Adaptive tutorials for design in engineering

Gangadhara B. Prusty[a]; Gim Soh[b], and Robin Ford[c].
Associate Professor[a], Student[b] , Retd. Associate Professor[c]
School of Mechanical and Manufacturing Engineering, University of New South Wales, Sydney NSW 2052
Corresponding Author Email: G.Prusty@unsw.edu.au

Structured abstract

BACKGROUND

Online Adaptive Tutorials (ATs), already well-established in engineering science courses, promise particular benefits for design education. AT's have shown to help overcome the constraints of limited resources while *providing students with improved and personalised support when and where they want it*. However, due to the entirely different character of the design task from the science task, existing developments cannot simply be carried over into this new realm. Engineering science places a problem before students that is more or less predefined and has one expected outcome. In engineering design, *each student must devise their own solution to each design problem they face*. The problem factors to be analysed during the design process are difficult to specify at the outset, meaning that the tutorial guidance must adapt to the particular solution that each individual student devises. It is critical that guidance is not prescriptive and avoids the imposition of unwanted or unnecessary constraints on the student's creativity.

PURPOSE

In this paper, we will describe a pilot study that has been carried out to support students in designing a structural component. This is a first step in moving from engineering science towards the design environment.

DESIGN/METHOD

Using the state of the art Adaptive eLearning Platform (AeLP), which was used in the development of "Adaptive Mechanics: http://adaptive-mechanics.eng.unsw.edu.au/", we have developed an Adaptive Tutorial which introduces the student a constrained form of design experience in a virtual environment. Students can do this exercise at their own pace and in their own time. More essentially the students get appropriate feedback when they need it. The outcomes are assessed by student surveys conducted at the end of tutorials.

RESULTS

This Adaptive Tutorial enables blended teaching to be used in design with all the flexibility and targeted feedback that Adaptive Tutorials can provide.

CONCLUSIONS

Positive comments from students demonstrate the potential of the Adaptive Tutorials in the design environment. This will be further developed over the next 18 months through a major study support by OLT and involving seven different national universities.

KEYWORDS

Online Adaptive Tutorials, Design in engineering, eLearning

Introduction

‘Design’ has been widely considered as the essence of engineering, i.e. “to engineer is to design” (Wilczynski & Douglas, 1995), and it has been well established that “engineering programs should graduate engineers who can design effective solutions to meet social needs” (Dym, Agogino, Eris, Frey, & Leifer, 2005). Numerous efforts have been made to better-integrate design into engineering curricula (Carroll, 1997; Kartam, 1998; Kurfess, 2003), and to better-prepare graduate engineers for the industry (Todd, Magleby, Sorensen, Swan, & Anthony, 1995).

Current methods for teaching engineering design such as project-based and problem-based learning have been proven to be effective, as they are able to actively engage students in the learning process (Heywood, 2005). However they are costly to implement because they usually involve hands-on projects or design assignments in physical laboratories and/or workshops that require space, logistics, equipment, time and money which are always limited resources.

Educators around the world have been quick to adopt e-learning as an educational tool for engineering design. Some examples are the design of a bridge (Ressler and Ressler, 2004), a heat exchanger (Tan and Fok, 2006), and a shaft (Alvarez-Caldas et al., 2007). The advantage of teaching design through e-learning is that once the educational tool itself has been developed fewer resources are needed than with traditional project-based and problem-based learning approaches. However the challenge here is to develop a virtual environment that simulates a true engineering design experience.

Online Adaptive Tutorials (ATs), already well-established in engineering science courses, promise particular benefits for design education. As well as helping to overcome the constraints of limited resources ATs can *provide students with improved and personalised support when and where they want it*. However, due to the entirely different character of the design task from the science task, existing developments cannot simply be carried over into this new realm. Engineering science places a problem before students that is more or less predefined and has one expected outcome. In engineering design, *each student must devise their own solution to each design problem they face*. The problem factors to be analysed during the design process are difficult to specify at the outset, meaning that the tutorial guidance must adapt to the particular solution that each individual student devises. It is critical that guidance is not prescriptive and avoids the imposition of unwanted or unnecessary constraints on the student’s creativity.

The pilot study described in this paper used an Adaptive Tutorial to support the teaching of engineering design. Within this virtual environment students were provided with a partially constrained design task.

Experience from this study will be used in the next step, which is to develop a comprehensive on-line system of ATs covering the full design process. This is currently the subject of an eighteen-month study supported by Office for Learning and Teaching (OLT) and involving seven Australian universities.

Adaptive tutorials and the adaptive eLearning platform

This pilot study uses the Adaptive Tutorial system pioneered at The University of New South Wales (UNSW) (Ben-Naim, Marcus & Bain, 2009; Prusty, Ho & Ho, 2009). This technology has been in use since 2006 in engineering programs at UNSW where it has been found to be sustainable and effective in engineering science courses (Prusty et al., 2013).

Adaptive Tutorials (ATs) are web-based, intelligent and interactive eLearning tools which are implemented on an Adaptive eLearning Platform (AeLP). Two features of the Adaptive Tutorial are particularly attractive for teaching design:

1. The visual and interactive capabilities of the AeLP offer a virtual environment with interactive tools to better engage students in engineering design.
2. The Adaptive Tutorial provides timely feedback that is tailored to each student's actions and responses. This provides students with improved and personalised support when and where they need it.

Development of the AT

The aim of this study was to demonstrate how elements of structural mechanics are incorporated into the design process. To achieve this, the AT in this pilot study required each student to design the main beam for a gantry crane. Each student had their own set of loading conditions and access to the same set of choices for structural components. Their objective was to devise a solution to the design task, show that it will work and optimise it. There were three steps in developing the AT.

1. Storyboarding

The first step in developing the tutorial was to storyboard the pedagogical flow of questions, to achieve the following:

a. Application of mechanics concepts in design

The tutorial should demonstrate to students how various concepts (Free-Body Diagram, Shear Force and Bending Moment Diagram, Mohr's Circle) fit together in structural design. Students will experience improved learning by understanding the significance of these concepts when applying them directly in a design task.

b. Iterative nature of engineering design

The tutorial should also illustrate to students that the design process requires revisiting of their existing designs, either to increase the strength for safety requirements or to reduce the material used to decrease cost.

2. Developing Interactive Simulations

Using the software Adobe Flex Builder 4, the following tools were developed:

a. Randomising Tool

A tool was developed to randomise the parameters for the loading conditions. It was important that each student had a unique design problem.

b. Customisable Section Tool

Students were given four different sections to choose from: I-Section, C-Section, Rectangular Section and Circular Section. The Section Tools developed allowed students to design their own section by setting the dimensions for the section of their choice. Their designs were then visually represented according to the dimensions set, as shown in Figure 1.

The Section Tools were also designed to give students freedom for creative design. For example students could set the flange width of the I-Section to be the same as the web thickness, resulting in a T-Section. Similarly the C-Section could be modified to be an Angle-Section.

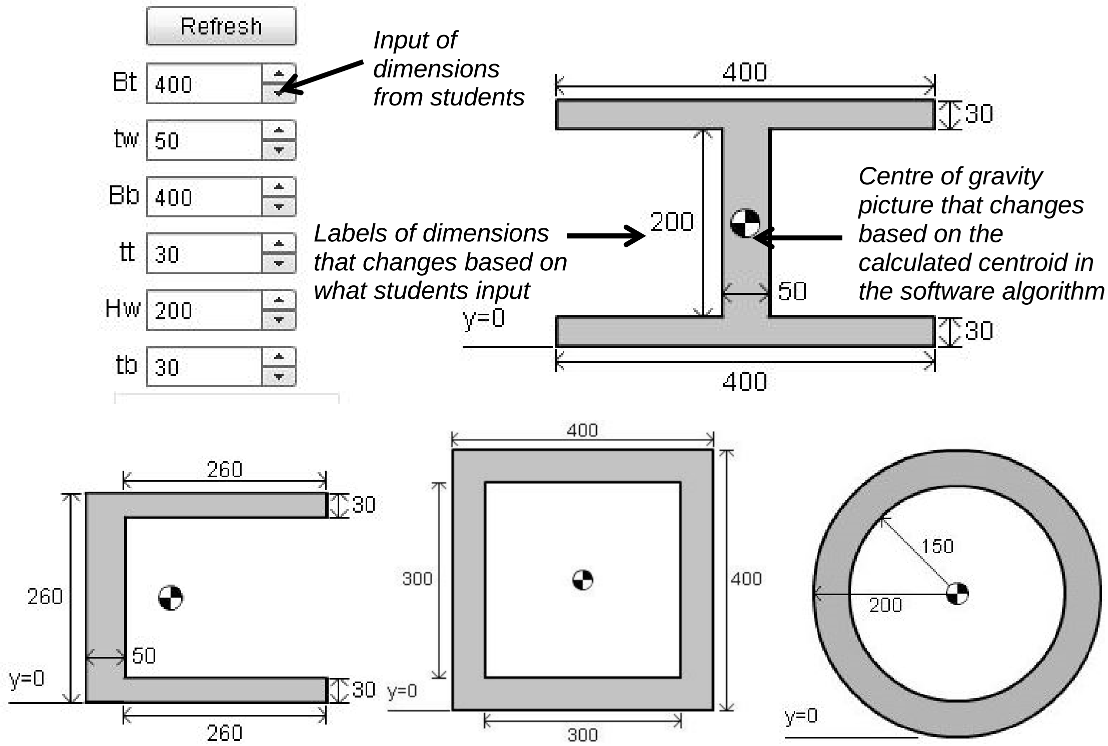

Figure 1: Section Tools developed for I-Section, C-Section, Rectangular Section and Circular Section

3. Tutorial Development in AeLP

The Design Adaptive Tutorial was developed in the AeLP authoring environment. At this stage, the questions with the corresponding feedback prepared from the storyboard were scripted and the simulations inserted.

Description of the AT

The layout of the Design Adaptive Tutorial is described below:

1. Problem Definition

The tutorial starts by describing the design problem at hand to the students (Figure 2). Students are to design the beam of a gantry crane that is safe under the given loading conditions. The gantry crane problem is chosen to allow students to undertake a design task that is simple yet highly applicable in the real world.

2. Preliminary Design

At this stage, students create a preliminary design of their beam by selecting the section type, setting the dimensions and choosing an appropriate material.

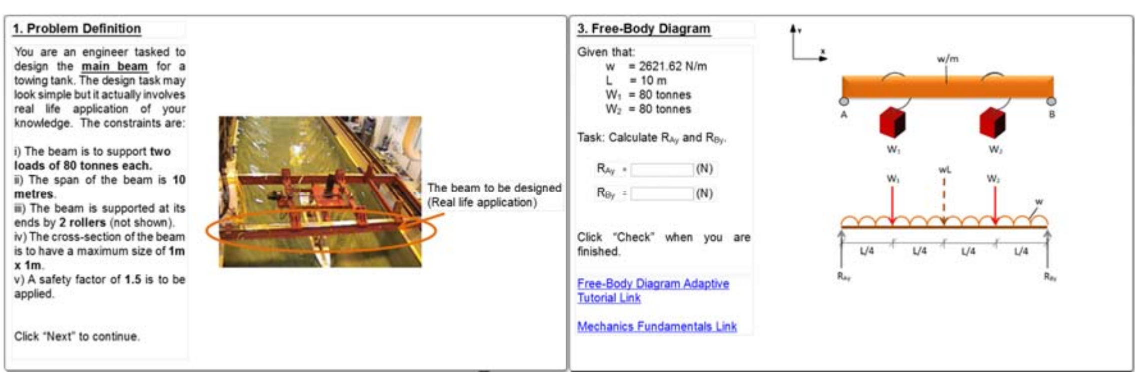

Figure 2: Problem definition (left) and Free-body diagram (right)

3. Design Analysis

With the preliminary design ready, students then proceed to analyse their design by applying Solid Mechanics concepts. Students start by calculating the reaction forces from the Free-Body Diagram (Figure 2), then obtaining the maximum shear force and bending moment (Figure 3), followed by calculating the maximum bending and shear stresses and finally using the Mohr's Circle to evaluate the principal stresses (Figure 3).

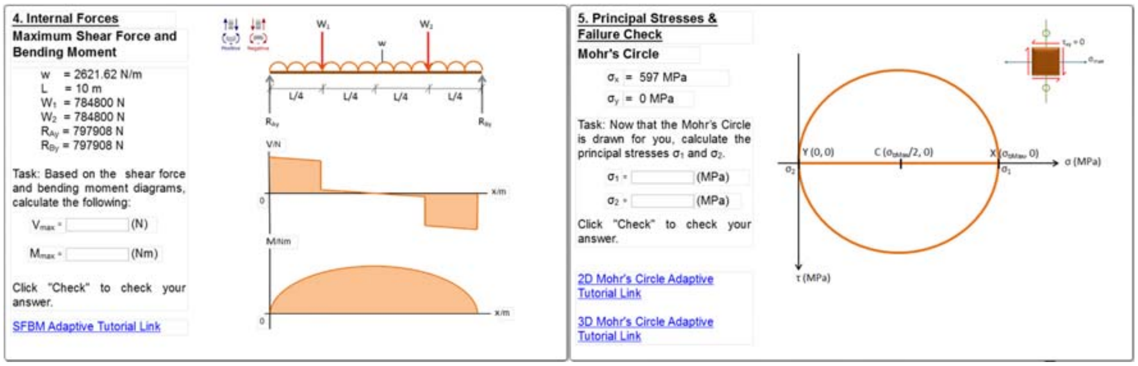

Figure 3: Shear force and bending moment (left) and Mohr's Circle (right)

4. Failure Check

This step allows students to check the safety of their design by comparing their design's maximum principal stress against the yield stress of their selected material (Figure 4). A safety factor of 1.5 is used.

5. Redesign/Optimisation

In the final stage of the tutorial, students are given the opportunity to improve their existing design (Figure 4). If their initial design failed, students can either modify or change their section to reduce the stress, or change the material to increase the yield strength. If their initial design is safe, students can reduce the dimensions of their section or use a cheaper material for optimisation purposes. This setting of various parameters allows students to design in an iterative and open-ended manner.

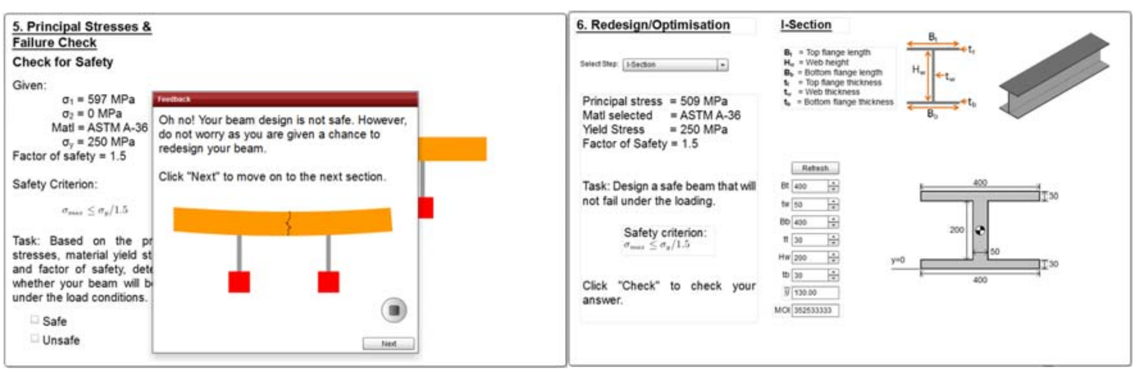

Figure 4: Failure check (left) and Redesign/optimisation (right)

Implementation

The Design Adaptive Tutorial was implemented as an exercise in a 2nd year Solid Mechanics course. It was released in 2012 and 2013, towards the end of the semester after the Solid Mechanics concepts had been taught to the students. Students' feedback on their experience of the Adaptive Tutorial was gauged by means of a simple questionnaire and open text feedback. For the 2013 release, a total of 304 students attempted the tutorial with an average mark of 92%. The survey data was collected for the 2013 release but not for the preliminary release in 2012.

Results and Discussion

The results of the survey are analysed as shown in Figures 5 and 6.

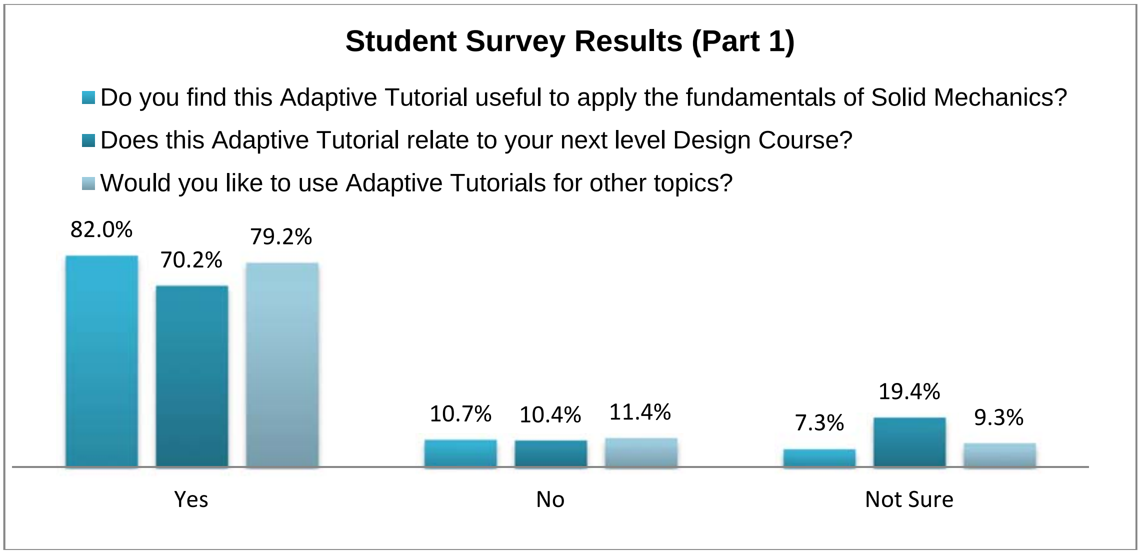

Figure 5: Student survey results (Part 1)

From Figure 5, the following can be inferred:

a. The tutorial successfully provided an environment conducive to applying Solid Mechanics concepts in a simple design task. This is further demonstrated by some of the student feedback below:

"The tutorial pinpointed some key aspects and fundamentals and allowed us to learn them in an easier way."

"Combined all steps FBD, SFD, BMD, Mohr's Circle etc. which gave me a good understanding on how to use all the calculations to design a simple problem."

"It was really interesting to see an actual application of what we learn in class to the design of a component."

b. The design approach introduced in this Adaptive Tutorial was perceived by students to be extendable to higher level design courses. The higher percentage of uncertainty (19.4%) may be because students have yet to actually take the higher level design. Some of the student feedback is as follows:

"It was one of the first examples of performing real world analysis."

"This will be vital to find the safe stresses in future design courses."

"This tutorial has explained how the material selection is carried out, which allows for the design of safe structures for low cost."

c. The Adaptive Tutorial is an effective learning tool that students would like to have for other courses as well.

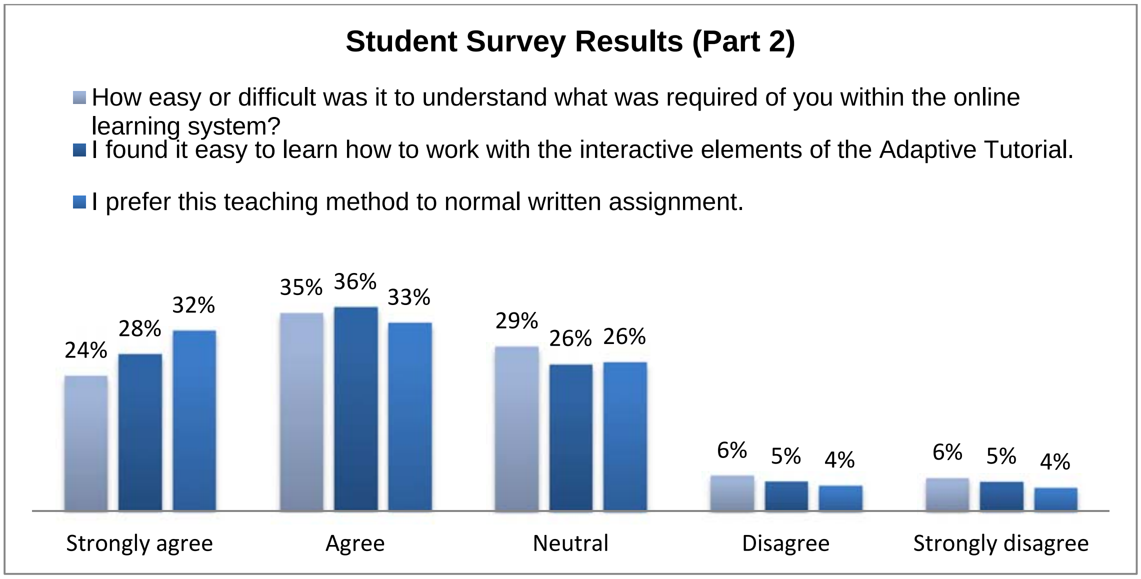

Figure 6: Student survey results (Part 2)

From Figure 6, the following can be observed:

a. The interactive tools developed for the Adaptive Tutorial were easy for students to work with. This allowed students to focus their learning on the actual design content rather than on the usage of the tool itself.

b. Positive response from students indicated a preference for using Adaptive Tutorials as a learning tool. This supports the usage of Adaptive Tutorials for teaching design.

Some of the student feedback is as follows:

> *"I have found this tutorial to be great, I have learned a lot. 1. Gave me a framework on how to approach problems 2. Visual connection between steps to solve the problem"*

Conclusion

An Adaptive Tutorial has been developed for a partially constrained design task that shows how structural mechanics can be applied in practice. It has been successfully implemented in a Solid Mechanics course. The tutorial was well-received by students with survey results indicating effectiveness in allowing students to apply Solid Mechanics concepts to a simple design task in an iterative manner. The students' positive response demonstrates the potential for the use of Adaptive Tutorials in the design environment. This pilot study will provide useful practical experience for a major eighteen-month project to extend ATs to the full design process.

References

Alliance for Excellence in Education. (2012). The Digital Learning Imperative: How Technology and Teaching Meet Today's Education Challenges.

Alvarez-Caldas, C., Garcia, J. L. S. R., Abella, B. M. & Gonzalez, A. Q. (2007). Educational software to design shafts and analyze them by FEM. *Computer Applications in Engineering Education, 15*(1), 99-106.

Ben-Naim, D., Marcus, N., & Bain, M. (2009). A User-Driven and Data-Driven Approach for Supporting Teachers in Reflection and Adaptation of Adaptive Tutorials. Paper presented at the Educational Data Mining 2009: 2nd International Conference on Educational Data Mining, Cordoba, Spain.

Carroll, D. R. (1997). Integrating Design into the Sophomore and Junior Level Mechanics Courses. Journal of Engineering Education, 86(3), 227-231.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering Design Thinking, Teaching, and Learning. Journal of Engineering Education, 94(1), 103-120.

Heywood, J. (2005). *Engineering Education: Research and Development in Curriculum and Instruction*. NJ: IEEE Press.

Kartam, N. A. (1998). Integrating Design into Civil Engineering Education. Journal of Engineering Education, 14(2), 130-135.

Kurfess, T. R. (2003). Producing the Modern Engineer. International Journal of Engineering Education, 19(1), 118-123.

Prusty, G. B., Ho, O., & Ho, S. (2009). Adaptive Tutorials using eLearning Platform for Solid Mechanics Course in Engineering. Paper presented at the 2009 AaeE Conference, Adelaide, Australia.

Prusty, G. B., Vrcelj, Z., McCarthy, T., Gardner, A., Ojeda, R., Russell, C., Khawaja, M. A. (2013). Final Report: An Adaptive e-Learning Community of Practice for Mechanics Courses in Engineering - CG10-1586. Australia: Australian Government, Office of Learning and Teaching. ISBN: 978-1-921916-73-1

Ressler, S. J. & Ressler, E. K. (2004). Using a Nationwide Internet-Based Bridge Design Contest as a Vehicle for Engineering Outreach. *Journal of Engineering Education, 93*(2), 117-128.

Tan, F. L. & Fok, S. C. (2006). An educational computer-aided tool for heat exchanger design. *Computer Applications in Engineering Education*, *14*(2), 77-89.

Todd, R. H., Magleby, S. P., Sorensen, C. D., Swan, B. R., & Anthony, D. K. (1995). A Survey of Capstone Engineering Courses in North America. International Journal of Engineering Education, 84(2), 165-174.

Wilczynski, V., & Douglas, S. M. (1995). Integrating Design Across the Engineering Curriculum: A Report From the Trenches. Journal of Engineering Education, 84(3), 235-240.

Copyright Statement