An inquiry-based physics lab for biologists (UQ)

Margaret Wegener, Tim McIntyre
School of Mathematics and Physics, University of Queensland

Introduction
In the introductory service course "The Physical Basis of Biological Systems" students come from a wide range of backgrounds, many not having taken physics at high school. They are generally interested in biological or medical sciences. There are also some Engineering students catching up on physics fundamentals. After previous success in developing an extended experiment especially for the BBiomed cohort in this course, we were keen to introduce another activity so that all students in PHYS1171 would be able to experience an inquiry-based lab. This approach fits with our interest in developing active learning in physics. The project fits well with the University of Queensland's strategy of encouraging undergraduate research experiences, along with its drive for sustainable energy.

We have developed an inquiry-based laboratory module to illustrate concepts related to heat. We aim to improve student learning through inquiry-based activity. The goal is for students in small groups to take charge of the experimental design, developing their own method and analysis (with some guidance). The benefits of this experiment are that students:

- become more familiar with physical phenomena and their relative importance in a particular situation, in a research-like experience
- need to develop understanding of the relevant concepts and apply that knowledge to successfully perform the experiment
- work as a group to design their experiment and make decisions to optimise its effectiveness.
- practice general scientific skills such as interpretation of graphs in a meaningful way.
- gain experience with using modern sensors and digital data.

Methods
The topic of heat transfer and how thermal properties of materials affect that process is introduced in lectures. Various mechanisms that exist in nature are discussed. Examples include heat being transferred through a layer of body fat and radiated to the surrounds.

This experiment focuses on the physics of how the temperature inside a building varies over time, depending on heat from the sun, atmospheric conditions, and the way it's built. We were inspired to do this by an ANU undergraduate experiment. As reference, we used materials developed by others for similar activities.

The initial stage of the development process was feasibility experiments with sample sensors and materials. With a working prototype, we designed the learning activity. First implementation was with students enrolled in PHYS1171 in Semester I, 2012 (170 students). We evaluated the student experience and made some modifications. All non-BBiomed students in PHYS1171 in Semester II (enrolment of 310 students) did the revised activity.

Besides us (the two academics who teach the course), development of this lab module involved a number of other people. The Teaching Laboratory Manager and Workshop designed and created items for the experimental setup. The Lab Manager was also involved in sourcing instrumentation and writing required Occupational Health and Safety documentation. IT support staff set up remote monitoring of the experiment. UQ solar PV array researchers ensured that our students could access local weather and solar irradiance data. Through participation in the AFFA scheme we gained access to expert advice and independent external observers. The PHYS1171 laboratory tutors as a group worked through the experiment, spending considerable time discussing the apparatus and theory, and provided informal and structured feedback.

The activity is done in the later part of the semester, after students have some lab experience. It is structured as two three-hour sessions for students in small teams. In the first session, students start with guided experiments similar to the style they have done previously. They become familiar with heat transfer by exploring the importance of the type and thickness of insulating materials (using adapted commercial experiment kit), and then making measurements with digital sensors in very short independent experiments. Teams then build a simple model house using a modular structure, choosing from a limited range of materials. The house is instrumented and placed in a safe location on the lab building rooftop to experience ambient conditions over a 24-hour period. Students are able to view their house's internal temperature (and outside conditions) live via the internet. Images of the experiment are now also streamed live so students can see the progress of their experiment. In the second session, students discuss and explain the temperature data of the class houses, and then teams decide their own goal for the temperature of a structure, develop a design based on their acquired knowledge of heat transfer, and build it. This structure is tested in a similar manner. After each session students download their data for analysis and write a report.

We evaluated the lab via:

- observation and analysis of students working
- focus group of first student users
- survey of staff involved in delivering the activity

Academics visited the labs to observe students working on the experiment. The very first time that the lab ran was observed by the ALTC Fellow. In the first implementation (Semester I), the course lecturers supervised and interacted with students when setting up experiments on the rooftop. All made professional judgements about what students were doing in the lab. Survey questions provided by the ALTC Fellow were used to get structured evaluation from staff (tutors, lab manager, academic).

Analysis

Assessment of outcomes occurred with three foci - practicalities, student attitudes and student learning.

With regard to practicalities, the experimental setup passed testing. Measurably different temperatures were obtained inside structures made of the various materials, and expected trends were apparent. Remote access to the data worked reliably. The activity was able to be done by students in the time available. Management of people and apparatus took more effort than usual for teaching staff. Acquiring extra equipment relieved pressure in one aspect, but it is still necessary to move some apparatus between lab and rooftop, and to have students supervised in both places. Using a rooftop tutor in Semester II made the experiment sustainable in terms of involvement of academic staff. The controlled variation in design made the activity's supervising and marking load workable. Surveyed staff all agreed or strongly agreed that "The experiment worked", "The laboratory manual had sufficient detail", and "Assessment was manageable".

Staff agreed or strongly agreed that "The experiment is interesting". Students concur. All focus group participants agreed that the experiment was involving - "one of the best experiments we have done interest-wise". The relationship to the real world was valued, and very successful in engaging students. They were entertained by the idea, eg: for the simple structure some announced they were going to build a "metal shed" or "esky"; someone's report was labelled "The Hotbox". The activity engaged students through a feeling of some ownership of design: "There was more room and control that made it different, it made it fun". One group was sufficiently motivated to bring in their own materials to use on their structure. Students were interested in the novel experience of monitoring progress of their experiments remotely. Positive student attitudes to the activity were also apparent in the way that they were confident (and correct!) in their reasons for design choices based on physics of heat transfer.

As a measure of student learning, how the students performed on assessment was encouraging - tutors reported that most students got reasonable experimental results, and the standard of write-ups was fine in general. The experiences of the tutors were very valuable feedback. Assessment requirements were an area they suggested for more development, and some refinements were made in the assessment scheme and how students were directed in the lab, for the second offering.

Staff agreed or strongly agreed that "Students developed their conceptual understanding of physics", "The experiment assists students to develop experimental skills" and "The experiment encourages students to think critically". Students were conscious of the demands of this experiment on them: "You wonder ‘why’ and ‘why’ is a way of improving on what you know and consolidating what you brought into the experiment”. Advice from the external observer about using class discussions was particularly beneficial on this aspect.

The degree of variation in the structures that students built turned out to be significant. In initial experiments students were constrained to use one material so it would be simpler to analyse – most students did not originally appreciate this as an issue, showing novice’s grasp of experimental design. On the other hand, variation in the structures built by different teams within a class was encouraged as a useful prompt for whole-group discussion.

The strategy of telling students that they had to design to achieve their own particular aims worked well. Their aims were as diverse as building a greenhouse; minimising temperature variations; making as hot /cold as possible. Most aimed to make a house comfortable for humans. A fairly wide variety of designs was used. The strategies students used in building their structures showed a range of effort. Some were straightforward applications of physics principles, eg: adding ceiling insulation layer. Others were more complex or original, eg: house built of double-layer walls with air gap; clear Perspex wall oriented to afternoon sun. Only a few design choices were questionable.

Student work shows use of physics knowledge that students had gained. Some final designs were informed by the first simple experiments, eg: finding that clear Perspex traps heat. Use of material of low thermal conductivity, and significant thickness, was informed by their measurements of conductivity, and what they knew of theory. They were able to apply the physics, eg: using triple layer of one material. Decisions about orientation of the structure, and choice of wall surfaces, eg: white and black walls to manage reflection and absorption of sunlight, showed some understanding of relevant theory.

Incidental learning occurred. With some students, thinking about the optimum orientation of their structure prompted discussion of seasonal variations in the path of the sun through the sky, so some more physics was learned.

Evidence of understanding occurred unexpectedly when students spontaneously identified from other students’ structures what their design aims had been (ie: they successfully interpreted the physics).

Asked to rate this activity as a learning experience, all staff involved agreed that the experiment is valuable (the group judging its quality as 4 on a scale of 5).

Conclusions

The aspects of this activity that worked particularly well were the semi-realism of the scenario, student ownership of experiments, and controlled variation in what students did through the design choices possible. These provided engagement, better motivating students to understand the physics involved, and a range of opportunities for learning, while being sustainable in terms of equipment and staffing requirements. Evidence of learning is seen in students successfully applying knowledge that they had gained – understanding of theory and/or results of preliminary experiments. This assessment of outcomes is paired with overwhelmingly positive evaluation by staff.

By doing this lab module in an introductory course, students are engaged in real scientific activity at the start of their university study. They are interested in *their* experiments. They have to deal with problems that arise. They come across other interesting questions as they try to achieve their goal, and learn some more science in the process. Therefore the inquiry-based activity has been very effective in engaging students in science.

We plan to extend the experiment to include another biologically relevant situation involving heat transfer - the insulating characteristics of animals. In each possible experimental pathway, then, students would be aiming to regulate an internal temperature in their model structure (animal or building) exposed to a varying external environment. This project's results have already been disseminated via the national Fellowship Forum, and presentations internal to UQ, both with positive audience reactions. With the further development outlined above, we expect to have something sufficiently original and worthwhile for presentation at science education conferences, and for publication in international journal(s).

Finally, we want to say that inquiry-based labs are more interesting and more challenging than recipe-based labs for everyone involved – the students, tutors and academic staff. The extra challenge is worth it.