the tubes together and stick a strip of paper around the outside.

Photograph by Kieran F Lim and Esther Wan.

Extension: what is the purpose of the strip of paper around the outside of the bundle of tubes?

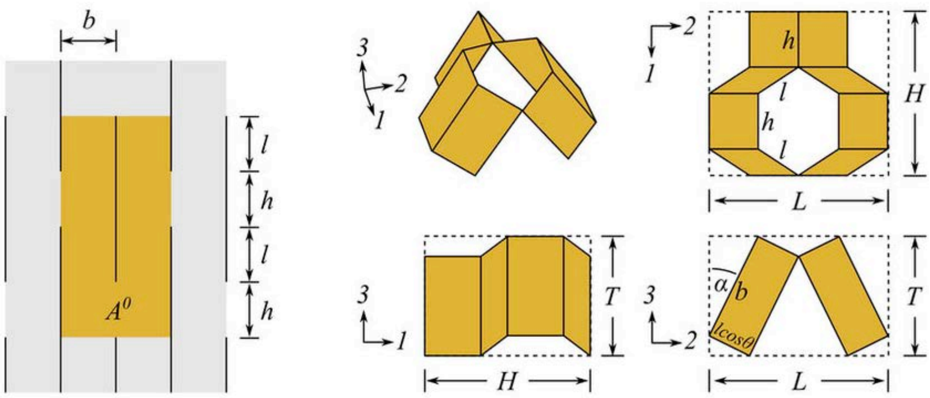
Extension: is the honeycomb stronger if the tubes are glued to each other?

Extension: is the honeycomb stronger if the tubes smaller or bigger?

Extension: Does the strength of the honeycomb depend on having all the tubes of the same size?

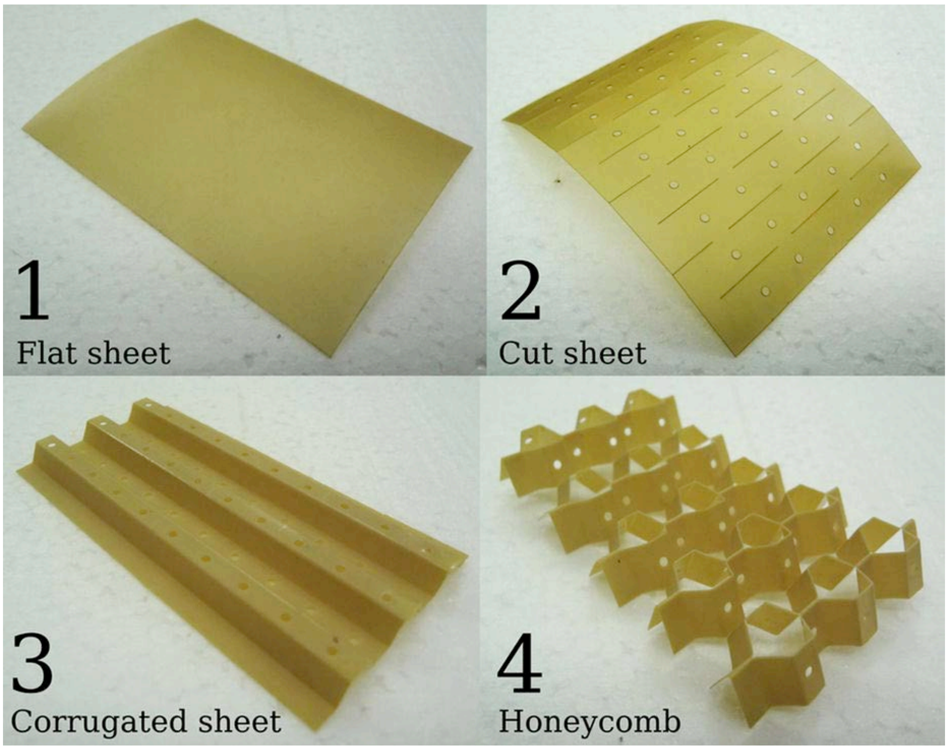
Kirigami hexagonal honeycomb structure

The Japanese art of kirigami involves both cutting and folding sheets of paper to obtain three-dimensional shapes. Recently, Neville, Scarpa, and Pirrera (2016) used kirigami to create shape-shifting metamaterials, which could have large shape and volume changes and with extremely directional, tuneable mechanical properties. They describe how to construct three different honeycomb structures. Their designs are intended to be flexible. The version here is based on their "open rectangular" hexagonal honeycomb structure and has been altered to include gluing to make a rigid structure. (The name "open rectangular" structure refers to the rectangular shape of the walls forming the structure.)



Kirigami hexagonal honeycomb structure. Extract from Figure 1 of Neville, Scarpa, and Pirrera (2016).

<https://www.nature.com/articles/srep31067>



Making a kirigami hexagonal honeycomb structure. Figure 2 of Neville, Scarpa, and Pirrera (2016).
Figure used under a Creative Commons (CC BY 4.0) licence.
<https://www.nature.com/articles/srep31067>

In the paper by Neville, Scarpa, and Pirrera (2016), the honeycomb structure was not glued and strings passed through the holes were used to flex the structure and change its shape. In the current application, there are no need for the holes, and the structure should be glued where folds cause two parts of the structure to touch.

Drinking-straw honeycomb structure

This version has not been tested. It would be similar to the **tubular honeycomb structure**.

PVA-glue and paper honeycomb structure

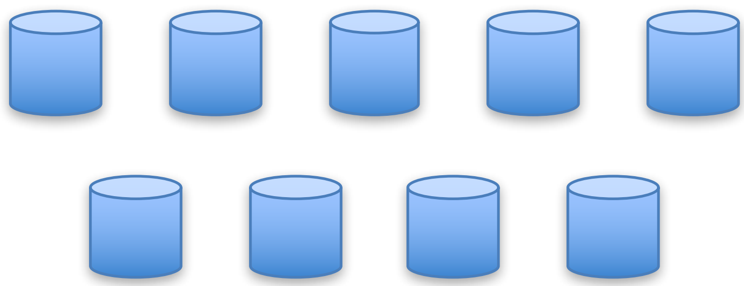
This is made by taking a paper honeycomb structure (one of the above designs) and pouring PVA glue (Footnote [8]) all over the structure. This will take several hours to dry. When we tested this version, the structure was dried overnight with hot air blowing on the structure.

[8] There are various brands of PVA Craft Glue, and PVA Wood Glue.

This essentially gives a polymer-and-paper honeycomb structure. This is similar to the commercial honeycomb structures made by coating (or soaking) paper honeycombs with (in) different resins (Footnote [9]).

Possible scientific questions

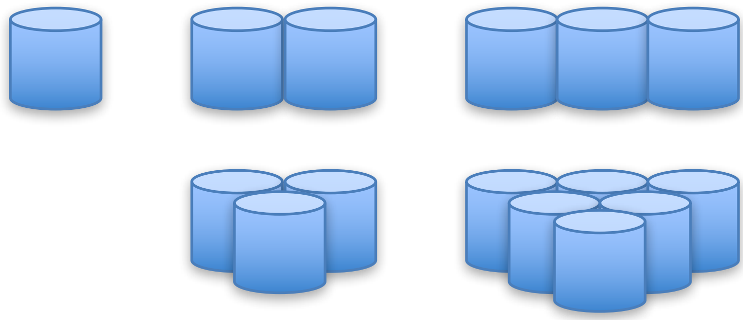
- How does the strength of the honeycomb structure depend on the number of tubes? (This is a possible quantitative investigation.)



What load can be supported by a number of separate (but identical) "tubes"?
independent variable: number of separate "tubes".
Dependent variable: maximum load.
Diagram by Kieran F Lim.

[9] Examples of resin-and-paper honeycombs include: Advanced Honeycomb Technologies (2005) AHK Kraft paper/phenolic coated honeycomb <http://www.ahtinc.com/products/kraft.htm>; Axxor IPHC (2015) Axxor IPHC to impregnate paper honeycomb with resins <http://axxor.eu/paginas/1970/axxoriphctoimpregnatepaperhoneycombwithresins>.

- Does the strength of the honeycomb structure depend on whether the tubes are glued together? (When combined with the previous question, this is a good quantitative investigation.)



What load can be supported by a number of joined identical "tubes"?
independent variable: number of "tubes".
Controlled variable: arrangement of "tubes".
Dependent variable: maximum load.
Diagram by Kieran F Lim.

- Does the strength of the honeycomb structure depend on the cross-sectional shape of the tubes?

- How does the strength of the honeycomb structure depend on the height, and diameter of the opening of the "tubes"?

Other teaching notes for honeycomb structures

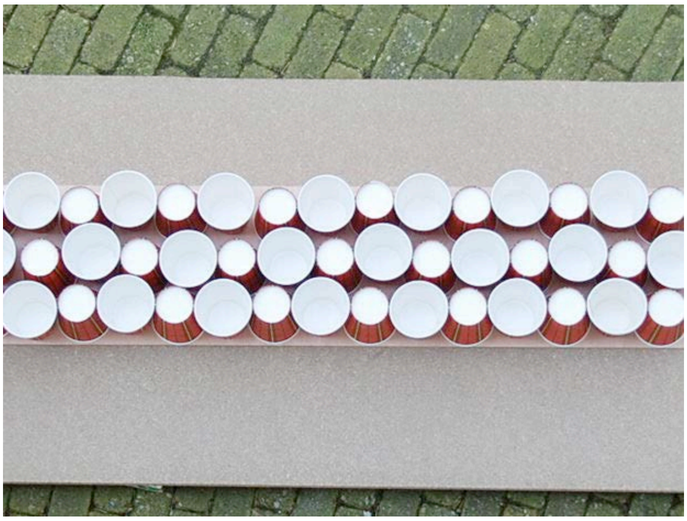
We have tested a number of glues. The best glues are glue sticks (Footnote [10]). A liquid glue like PVA glue (Footnote [8]) takes several hours to dry. Students must use minimal amounts of glue unless they are trying to make a **PVA-glue and paper honeycomb structure**.

[10] The ´various brands of glue stick include: Bostik Glu Stik, Keji Glue Stick, Studymate Blue Stick, UHU Glue Stic, and similar products.

Links to similar activities

After this activity was designed, the authors became aware of a similar activities:

- bertus52x11 (n.d.). Coffee cup - honeycomb sandwich structure. Retrieved 10 October 2017 from <http://www.instructables.com/id/Coffee-Cup-Honeycomb-Sandwich-Structure/>.



Coffee cup - honeycomb sandwich structure.
Photograph by bertus52x11, and used under a Creative Commons Generic (CC BY-NC-SA 2.5) licence.
<http://www.instructables.com/id/Coffee-Cup-Honeycomb-Sandwich-Structure/>

- Curiosity Machine (n.d.). Build a strong honeycomb structure. Retrieved 9 October 2017 from <https://www.curiositymachine.org/challenges/50/>.

Assessment

The teachers can compare the student's performance with the curriculum descriptors and make judgements about whether the outcomes have been achieved. Peer and self-assessment of effectiveness of created composite structures.

References

Bruck, L.B., Bretz, S.L., & Towns, M. H. (2008) Characterizing the level of inquiry in the undergraduate laboratory. Journal of College Science, 38(1),52-58.

National Research Council (2000). Inquiry and the national science education standards: A guide for teaching and learning. Washington DC: National Academic Press.

Tytler, R., Prain, V., Hubber, P., & Waldrip, B. (Eds.). (2013). Constructing representations to learn in science. Springer Science & Business Media.

Neville, R. M., Scarpa, F., & Pirrera, A. (2016). Shape morphing Kirigami mechanical metamaterials. *Scientific Reports*, **6**, Article number 31067. doi:10.1038/srep31067. Retrieved 10 October 2017 from <https://www.nature.com/articles/srep31067>

Airless Tires (2015). Airless Tires. Retrieved 9 October 2017 from <http://airlesstiresonline.com/>.

Corky's Pest Control (2016). Architects and engineers; bio-inspired to design and create by nature's finest builders, insects! Retrieved 9 October 2017 from <http://blog.corkyspest.com/?p=853>.

David Russell Schilling (2015). New airless tires improve battlefield and off-road performance. Retrieved 9 October 2017 from <http://www.industrytap.com/new-airless-tires-improve-battlefield-off-road-performance/24703>.

- Honicel (n.d.). Honicel paper honeycomb applications. Retrieved 11 October 2017 from <http://www.honicel.com/page/2543/applications.html>.

Federal Aviation Administration (USA) (2012). Chapter 7: Advanced Composite Materials, in Aviation Maintenance Technician Handbook—Airframe Volume 1 (FAA-H-8083-31). Retrieved 9 October 2017 from

<https://www.faa.gov/regulations_policies/handbooks_manuals/aircraft/amt_airframe_handbook/media/ama_ch07.pdf>.

Rainer Groh (2012). Sandwich Structures and Composite Materials, in A Brief History of Aircraft Structure. Aerospace Engineering Blog. Retrieved 9 October 2017 from <http://aerospaceengineeringblog.com/aircraft-structures/>.

Bertus52x11 (n.d.). Coffee cup - honeycomb sandwich structure. Retrieved 10 October 2017 from <http://www.instructables.com/id/Coffee-Cup-Honeycomb-Sandwich-Structure/>.

Curiosity Machine (n.d.). Build a strong honeycomb structure. Retrieved 9 October 2017 from <https://www.curiositymachine.org/challenges/50/>.

Advanced Honeycomb Technologies (2005) AHK Kraft paper/phenolic coated honeycomb. Retrieved 10 October 2017 from <http://www.ahtinc.com/products/kraft.htm>.

Axxor IPHC (2015) Axxor IPHC to impregnate paper honeycomb with resins. Retrieved 10 October 2017 from <http://axxor.eu/paginas/1970/axxoriphctoimpregnatepaperhoneycombwithresins>.

Suggestions

Suggestions for improvements of these activities should be sent to the Project Officer, ASELL for Schools (Victoria), Ian Bentley i.bentley@deakin.edu.au

Acknowledgements

The contributions of members of Scouts Victoria to the refinement of this laboratory learning activity are gratefully acknowledged.

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