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# LEARNING-BY-MAKING IN BUILDING SCIENCE EDUCATION

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**Abstract.** The School of Architecture & Design at the University of Tasmania has a long history of incorporating a 'learning by making' pedagogy to the teaching approach within building science, design studio and elective units. Its role within building science has increased and been reinforced by the Course and Unit review processes for two key reasons. Firstly, students' prior knowledge and experience of building have significantly changed. Secondly, the influence and effect of constructivist learning model (Biggs & Tang, 2011) when applied at course, year and unit level, resulting in unit content modifications. These processes have lead to a change in the order of building science content delivery and a strong inclusion of learning-by-making activities within three of the six undergraduate building technology in design units, (of which the author is the unit co-ordinator). This paper focuses on the use of the learning-by-making principles with the Building Technology in Design 1 unit. This paper will discuss the intended learning outcomes, the workshop based learning-by-making experience, and linkages to the assessment tasks.

**Keywords.** Building science education; learning-by-making.

## 1. INTRODUCTION

It is written by many that Confucius said, I hear and I forget, I see and I remember, I do and I understand. Similarly, or maybe even more correctly the Confucian philosopher Xunzi, (312-230 BCE), by translation wrote "Not hearing is not as good as hearing, hearing is not as good as seeing, seeing is not as good as mentally knowing, mentally knowing is not as good as acting; true learning continues up to the point that action comes forth" (Knoblock, 1990).

The School of Architecture & Design at the University of Tasmania has a long history of incorporating a 'learning by making' pedagogy to their teaching approach within building science, design studio and elective units (Wallis, 2005). This approach is often associated with experienced based learning (EBL) and inquiry based learning (IBL) (Andresen, Boud, & Cohen, 2000 Kahn & O'Rourke, 2003; Knapper, 2004; Lee, 2004). For this approach of learning and teaching to succeed a strong partnership needs to develop between lecturers, workshop staff and a diverse mix of national and international students (Spronken-Smith, Walker, Batchelor, O'Steen, & Angelo, 2011). Within this context the lecturer must have a deep understanding of the tasks which students are expected to undertake and complete, to ensure a student-centred approach. In recent years, the scope has been further expanded, with the ever increasing workplace safety requirements (Safe Work Australia; University of Tasmania, 2013), as many students have a very limited, (if any) experience of using tools or making objects.

A reflection on building science education, within the School of Architecture & Design, UTAS, has seen significant change over the last fifteen years. These changes have been driven by responses to industry, educational and university policy changes (Crossouard, 2010; Savage, Jack, & Allbutt, 2011). Until 1998, inclusive, the learning pattern for first year students comprised:

- Design Studio A – Architectural design (25%)
- Design Studio B – Understanding place and context (25%)
- Design Studio C – Communication (25%)
- History and Theory (12.5%)
- Building Technology (12.5%)

Since 1999, the learning pattern for first year students has comprised:

- Design Studio (25%)
- Design Communications (25%)
- History and Theory in Design (25%)
- Building Technology in Design (25%)

The change from a 12.5% to a 25% loading for building technology required the development of deeper learning materials and semester based linkages and support to other units, principally Design Studio.

Annually, the school reviews the ongoing improvement to course content and teaching strategies. This process has identified key learning and teaching aspects within the three-year undergraduate and the two year post graduate courses. Two of these have had a significant impact on the constructivist approach of teaching building science. Firstly, there has been a significant change in the knowledge and life experience that students bring with them to the first semester of the course. Secondly, the annual review continually examines the constructive alignment of learning outcomes across course, year and unit levels. For the building technology in design stream, this includes an in-depth analysis of historical, contemporary and future construction systems and built environment regulation. These processes have lead to a change in the order of building science content delivery and a strong inclusion of learning-by-making activities within three of the six undergraduate building technology in design units, (of which the author is the unit coordinator).

This paper focuses on the use of the learning-by-making principles with the Building Technology in Design 1 unit. This is the first building science orientated unit that students experience. The unit includes a weekly lecture followed by a three hour workshop based making and testing learning experience.

## 2. COURSE AND UNIT ORGANISATION

The building science learning outcomes for first year students includes an introduction to energy flows within buildings, human comfort and structures, within a general discussion on sustainable design. For more than two decades this learning process has had a first semester focused on heat/energy flow, thermal comfort and sustainable design theory followed by a second semester focus on structural theory. However, the acknowledged difference in new student architectural capabilities was becoming very apparent in the application of building science theory to structures.

Historically, students commenced architectural studies with some knowledge of building structures. Upon this assumption, the first aspects of building science learning were focussed on heat flow, thermal comfort and climate responsive design. This was often matched to Design studio, where students were engaged in small-scale design tasks. However, it became apparent that students were not fully aware of basic structural principals to provide informed design ideas and in classes about heat flow there was a very limited demonstrated understanding about the materiality of the built fabric. Within this context, it was agreed to switch the order of the first two building science units for 2012, such that;

- Building Technology in Design 1: This unit develops key structural and materials concepts required for the design of architectural structures. It covers structural mechanics, forces, material properties, bending and shear as they apply to the beams and trusses found in small buildings. Typical timber framing construction practice is studied in relation to structural principles. The emphasis is on learning by making, testing, and student reflection. Models and full-scale parts and assemblies are constructed and tested in the school workshop.

- Building Technology in Design 2: This unit introduces and develops concepts of built environment sustainability. The focus is on using knowledge in the decision-making context of building design. The unit includes appropriate theory, methods of analysis and the effective use of these concepts in problem solving. The content covers human comfort, climate and sun, building heat flows, materials, operational and embodied energy, site and planning and infrastructure. This unit underpins key concepts of sustainability that are further studied and applied throughout the design course.

This modification in the delivery order and renaming of the units allowed for a deeper design discussion in design studio and a more informed and critical discussion within the Building Technology in Design 2 unit. A review of assessment task submissions from 2011 to 2014 show a deeper learning experience but care needs to be taken in a broad acceptance of a deeper learning experience (Pellegrino, Baxter, & Glaser, 1999; Spronken-Smith et al., 2011). Whilst the units have been reordered, a greater unit based review has carefully examined the unit descriptions, the intended learning outcomes and linkages to assessment tasks (Biggs & Tang, 2011). Within this framework of continuous improvement the Building Technology in Design 1 workshop tasks and the workshop workbook have been continually reviewed.

## 3. THE BUILDING TECHNOLOGY IN DESIGN WORKSHOP TASKS

The tasks that students complete within the workshop vary in their complexity during the semester. The design of the learning experience must consider the learning and teaching outcomes, the capabilities of the students and workplace safety requirements. All three aspects are interwoven between the lecture, and directed and self-directed workshop tasks.

Each week a new structural principle is introduced to the students through a lecture. The lecture incudes the theoretical proposition and then illustrates how the theory is applied to building elements and/or element assemblages. The principles of constructive alignment (Biggs & Tang, 20011) are employed in the semester learning and teaching program. However, fed into this framework is the inclusion of historical introductory structural theory and modern building systems. To ensure cohesion the workshop based learning and teaching activities are strongly aligned to the unit intended learning outcomes and the assessment tasks are completed through the completion of workshop based challenges and specific sections of the workshop workbook.

During the weekly three hour workshop based learning experience students are expected to use a range of tools, construction materials and testing equipment. From a workshop based teaching perspective this raises some interesting challenges as the age and life experiences of students vary significantly. This has led to the development of a skills acquisition plan for the semester, where students perform simple tasks in week 1, as shown in Figure 1, where students are measuring the stiffness of softwood, hardwood, aluminium and plastic. From week one onwards students are introduced to, and trained in, the use of a range of hand tools, portable electric tools, pneumatic tools and larger fixed tools (drop saw, table saw, drill press, etc). During weeks 8 to 10 the students design and manufacture a truss or composite beam, which involves the integral use of a variety of tools and the careful manufacture and connection of many components. The trusses and beams are then tested for deflection and ultimate strength, as shown in Figure 2. As the semester progresses toward week 13 more complex structural systems are explored and the principles of Australian residential timber construction practice (Standards Australia, 2010) are introduced and interwoven, leading to the students constructing a small shed, as shown in Figure 3 and Figure 4. The sheds are then clad, insulated and lined in Building Technology in Design activities in semester 2.

*Figure 1: Week 1 – Students measuring material stiffness*

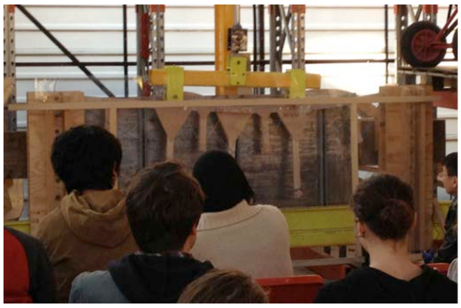


*Figure 2: Week 10 – Trusses that have been designed and manufactured by students are tested for deflection and failure*

Additionally, for most weeks the workshop session includes a group challenge. The challenge generally occupies one-third of the workshop class time. In this task the students need to apply their new-found knowledge and construct a scaled object (column, beam, braced wall) from a limited palette of provided materials. One group of students completing the column task in 2014, (5 skewers and a strip of paper), provided a 230mm high column that supported 160kg. The group and class learning that occur in this frenetic experience provides on-going discussion between the students within the class and the school as a whole (Dobbelsteen, 2007). There is often an inter-year comparison of results. An example of the workbook component of a challenge and a column are shown in Figures 5 and 6 respectively.

*Figure 3: Week 13 – A group of 4 students has constructed a shed wall to AS1684.2-2010*

*Figure 4: Week 13 – A completed shed that has been completed by six groups of students*

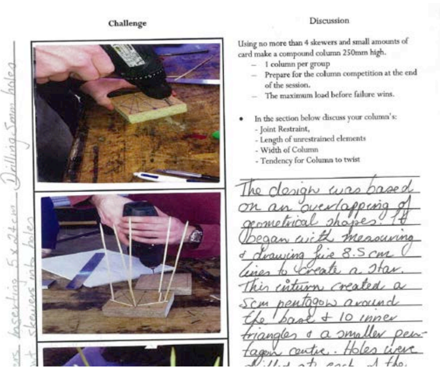



*Figure 5: The workbook component of the weekly challenge tasks*

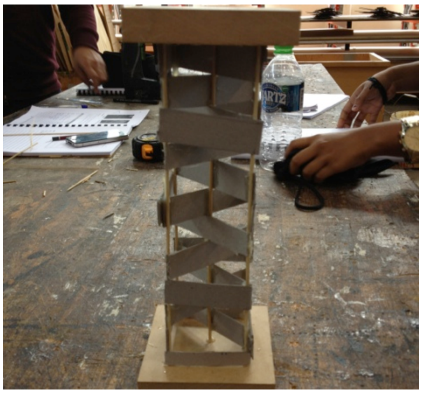


*Figure 6: A groups attempt to make a 230mm super column in week 3 (5 bamboo skewers and a A6 piece of card)*

This mode of workshop learning applies the principles of constructivist learning and teaching that the student constructs their knowledge by facilitating the design and support of an enriched task. The involved processes of using tools, reshaping of materials, the selection and use of joining systems, simple and complex structural systems, allows for the measurement and evaluation of serviceability, and building science performance.

## 4. THE BUILDING TECHNOLOGY IN DESIGN WORKSHOP WORKBOOK

The workshop workbook is an integral tool in the learning and teaching program for Building Technology in Design 1 and has been revised annually since 2009. Prior to 2009 students were expected to keep a sketchbook style of journal to record and document their learning experiences. The problem with this form of documentation was two fold, difficulty of locating and consistently applying the related assessment criteria and the information recorded was often descriptive and lacked critical reflection, which could be argued that the demonstrated learning approach was at a surface level than the intended deep level.

In response to these assessment and learning problems, Justin Beall, the unit coordinator at the time (2009), in collaboration with other staff, developed the first version of the workshop workbook. The workbook included guidance and spaces for recording information from the weekly workshop tasks and a thirty-page appendix that included relevant building structural science information. An example of two pages from the workbook is shown in Figures 7 to 9. This format allowed for a much easier review of student learning and additionally provided more structure and instruction for the weekly experiments. It must be noted that students would paste in other bits of relevant information and there was an on-going workplace safety discussion. The workbook for 2010 and 2011was not significantly altered, with only small amendments such as the Job Safety Assessment form, as shown in Figure 10 (2012).

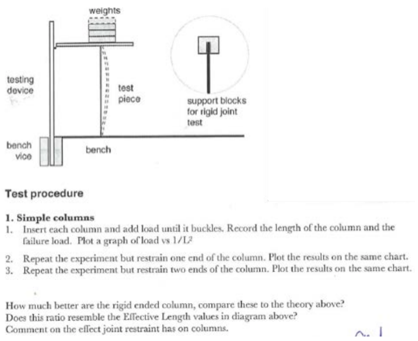



*Figure 7: A Week 3 workshop task on columns and buckling*

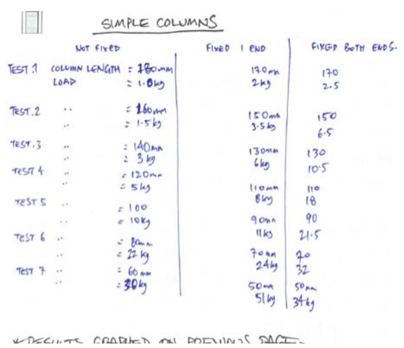



*Figure 8: Part of a students record of the week 3 columns and buckling experiment*

In 2012, with the change of unit coordinator (Dewsbury), more refinements were made in, response to student feedback and the assessment process of the workbook. This involved the inclusion of spaces in the workbook for:

- Workshop experiment based personal photographs and/or diagrams (Figure 11)
- Workshop experiment based personal student discussion with introductory questions
- A weekly task specific externalisation promoting the use of diagrams, images and discussion (Figure 12), and
- The integration of the Job Safety Analysis within the workbook.

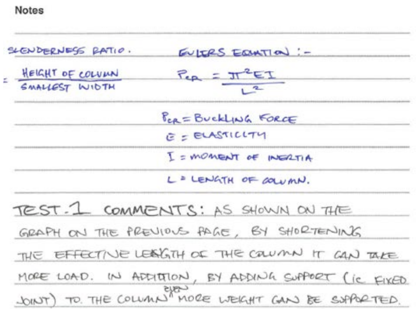
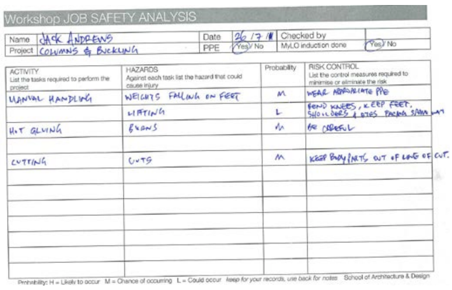



*Figure 9: Part of a students record of the week 3 columns and buckling experiment*



Workshop JOB SAFETY ANALYSIS

| Name | JACK ANDREWS | Date | 26/7/11 | Checked by | |
|---|---|---|---|---|---|
| Project | COLUMNS & BUCKLING | PPE | Yes / No | MyLO induction done | Yes / No |

| ACTIVITY List the tasks required to perform the project | HAZARDS Against each task list the hazard that could cause injury | Probability | RISK CONTROL List the control measures required to minimise or eliminate the risk |
|---|---|---|---|
| MANUAL HANDLING | WEIGHTS FALLING ON FEET | M | WEAR APPROPRIATE PPE |
| | LIFTING | L | BEND KNEES, KEEP FEET, SHOULDERS & EYES FACING SAME WAY |
| HOT GLUING | BURNS | M | BE CAREFUL |
| | | | |
| CUTTING | CUTS | M | KEEP BODY PARTS OUT OF LINE OF CUT. |

Probability: H = Likely to occur M = Chance of occurring L = Could occur keep for your records, use back for notes School of Architecture & Design

*Figure 10: Part of a students record of the week 3 columns and buckling experiment*

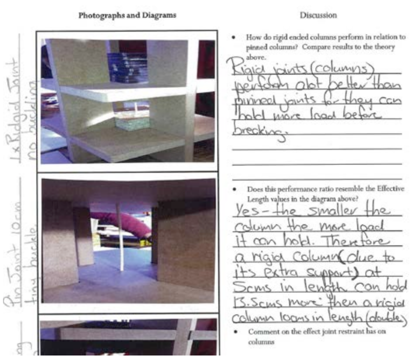



*Figure 11: Part of a students record of the week 3 columns and buckling experiment*

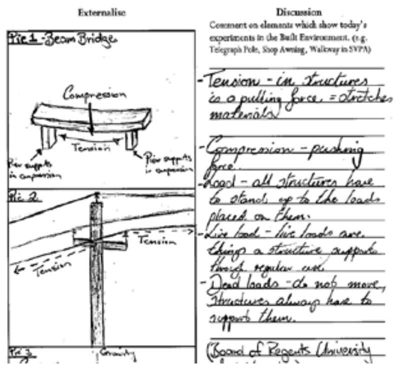



*Figure 12: Part of a students record of the week 3 columns and buckling experiment*

The success of the new format was apparent from the documentation of experiments, challenges and externalisation within the student workbooks. Additionally, students requested more of the same formatted space to include more information from each class. The unit review identified a deficiency in student diagramming and scaled drawing skills (Coates & Seifert, 2011). These two matters were addressed by the inclusion of more structured pages within the workbook to promote the recording and analysis of experiments and the provision of full pages with the heading of ‘Plans, Elevations, Sections & Diagrams’. To encourage students to draw, the intended learning outcomes and assessment tasks included a drawing component and tutors were encouraged to help students with free-hand drawing skills within the workbook.

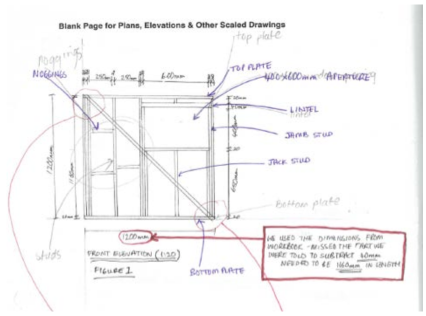



Figure 13: The workbook component of the weekly challenge tasks

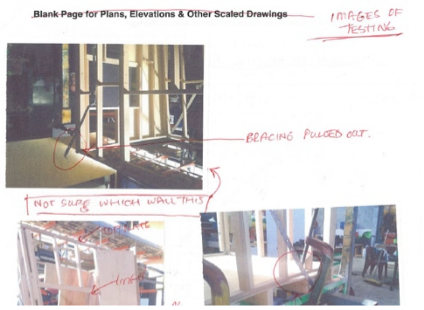



Figure 14: A groups attempt to make a 230mm super column in week 3 (5 bamboo skewers and a A6 piece of card)

## 5. WORKPLACE SAFETY

Workplace safety has been legislated in Australia since 1983 (NSW Government, 1983). More recently, significant changes were made to workplace safety legislation (Safe Work Australia). The new regulations have significantly increased the accountability of staff, line managers and organisations. For many in the building industry, the new safer working practices have led to an increase in equipment and personnel resulting in higher construction costs. At the University level, there has been extensive pressure to reduce activities that may provide a risk. The activities within the workshop are classed as risks.

To minimise risks the students complete a web based theoretical workplace safety course and a practical equipment training session as a prerequisite to use equipment in the workshop. To reinforce this process, the first four pages of the workbook for 2014 included a detailed description of the risk matrix, the required workplace theoretical and practical training and the acceptable types of student provided personal protective equipment (e.g., boots).

To reinforce this style of safe work practice, the start of each workshop class incorporated a whiteboard discussion that listed the tasks, the equipment required, possible risks, risk minimisation strategies and a revised task risk. After this discussion was completed students completed the Job Safety

Analysis template within their personal workbook. By the end of semester this practice, which would need to be considered in private profession practice (Savage et al., 2011), had been completed at least thirteen times. Through this process no accidents of significance have occurred for several years and special mention must go to the workshop manager, Mr Robin Green, who has been an ardent supporter of the Learning-by-Making and Inquiry Based Learning models.

## 6. CONCLUSION

The primary purpose of the first Building Technology in Design unit is to provide a solid base in structural science to a disparate group of students with substantially different capabilities. The redesign of the order of unit content delivery was a first step in the process of introducing built structures to students within the first semester of their undergraduate course. The development and enhancement of the workshop based learning by making and inquiry based learning has allowed for a deeper learning of structural principles and science. Finally, to reinforce the learning experience and to promote deeper enquiry, the workshop workbook has been developed ad revised to maximise the student learning outcomes. This has all been completed within a safe workplace framework where students are engaged in the use of tools and materials, which they will expect skilled trades-persons to use for their designs in the not to distant future. However, as discussed above, the workbook format, and workshop tasks will be continually reviewed within the context of student capabilities and industry guided intended learning outcomes.

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