

An introduction to the scientific process: Preparation of poly(vinyl acetate) glue

Supplementary Material for *JCE Online*

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Instructors' Guidelines

The key to the overall success of this practical is to encourage the students to think independently. In doing so, the practical teaches the students about the scientific method and how research is conducted in many groups around the world. It is important that the instructor *guide* the students through this process in a gentle way, rather than telling them what to do at each stage. The background information given to the students (in the form of a lecture) should cover the theory and terminology associated with the practical, while the information given to the students in the laboratory should be minimal: a basic recipe to make the latex and necessary safety instructions.

(i) Equipment Required

The "Toybox" should contain, but is not limited to, the following items:

Substrates: (numerous pieces approx. 5 × 10 cm)

- Hardboard e.g. Masonite
- Cardboard
- Loose-weave fabric e.g. cheesecloth
- Denim
- Paper
- Scissors
- Leather

Other Equipment:

- Permanent markers
- String
- Wire
- Pliers
- 4 L plastic bottles
- 5 kg spring balances with hooks ("fish scales")
- Masking tape
- Small paint brushes
- Wood glue

In addition, the following materials will be required (per pair of students):

- 100 mL brown glass bottle with lid ^(a)
- 2 × 50 mL beakers
- 50 or 100 mL measuring cylinder
- Spatula
- Funnel

^a Metal rather than plastic lids are advised as the latter may be swollen by monomer, with resulting loss of the reaction mixture. We used Cospak 100ml Amber bottles, Cat. No.M2180/S721

Requirements for the laboratory include:

- Safety glasses for all students
- Disposable gloves for all students
- Retort stands and clamps
- Top loading balances
- Thermostatted agitator ^(b)
- A pump dispenser for the vinyl acetate bottle
- A fumehood
- Plentiful water

^b A thermostatted water bath with the means to agitate the polymerization bottles. We wired a cage containing the immobilised bottles to the moving tray of a Haake SWB 20 thermostatted agitator.

Very useful but not essential are:

- An oven suitable for drying glued samples at 60 °C
- An electric drill

(ii) Chemicals Required

vinyl acetate	CAS 108-05-04
poly(vinyl alcohol) 87-89% hydrolyzed, 124,000 – 186,000 m.w. (Aldrich catalog no.36,310-3)	CAS 9002-89-5
AOT-75, bis(2-ethylhexyl) sodium sulfosuccinate, 75% w/w solution in water/alcohol (Aerosol OT-75, American Cyanamid Co.)	CAS 577-11-7
AMA-80, dihexyl sodium sulfosuccinate, 80% w/w solution in water/alcohol (Aerosol MA-80, American Cyanamid Co.)	CAS 3006-15-3
potassium persulfate	CAS 7727-21-1
sodium hydrogencarbonate	CAS 144-55-8

(iii) Before the Practical

Vinyl acetate must be filtered through a plug of alumina prior to use to remove inhibitor. As it is a suspected carcinogen with a strong odor, we recommend fixing a pump dispenser set to an appropriate volume to the bottle to minimize the risk of students coming into contact with it.

Approximately 40 mL of vinyl acetate should be purified for each pair of students.

The surfactant solution should be prepared at least 24 hours before the experiment, as the surfactants take considerable time to dissolve. 33 g of AMA-80 and AOT-75 should be dissolved in each litre of water.

Approximately 30 mL of surfactant solution should be prepared for each pair of students.

Two poly(vinyl alcohol) solutions should also be prepared 24 hours in advance; one 5% solution labeled “Poly(vinyl alcohol) for Latex B” and one 10% solution labeled “Poly(vinyl alcohol) for Latex C”.

Approximately 25 mL of poly(vinyl alcohol) solution should be purified for each student.

Before the first practical session, assemble the ingredients for the toolbox. The students will normally use more of everything than you think. Cutting the masonite/wood can be time consuming and should be done well in advance; the cut-up pieces do not need to be of uniform size, nor do they need to have the same roughness on both sides.

Turn on the thermostatted water bath before the session begins to ensure it is hot when required by the students.

(iv) During the Practical

SAFETY NOTICE:

Students should wear safety glasses at all times

Students should wear latex gloves when handling vinyl acetate.

The importance of **immediately** discarding the gloves should they become contaminated by vinyl acetate should be impressed on the students. They should also be told to ensure the pump dispenser is **pointed away** from their bodies. Under no

circumstances should the vinyl acetate bottle be removed from the fumehood. The surfactant solutions may irritate the skin, and care should be taken in their use.

Session 1

Begin by ensuring students are aware of the chemical hazards of the practical, and that they all have safety glasses. We had the students work in pairs, with each pair preparing one latex recipe. It is probably wise to give a brief introductory lecture, revising free radical polymerization, emulsion polymerization, and adhesion, even if these topics have been covered recently.

Distribute “recipe” sheets for Latex A, B, or C to the students. The three latex recipes include different amounts of poly(vinyl alcohol) to vary the observed adhesive interactions. The recipe sheets provided are written for high school students with very little practical experience.

Once the students have mixed the reagents together, ensure the lid of the bottle is tightly closed and the bottle itself is labelled fully enough that the students will be able to identify it later, noting that permanent marker may come off in the hot-water bath. Place all bottles in the thermostatted bath and begin agitation.

Briefly explain to the students that they will now be designing a procedure for testing the glue they are making. Show them the contents of the toolbox. Divide them up into groups of twelve or less, each under the guidance of a demonstrator/facilitator, obtain a volunteer to keep the notes of the brainstorming session. Try not to allow your body language or facial expressions steer the conversation and try to remain inconspicuous.

It is useful to:

- Ask the students to consider what variables need to be controlled and how they can be controlled in order to obtain reproducible measurements.
- Help students to see any obvious flaws in their proposals and reach a consensus on action to be taken.
- Stay in touch with other demonstrators and gently steer the discussion, if necessary, so that groups do not end up doing exactly the same thing. (If there is only one demonstrator, you may wish to distribute a sheet of starting suggestions and then circulate between groups.)
- Ensure that adequate notes are made of the decisions made of the students.

If sufficient time remains and elements of the students’ testing apparatus can be assembled beforehand, encourage them to do so.

Session 2

Remove all the latex bottles from the polymerization apparatus before the students arrive. If there have been any failures, suggest the students use a commercial poly(vinyl acetate)-based wood glue instead. Exhort the students to organize themselves – time will be of the essence! Encourage the students to quickly assemble their test strips and place them in an oven at 60 °C.

While the glue is drying in the oven, the students can assemble their apparatus, fill out the preliminary parts of the report sheet, and review any information that has been provided about previous experiments.

It is important that the glue be allowed to cool after removal from the oven. Five minutes is usually sufficient. Not allowing the glue to cool will lead to temperature

dependent failures – the hot glue fails cohesively as it is less viscous. Advanced classes may like to include this in their list of variables that need to be controlled.

Ensure that the results the students obtain are recorded. Encourage them to examine the “failures” and note their appearance to judge whether failure was adhesive, cohesive, or structural. The interpretation of the results is influenced by the nature of the failure:

- Structural failures mean that their results will have a correlation with the strength of the substrate used, rather than the actual adhesive strength of the glue.
- Adhesive failures mean that their explanation for any differences between the three glues should relate to binding of the glue with the wood.
- Cohesive failures mean their explanation should focus on the chemical and physical effects of adding poly(vinyl alcohol) on the strength of the glue itself.

(v) After the Practical

Tabulate the results obtained by the students and lead them in a discussion to see if any conclusions can be drawn. Have the group prepare a list of suggestions for the next group of students.

- Which variables may not have been considered?
- Is the sample size sufficient to make any meaningful comparisons between latexes A, B, and C?
- What unforeseen practical difficulties may suggest improvements in the testing methods?

The instructor should bear in mind the reasons poly(vinyl alcohol) is added to commercial wood glues:

- As a steric stabiliser – as a surfactant, it might be expected to give smaller particle sizes. It may be interesting to change the relative surfactant:poly(vinyl alcohol) concentration and see what happens.
- As a plasticizer (glass transition temperature, T_g , modifier) – it lowers the glass transition temperature of poly(vinyl acetate), giving better film formation. ($T_g = 30\text{ }^\circ\text{C}$ for poly(vinyl acetate))
- As a rheology modifier – non-Newtonian fluid properties can be imparted with appropriate molecular weights, degrees of hydrolysis, and blockiness of hydrolysis give high viscosity at low shear and low viscosity at high shear, an ideal set of properties for adhesive application.
- In order to provide hydroxyl groups as targets for crosslinking agents – this is not done with “supermarket” glues, but with industrial and “two-pack” preparations

Clean up, ensuring especially that the vinyl acetate is disposed of in accordance with local regulations. Latex waste should not be disposed of in the sink, but collected in a waste bottle for appropriate disposal.

(vi) Troubleshooting the Practical

The design of the practical allows experimentally inexperienced students to undertake the practical and obtain meaningful results with a high degree of success. The following difficulties were encountered with some groups and are easily worked around.

Problem:

- reaction lost: cap loose on reaction bottle, ingredient missing, coagulates
- glue fails cohesively and easily
- glue cannot be broken with testing apparatus
- students' glue stronger than commercial glue
- one student dominates group discussion
- groups do not share information well between sessions

Solution:

- give the students a sample of a commercial poly(vinyl acetate)-based wood glue for their testing
- make sure the samples were cooled before testing
- use smaller amounts of glue in the testing apparatus
- NOT a problem! commercial glues are made to give economic efficiency (i.e. strong enough) not necessarily the maximum strength
- facilitator should actively seek input from all students
- set up a formalized reporting system whereby information is shared between groups, *e.g.* a sheet where students give details of their apparatus and suggested improvements.

Instructions for Latex Preparation: LATEX A

Equipment: Balance
Beakers (50 mL)
Measuring cylinders (50 mL, 10 mL)
Glass funnel
Stirring rod/spatula
Polymerization bottle (100 mL)
Thermostatted agitator

Materials: Vinyl acetate*☠
Surfactant solution (AMA*, AOT*)
Sodium hydrogencarbonate
Potassium persulfate*
Deionized/Distilled Water

* **IRRITANTS:** avoid contact with skin and eyes

☠ **TOXIC:** avoid exposure – use in fumehood with gloves

Safety goggles must be worn at all times in the laboratory

- Procedure:**
1. Into a 50 mL beaker weigh out
 - 0.12 g Sodium hydrogen carbonate (Buffer)Into another 50 mL beaker weigh out
 - 0.12 g Potassium persulfate (Initiator)Avoid cross-contamination by cleaning the spatula between weighings.
Remove from balance and add distilled water (5 mL) to each beaker, stir and leave aside.
 2. Into the polymerization bottle, using the 50 mL measuring cylinder and the funnel to avoid spillage add;
 - Surfactant solution (20 mL)
 - Water (40 mL)
 3. Into the polymerization bottle add 2 aliquots of vinyl acetate ($2 \times 14.5 \text{ mL} = 29 \text{ mL}$). Tighten the cap and shake for 20 seconds.
 4. Pour the initiator and buffer solution (made previously in the 50 mL beaker) into the polymerization bottle, **firmly** tighten the cap and label the bottle with a marker including your name, date, and latex preparation.
See a demonstrator to place your bottle in the thermostatted agitator for 15 hours at 60° C.

Instructions for Latex Preparation: LATEX B

2.5% Polyvinyl Alcohol

Equipment: Balance
Beakers (50 mL)
Measuring cylinders (50 mL, 10 mL)
Glass funnel
Stirring rod/spatula
Polymerization bottle (100 mL)
Thermostatted agitator

Materials: Vinyl acetate*☠
Polyvinyl alcohol 88% hydrolyzed*
Surfactant solution (AMA*, AOT*)
Sodium hydrogencarbonate
Potassium persulfate*
Deionized/Distilled Water

* **IRRITANTS:** avoid contact with skin and eyes

☠ **TOXIC:** avoid exposure – use in fumehood with gloves

Safety goggles must be worn at all times in the laboratory

Procedure:

1. Into a 50 mL beaker weigh out
 - 0.12 g Sodium hydrogen carbonate (Buffer)Into another 50 mL beaker weigh out
 - 0.12 g Potassium persulfate (Initiator)Avoid cross-contamination by cleaning the spatula between weighings.
Remove from balance and add distilled water (5 mL) to each beaker, stir and leave aside.
2. Into the polymerization bottle, using the 50 mL measuring cylinder and the funnel to avoid spillage add;
 - Surfactant solution (20 mL)
 - **Polyvinyl alcohol solution for Latex B** (37 ml)Rinse the measuring cylinder with distilled water between additions.
3. Into the polymerization bottle add 2 aliquots of vinyl acetate ($2 \times 14.5 \text{ mL} = 29 \text{ mL}$). Tighten the cap and shake for 20 seconds.
4. Pour the initiator and buffer solution (made previously in the 50 mL beaker) into the polymerization bottle, **firmly** tighten the cap and label the bottle with a marker including your name, date, and latex preparation.
See a demonstrator to place your bottle in the thermostatted agitator for 15 hours at 60° C.

Instructions for Latex Preparation: LATEX C

5% Polyvinyl Alcohol

Equipment: Balance
Beakers (50 mL)
Measuring cylinders (50 mL, 10 mL)
Glass funnel
Stirring rod/spatula
Polymerization bottle (100 mL)
Thermostatted agitator

Materials: Vinyl acetate*☠
Polyvinyl alcohol 88% hydrolyzed*
Surfactant solution (AMA*, AOT*)
Sodium hydrogencarbonate
Potassium persulfate*
Deionized/Distilled Water

* **IRRITANTS:** avoid contact with skin and eyes

☠ **TOXIC:** avoid exposure – use in fumehood with gloves

Safety goggles must be worn at all times in the laboratory

Procedure:

1. Into a 50 mL beaker weigh out
 - 0.12 g Sodium hydrogen carbonate (Buffer)Into another 50 mL beaker weigh out
 - 0.12 g Potassium persulfate (Initiator)Avoid cross-contamination by cleaning the spatula between weighings.
Remove from balance and add distilled water (5 mL) to each beaker, stir and leave aside.
2. Into the polymerization bottle, using the 50 mL measuring cylinder and the funnel to avoid spillage add;
 - Surfactant solution (20 mL)
 - **Polyvinyl alcohol solution for Latex C** (37 ml)Rinse the measuring cylinder with distilled water between additions.
3. Into the polymerization bottle add 2 aliquots of vinyl acetate ($2 \times 14.5 \text{ mL} = 29 \text{ mL}$). Tighten the cap and shake for 20 seconds.
4. Pour the initiator and buffer solution (made previously in the 50 mL beaker) into the polymerization bottle, **firmly** tighten the cap and label the bottle with a marker including your name, date, and latex preparation.
See a demonstrator to place your bottle in the thermostatted agitator for 15 hours at 60° C.

Adhesive Test Report Sheet

Latex preparation:

Names:

Date:

Points to consider:

Application method
Comparison with other groups
Reproducibility
Adhesive failure, cohesive failure, or structural failure?

Description of test:

How did you construct and carry out the test to give reliable and meaning full results?

Results:

Record your observations. Can you quantify the results to make a more accurate conclusion?

Comparison with other latex preparations:

Here you should compare and correlate the results obtained from your collaboration with other groups with the same and different latex preparations.

Problems/ Sources of error:

What problems were associated with the measurement techniques? How did these problems effect correlation with other groups and latex preparations?

Conclusions:

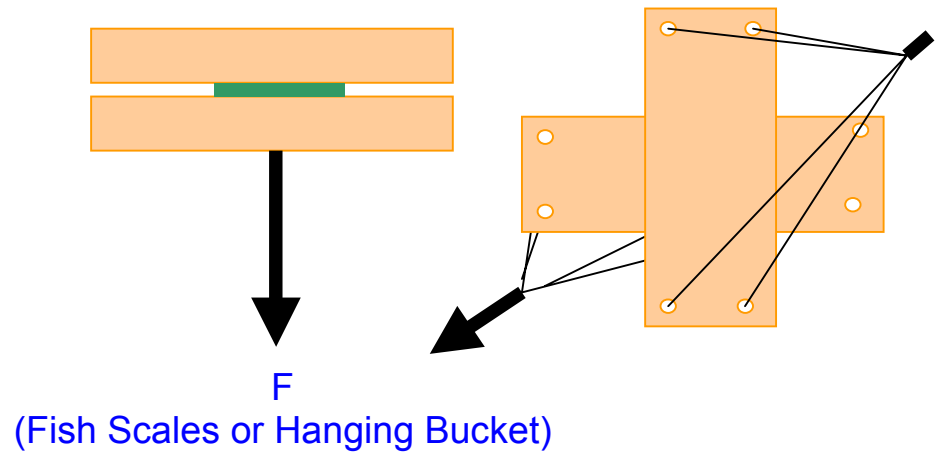
Write a brief summary of the experiment and test results. Do you think the experiment gave reliable information on the adhesive properties of the latices? If not, why? What do you think are important points to consider when trying to obtain reliable information from any experiment?

Sample Results Set

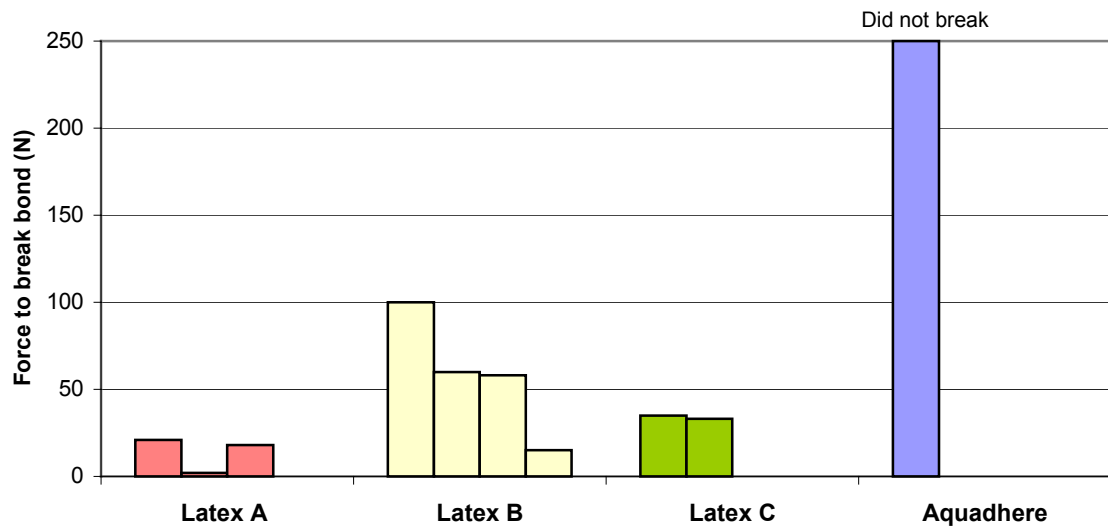
Obtained by Students at the International Science School, July 1999

7/7/99

"Pull-away" Test 1



"Pull-away" Test 1, 7/7/99

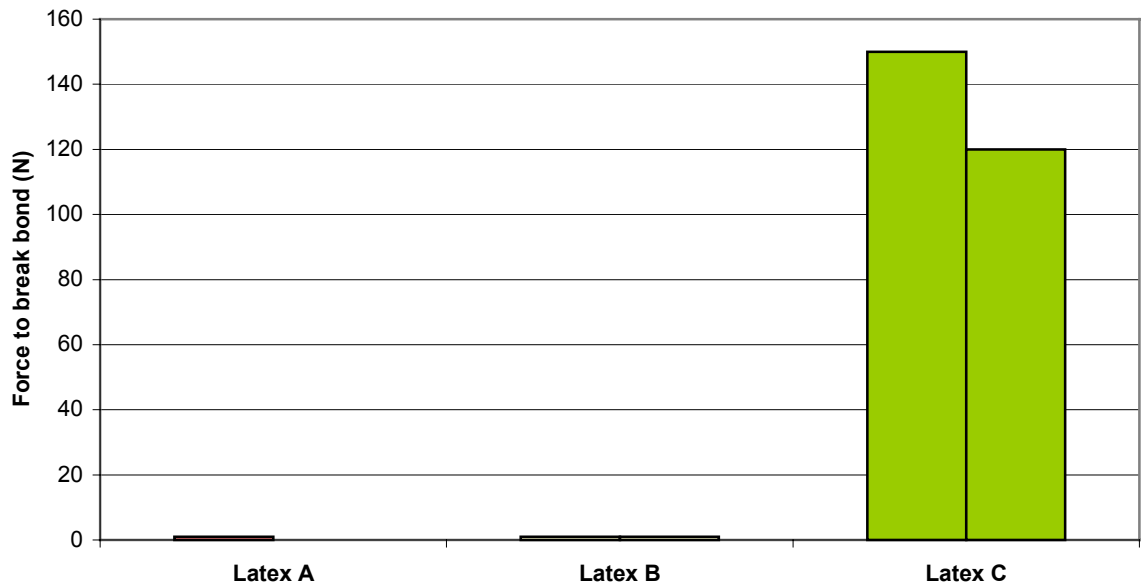


Masonite on Masonite, 2 x 2 cm area, 20 minutes drying, 5 minutes cooling. Force to pull pieces apart measured with fish scales.

The main problem encountered was that the area covered by the glue was found to be far from constant, giving irreproducible results.

“Pull-away” Test 2

“Pull-away” Tests 2 and 6, 7/7/99 and 15/7/99



Masonite on Masonite, 1 x 1 cm area, 20 minutes drying, greater than 10 minutes cooling. Force to pull pieces apart was measured by adding 100 ml aliquots of water to hanging bucket.

Pull-away Test 6 was similar.

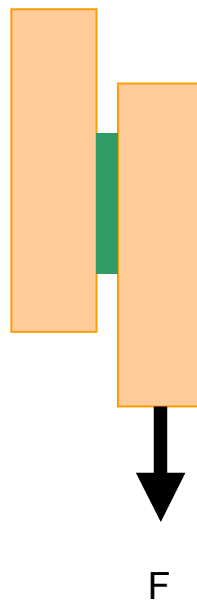
There are limited results for both tests, due to

(1) In the case of Test 2, most were tested without cooling

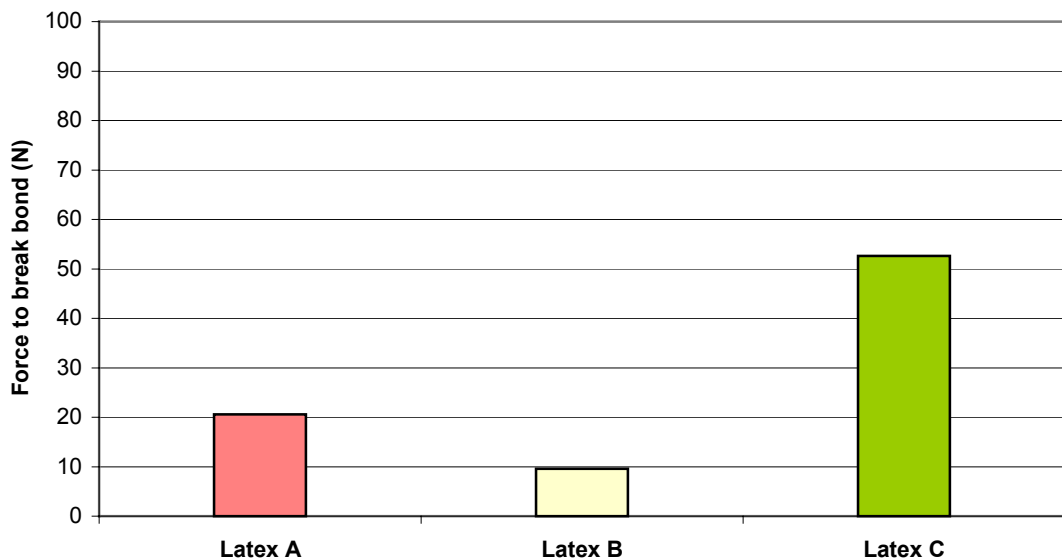
(2) In the case of Test 6, many latexes did not stick (probably due to coagulation of latex overnight?)

8/7/99

Shear Test 1



Shear Test 1, 7/7/99

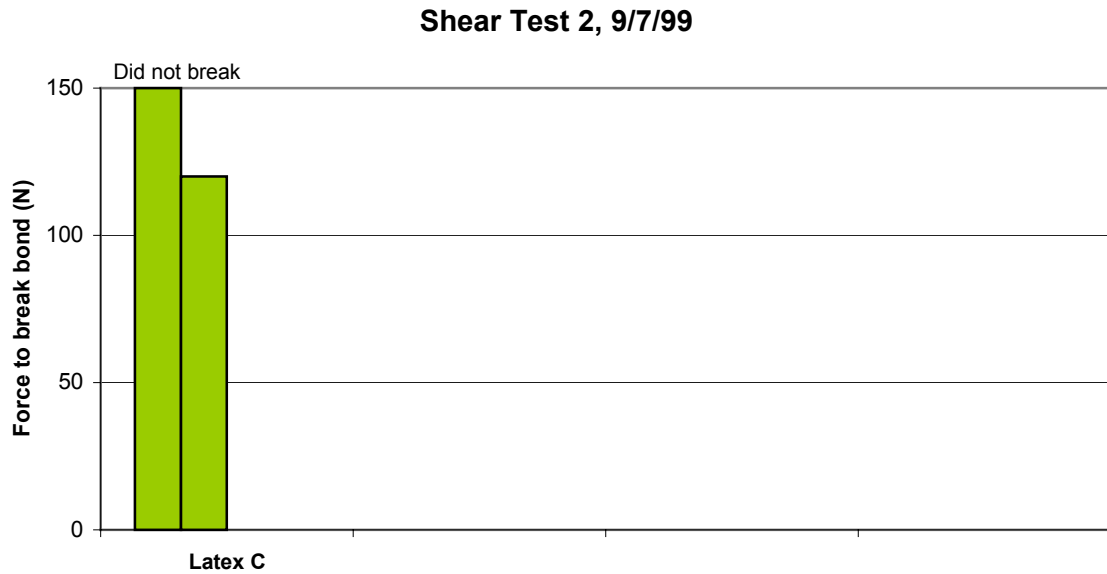


Masonite on Masonite, 1.5 x 1.5 cm area, 20 minutes drying. Approximately 10 minutes cooling. Force was measured by adding 100 ml aliquots of water to hanging bucket.

All the results shown thus far are for “smooth-smooth” masonite joins. Attempts to glue masonite together by the rough sides were unsuccessful. Due to equipment problems on the night of the 7th-8th, the latexes were insufficiently agitated and a product was obtained that was too runny, giving poor adhesion.

9/7/99

Shear Test 2

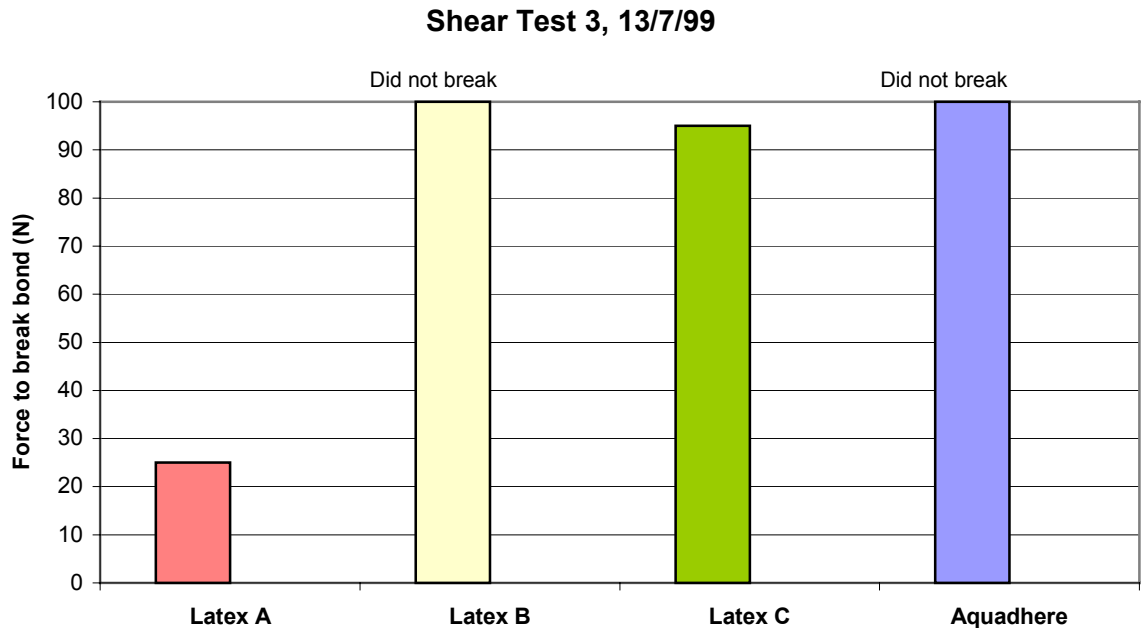


Masonite on Masonite (smooth sides), 0.3 grams of glue, 20 minutes drying. Approximately 10 minutes cooling. Force was measured by adding 100 ml aliquots of water to hanging bucket.

The other group attempted a "lever" test where the pieces of masonite were levered apart by a hanging bucket. To ensure that an even area was covered, a piece of cardboard soaked in latex was used to glue the pieces of masonite together. Unfortunately, structural failure of the cardboard was seen in every case (another tragic case of bad demonstrator advice? You be the judges.)

13/7/99

Shear Test 3

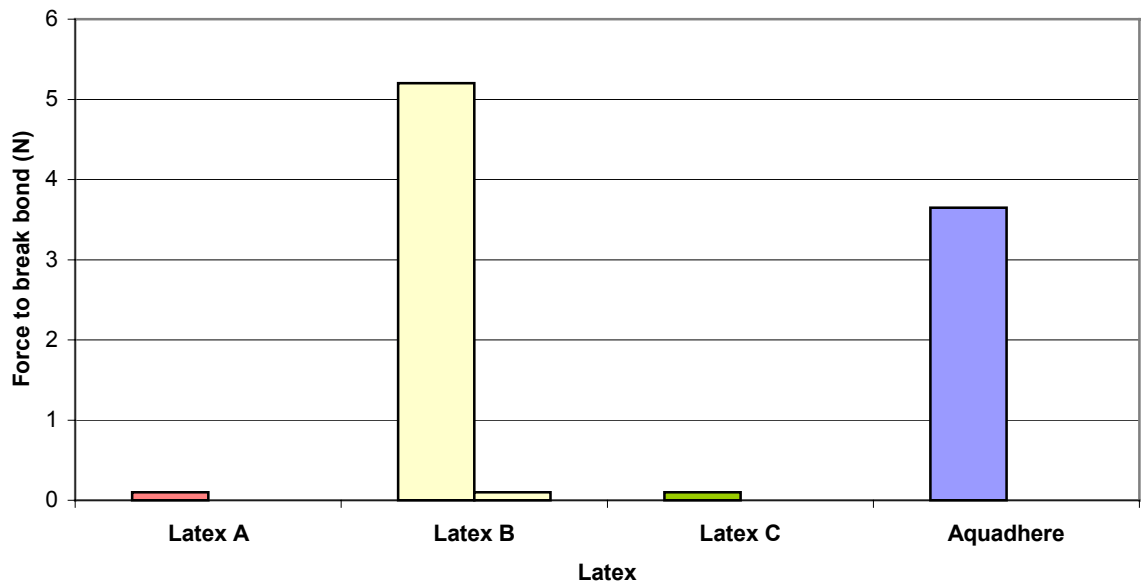


Masonite on Masonite (smooth sides), a measured quantity of glue painted on to lightweight fabric squares of about 1.5 x 1.5 cm used to stick the pieces together. 20 minutes drying. Approximately 10 minutes cooling. Force was measured by continuously pouring water into a hanging bucket.

As you can see from the plot, with this test the main problem was that the pieces of wood stuck together too well – we cannot differentiate between glues when neither bond can be broken.

“Pull-away” Test 3

“Pull-away” Test 3, 13/7/99

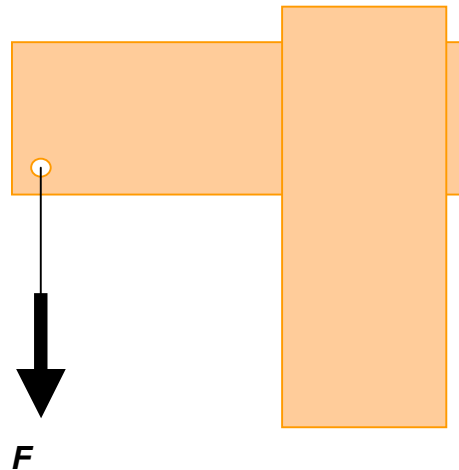


Masonite on Masonite (rough sides), sticky tape stencil used to mark out region on which glue was applied. Force was measured by continuously pouring water into a hanging bucket.

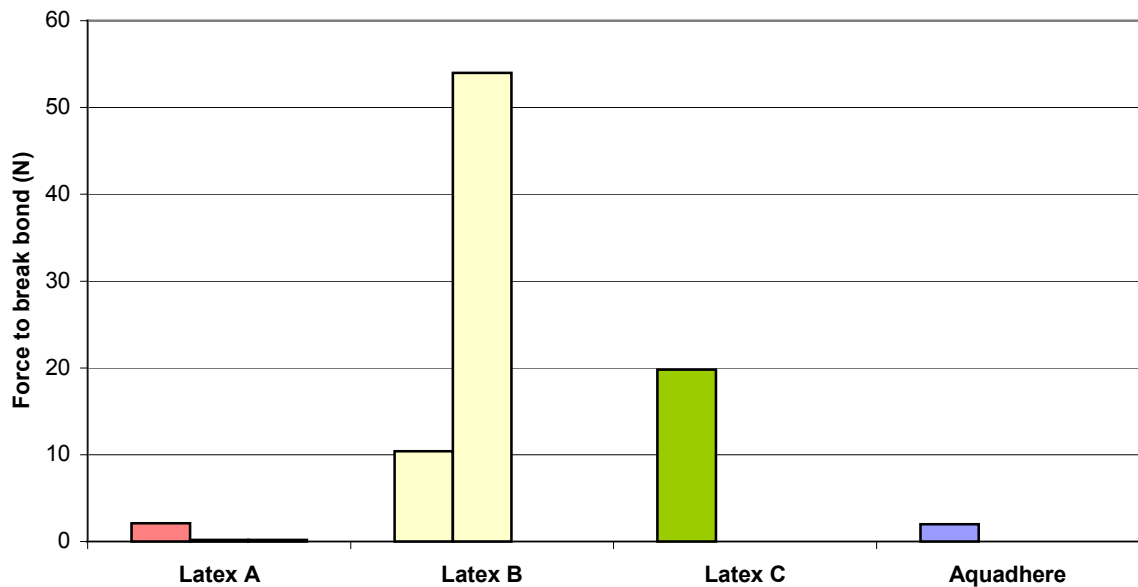
The rough side was again observed to “soak up” the glue, giving poorer adhesion and less reproducible results.

14/7/99

Shear Test 4 "Twist-Shear"



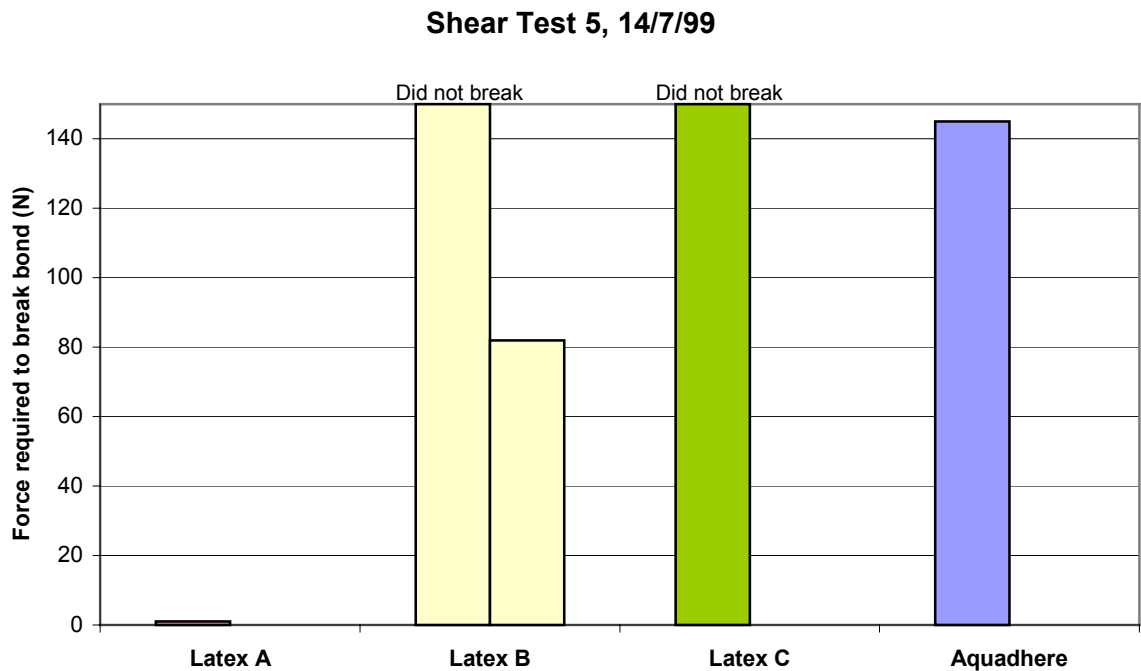
Shear Test 4, 14/7/99



Masonite on Masonite (smooth sides), essentially as Shear Test Three. Instead of applying a direct shear, the two pieces of masonite were placed at 90 degrees to one another and the force applied magnified by a lever effect.

With this test, a value for the strength of each glue could be found without the use of huge weights; assemblies glued with Latexes B and C gave way at easily measurable values.

Shear Test 5

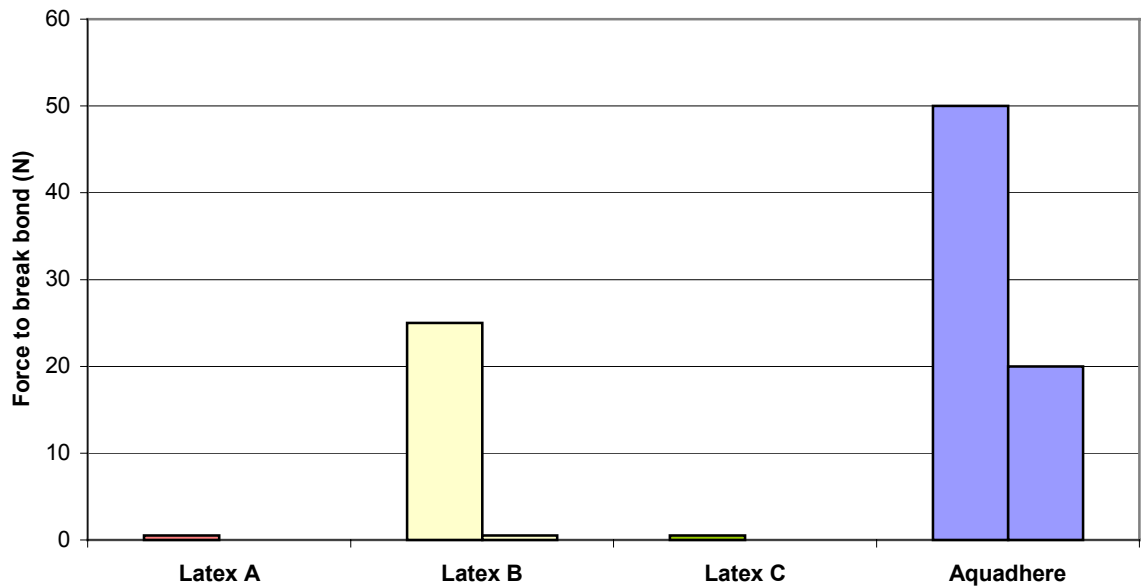


Masonite on Masonite (smooth sides), essentially as Shear Test Three. 1 x 1 cm squares of fabric were used, and a three minute “setting time” was employed before pieces of masonite were placed together

It was planned to do the test both with and without fabric; the only result reported without fabric suggests that the presence of fabric improves the strength of the bond formed. Again, it can be seen that the masonite stuck together too(?) well, making it difficult to differentiate between effectiveness of B, C, and Aquadhere.

“Pull-away” Test 4

“Pull-away” Test 4, 15/7/99

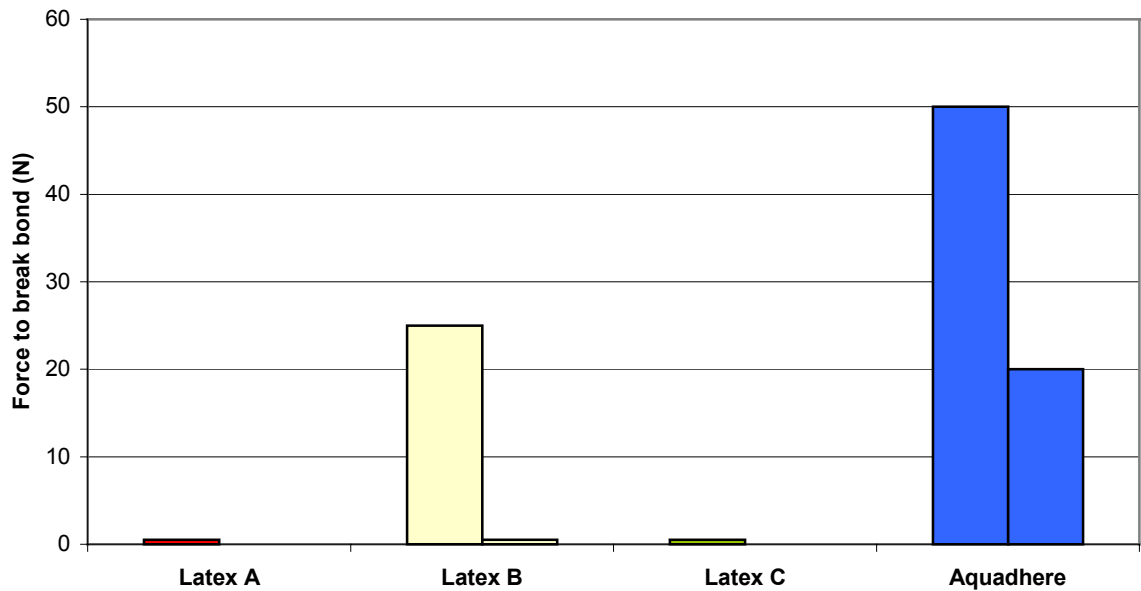


Masonite on Masonite (smooth sides), with a force applied horizontally through a pulley system. Assemblies were made of several pieces of wood in series, glued together with Latexes A, B, and C, so that their relative strength could readily be gauged.

15/7/99

“Pull-away” Test 5

“Pull-away” Test 5, 15/7/99



Three pieces of wood were glued together with two different glues and a force applied simultaneously by adding water continuously to a vessel, which was weighed using fish scales once the glue gave way.

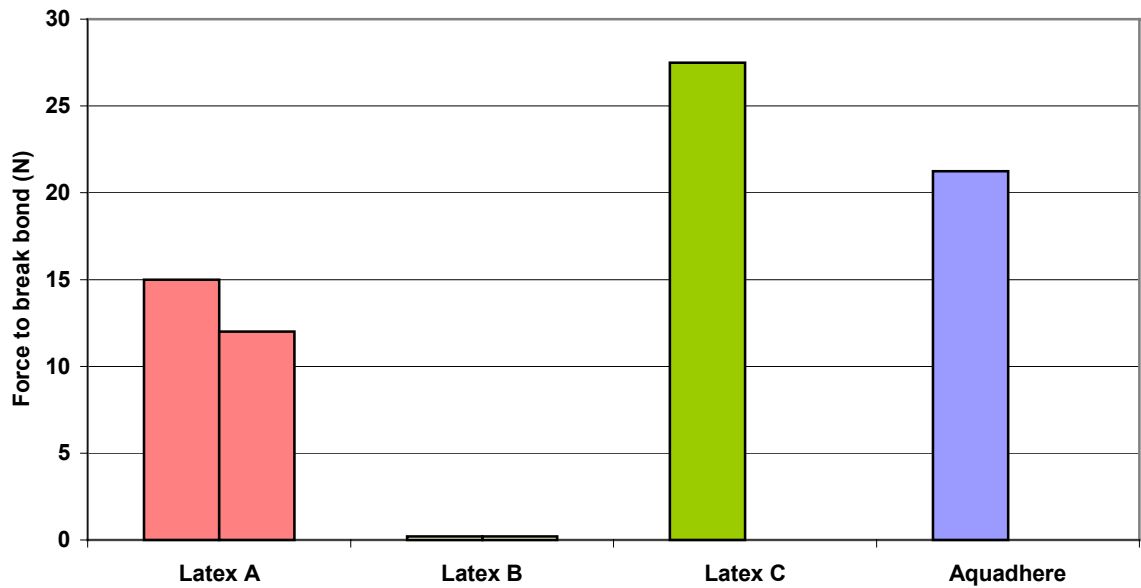
In one test, B was found to be weaker than Aquadhere; in another, it was found to be stronger. The problems seen with latexes not sticking on 15/7/99 were probably due to the newly repaired Bottle Polymeriser agitating the polymerisation bottles to too great an extent and bringing on Shear-Induced Coagulation, judging from the appearance of some of the poorly performing latices.

“Pull-away” Test 6

The results from this have been combined with those for “Pull-away” Test 2.

Peel Test

Peel Test, 15/7/99



Fabric was glued to masonite and suspended vertically. The hook of the fish scales was put through a flap of fabric reinforced with masking tape and a bucket suspended from the other end; a gradually increasing force was then applied by adding water until the fabric pulled completely away from the masonite surface.

Student Evaluation

The following responses are taken from an anonymous survey of the students involved in this program at the Professor Harry Messel International Science School in 1999. The survey was developed with the assistance of the Centre for Teaching and Learning at the University of Sydney and posed 12 multiple choice questions followed by four questions requiring short answer responses. Student responses to the latter are summarised with the key phrases used by the respondents and the number of respondents offering this opinion. Responses to the multiple choice questions are shown at the end of this section.

(i) Aspects Helpful to the Learning Experience

What are two things about the way the polymer chemistry labs and lectures were structured that were the most helpful to your learning? Why?

Lecture

The lecture took you right from basics to the complex bonding of glue. This allowed good understanding, interesting. Well explained.	43
Easily digestible modules; logical approach; interesting and understandable	3
Good handouts	14
Lecture demonstrations and pictures/diagrams	10
Explaining the process before using it, experiment after lecture	8
Lecture was a good refresher on polymers	

Practical

Freedom in the lab was most appreciated – it provided a supportive atmosphere which stimulated thinking. Designed and carried out the tests independent of supervisors, encouraging initiative. Not the “High School” system of doing pracs that you already know the results of. Creativity and openness. The responsibility was given to us with help when we needed it, weren’t told what to do as it forced us to think and question what others and ourselves said, thoughts developed freely. Had to follow guidelines and work within boundaries with limited materials.	31
Practical experience in research skills, opportunity to use real chemicals in a real lab.	10
Briefing sessions prior to the experiment informed and provoked thinking to the project and helped reinforce ideas	3
Needed to use discretion in interpreting data	
Purpose of experiments was well defined	3
Clear instruction and clear method made learning easy	15
Materials readily available so lab kept moving	2

Group Work

Talking to supervisors about what to do and what to expect, good guidance, available to answer questions, analysed our ideas and were very beneficial to the decision making processes	10
Group environment, discussion of method. Groups enabled development of ideas that I'd never have thought of	8
Collaboration with other groups	4
Learnt to work together as a team	2

Miscellaneous

Chris and James were really cool, knowledgeable and scientific. Friendly. Facilitators. They were easily excitable – great to see!	8
Lecture and practical well connected	7
Not rushed through in one day, spread across 2 weeks	
Looking at molecular structure of PVA, PVAc and cellulose to explain results	2
Concluding session, consolidate understanding as a big group	4
Stimulated to pay attention – not to miss out	
Developed an interest in the subject – showed relevance of chemistry	
Saw difference between knowing and applying	
Time overnight to think about it	
It was fun! Casual approach	2

(ii) Aspects Hindering the Learning Experience

What are two things about the way the polymer chemistry labs and lectures were structured that were the greatest hindrance to your learning? Why?

Knowledge and Guidance

Too many big words and chemical names at once. Assumed to much chemistry	10
Not enough knowledge to design an effective test	
Being in the first prac group – no guidance from other groups	
More guidance required, instructions not always clear. Not really knowing what we were doing	5
Too much guidance in the prac	
Explanations too complicated	2
Explanations not detailed enough (monkey learning)	2
Lecture became repetitive. Lecture covered material already known.	2
Too much time on procedure not on theory	
More stimulus materials needed	

Groups and Session Structure

Groups too big for the tests, not all contributed (12 in each group)	21
Older/more experience people dominated groups	4
Time too short for planning and testing	16
Not enough trial and improvement, not enough communication between groups, more feedback from previous groups required (a structured link)	20
Long time between lecture and lab or lab and wrap-up	7
Concluding session too structured and too short	
See results first hand, not just hear about them in concluding session	

Materials

Not high-tech equipment, just backyard tools	3
Better materials for testing	
Dirty glassware, faulty machinery	8
The instruments were poorly calibrated and the buckets were too small	
Different/unfamiliar instruments and equipment	
Became hard to find equipment in the mess	
Not enough different bits of equipment to perform tests (esp force measurements)	

Miscellaneous

Language barrier	11
Too many variables to analyse results effectively	
Irreproducible results	6
No oral explanation of what to do was given, only on sheet	2
No visuals (explosions)	2

(iii) Suggested Changes

What could be changed to make the labs and lectures a more effective learning experience for students?

Lecture

Lecture at a faster pace	
Lecture at a slower pace	
More simplified explanations	
More detailed explanations, diagrams of H-bonding	3
A more experienced lecturer	
Explosions, vivid colour changes	

Practical

Reduce the waiting around (give lecture info while waiting for stages in prac to finish). Use lab time more efficiently	4
More time for pracs, repetition of expts	5
Pracs too long	
More information about the motivations for doing the experiments	2
Greater variation in glue strengths to get wider variety in results	
More variety in the materials (and more of them) in the toy box eg thicker blocks	4
More polymer types	
A short bridging session (10min) before start of prac to link back to lecture	3
Should be no specified amounts for polymerisation (stifles initiative)	2
Provide a list of possible problems with adhesive tests	
Pose more questions or offer suggestions when students get stuck	
Warn about adding excess surfactants	
Develop a standard test-rig	
Make sure toy-box items come back to the toy box	

Session Structure

Use a structured sheet for reporting to next group: what the test was and what should be changed.	
Make more difficult	2
Distribute notes on polymers before the science school	
More labs, more lectures on polymer chem	
Concluding session: smaller discussion groups or small groups and large group	2

(iv) General Comments

This was by far the best practical in the ISS99.

New topic of polymer chemistry welcome! Not much done at school.

I must strongly congratulate the way that the lab was carried out as it promoted thinking and discussion within the group. At no time were we told what to do or what wouldn't work, something that we will be faced with if we take on a scientific career.

Cool!

(v) Multiple Choice Questions

