Sustainable Solutions in Structural Engineering and Construction
Edited by Chantawarangul, K., Suanpaga, W., Yazdani, S., Vimonsatit, V., and Singh, A.

ISBN: 978-0-9960437-0-0

ENGINEERING DESIGN EDUCATION AND TRAINING WITH PARTICULAR REFERENCE TO BRIDGE DESIGN

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This paper presents a case study of an undergraduate integrated civil engineering design project module. This module involved significant input from practicing structural engineers, civil engineers, and architects, leading to a holistic course of study taking into consideration technical, social, economic, and environmental issues. The teaching philosophy focused on engagement and motivation that concentrated on a) incorporating behavioral affective and cognitive dimensions, and b) providing appropriate support at the right time for maximum impact on learning. Educational theories related to acquiring skills, construction of knowledge based on cognitive apprenticeship, knowledge-scaffolding, and constructive alignment were explored and used in the design of the module. The assessment ensured engagement and motivation with clear support for just-in-time continuous formative assessment. Learning-diaries and minutes of design meetings were introduced as a tool contributing to knowledge-scaffolding. This paper presents a methodology of how the educational theories can be applied pragmatically for more effective education and training of engineers.

Keywords: Engineering education, Bridge design, Cognitive apprenticeship.

1 INTRODUCTION

Engineering graduate competences are increasingly questioned by employers. In response, there have been attempts to introduce problem-based learning (PBL) in engineering education. Brodeur et al. (2002) presented a good example of PBL in an Aeronautics and Astronautics program. The motivation to design engaging learning experiences and achieve active learning resulted in widespread use of PBL. The author's discussions with students in engineering programs in various universities indicated that while the aim is desirable, the design of learning activities for PBL was not appropriate. Furthermore, there was evidence that poorly-designed PBL was demoralizing and counter-productive. The construction and processing of knowledge is related to the students' knowledge base and how the connection and knowledge-activation is established. This paper was motivated by a desire to closely align the competences gained by the students with those required by the industry.

2 ACCREDITATION REQUIREMENTS FOR DESIGN EDUCATION

The Joint Board of Moderators (JBM) in the UK accredits civil and structural engineering courses for the Engineering Council UK under UK-SPECS output standards. The JBM produced guidelines for Design, Sustainable Development, and

Health and Safety in design education (Joint Board of Moderators 2014). A similar accreditation process in the United States is carried out by the Accreditation Board for Engineering and Technology (ABET), as discussed by College (2010) with respect to the Capstone project requirements.

In response to JBM accreditation requirements with respect to design and sustainable development, three modules were established within the degree program at the University of Portsmouth (UoP). The principles and concepts of holistic design were introduced progressively over three years of study. The specific modules related to the "Design Theme" were: first year: Introduction to Design; second year: Conceptual Design; and third year: Civil Engineering Design and Management Project. However, the holistic design modules did not operate in isolation; they relied heavily on knowledge gained in all subject areas, particularly structural engineering and professional skills.

3 UNDERPINNING EDUCATIONAL THEORIES

The planning of learning sessions and activities were based on generating a motivational need in the students. A local and national competition was involved, with prestigious prizes and industrial support in a dynamic PBL and Action Learning involving practicing engineers. PBL has been explored by a number of educationalists (e.g., Brodeur et al. 2002). A number of researchers explored and evaluated Cognitive Apprenticeship (CA) theory in various fields (e.g., Bouta and Paraskeva 2013). The application of CA, in supervision of engineering research assistants, was explored by Maher et al. (2013).

The fundamental aim of the module was to integrate engineering knowledge gained during the entire program of study. The integration of knowledge in relation to improving conceptual understanding was investigated by Chen and Bradshaw (2000), exploring issues related to Knowledge-Scaffolding (KS) in PBL projects. The improvement of learners' ability after implementing aspects of KS was evident in a number of studies (e.g., Dresner et al. 2013). The role of research diaries as a tool for KS was explored by Engin (2011).

Constructive Alignment (CA) theory attempts to achieve the desired learning outcomes and deep learning in the process of schema construct. The issues related to surface learning, which occur when the learning activities do not relate to the students' experience, was highlighted by Dames (2012). The development of expert competences is hugely important in vocational courses. The theory of Deliberate Practice (DP) related to improving competences and achieving expert performance was explored by Ericsson et al. 1993.

4 CASE STUDY: THIRD-YEAR DESIGN PROJECT

The author developed and started delivering this module during autumn 2007. The project was used as a vehicle to integrate the design theme with all other disciplines in the Civil Engineering Department. Emphasis was placed on creativity and imagination in developing and appraising design solutions, developing societal, technical, and team-work competences.

4.1 Client Brief

The 2008 bridge design brief was published by Corus (Figures 1 and 2). It asked for the design of a pedestrian and cycle link over a river through a city center. The bridge became necessary as a result of a brown-field development on one side of the river.

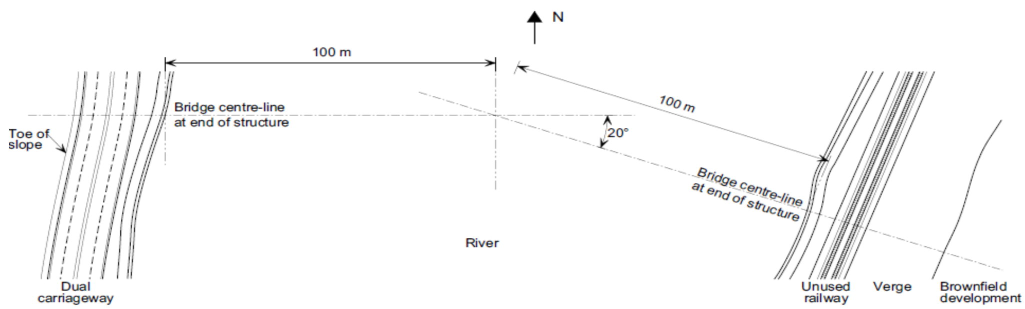

Figure 1. Site Plan: Corus Student Awards Bridges design brief, 2008.

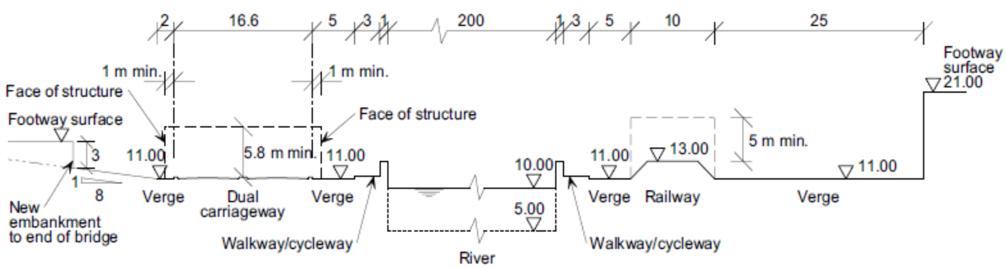

Figure 2. Cross-section of the river crossing along the center line of the bridge.

Students working in groups were appointed as a consultant to carry out an initial feasibility study and prepare a design report for the client. The report was required to propose two distinctive structural schemes with clear recommendations to the client justifying the preferred scheme. The report was also required to contain detailed structural design calculations for initial sizing and verifications for ultimate and serviceability limit state. The design brief also contained detailed clients' requirements related to site access, including disabled access.

The presence of a brown-field site on one river, as well as the fact that the river was not navigable, had implications for the construction methods. Future plans of the local authority to reopen the railway line were included. The clearance requirements and environmental impacts were aspects to be considered by the students. The brief contained very specific construction constraints related to the storage of materials, existence of the railway line, number and position of piers, and consideration for accidental impacts. In addition, the brief contained specific information related to structural behavior and design verification according to Eurocodes. Issues of materials, loading, substructure, and construction time rates and costs were also outlined in detail.

4.2 Contributions from Practicing Senior Structural Engineers

The author aimed at involving the industry at the planning stage of the module. Meetings took place with senior structural engineers and technical directors as well as human resources at Gifford (now Rambol). All aspects of the learning sessions and assessment were scrutinized by the author and industrial representatives. In addition to Rambol, a chartered engineer from Network Rail was appointed to provide tutorial support on aspects of practice and management of civil engineering projects. In addition, the author invited guest speakers from Atkins's Bridge Section, the Steel Construction Institute, and Mouchel.

The author brought aspects of structural engineering practice to the classroom. The typical presentations using PowerPoint were used to a limited extent during the introductory stage, and were in fact discouraged by the author. Instead, the author steered activity to include sessions when the practicing engineers attempted to simulate real-life design office activity. This involved the engineers analyzing a similar design brief with sketches and hand calculations in front of the students. This was followed by sessions when the engineers carried out detailed design calculations in real-time, including the inevitable mistakes.

The engineers also brought working drawings of their current projects to show the students the expected quality. The nature of assessment that was continuous throughout the module made it important to provide small-group tutorials. During such tutorials the students presented their concepts to the engineers and sought guidance. In the initial stages the tutorial sessions involved all the groups of students, but in the later detailed design stage, the support was given to individual groups in a focused manner.

4.3 Contribution from Architects

The inclusion of architectural design of bridges, and how bridges relate to the environment in terms of shape, function, lighting, and texture was fascinating for the civil engineering students. A Principal Lecturer from the School of Architecture in Portsmouth, a practicing RIBA (Royal Institute of British Architects) registered architect, was involved in the module and led relevant learning sessions. The architectural emphasis on developing iterative concepts to find the "beautiful idea" was highlighted. Details of the learning and teaching sessions are given in Table 1.

4.4 Continuous Assessment

The sessions, both as formal lectures and less-formal group tutorials, were designed to provide just-in-time learning motivated by strong emotional and intellectual needs. The level of engagement was evident in the approximately 100% attendance, as well as in the contribution to discussions and deep questioning. At the end of the module the students stated clearly that this method of assessment for learning was excellent for their motivation. Four continually-assessed submissions were included in the assessment strategy.

Table 1. Module learning and teaching sessions and contributors.

Week	Learning sessions with practicing structural engineers
1	Introduction to the unit. Defining the client's brief in engineering terms.
2	Bridge design concepts: Creative expression and aesthetics. Architectural perspective. Design: Is there a process?
3	Structural concepts for bridge superstructures and substructures.
4	High-performance steel bridges. Design criteria. Load-paths identification. Stability. Initial sizing of main elements. Bridge deck details.
5	Learning from bridge failures.
6 7	Bridge construction processes and details. Temporary works for bridge construction. Health and safety issues during the design stage. Sustainable development and societal issues.
8	Site visit: Clifton Bridge, First and Second Severn Bridge, Old Wye Bridge.
9	Structural design checks according to the codes of practice.
10	Bridge foundation.
11	Dynamics including wind engineering.
12 &13	Detailed design and reviews. Tutorials only.
14	Final Report and Interview.

For each submission, a detailed Task Descriptor was developed to include detailed learning outcomes, as well as a Grade Descriptor focusing on critical understanding and deep learning. The first three submissions involved groups of two students. The fourth submission involved two groups of two students merging into one group of four. The fourth submission was related to refining initial concepts and assessing various concepts against clear-design criteria on aesthetics, cost, buildability, health and safety, sustainability, and whole-life issues. Each group applied a decision matrix to short-list 4 concepts, then 2, and then arrive at the final concept for detailed design.

4.5 Final Assessment

During week 14, the final summative assessment consisted of two components accounting for 60% of the final mark, with equal weightings: group/individual interviews, and final submission. While the first four submissions were developed as a formative assessment, with more emphasis on learning and knowledge-scaffolding, the final assessment was mainly summative, but still included valuable feedback from all the teaching team. For the interview, each group was asked to produce two A1 working drawings of their final concept as well as a physical model. In addition, a number of students presented 3D virtual models with walk-through animations. The drawings were scrutinized by Paul Brown, a practicing structural engineer from Gifford, Jasper Baker (Network rail/UoP), as well as by the author. The student's performance during the interview significantly influenced the final mark.

The final submission included: a) design report, 35 A4 pages; b) structural behavior and design verifications calculations according to the code of practice, 35 pages; and c) two A1 drawings showing general arrangements with elevations, plans, sections and foundation loads, and various other important details. The final submission was color-coded to clearly identify individual contributions and confirm the individual assessment from the interviews.

5 CONCLUSIONS

The newly-developed module successfully satisfied the accreditation requirements set by the JBM. In addition, the students' output and the industrial input was praised and highlighted as an example of good practice by the visiting accreditation panel in autumn 2010. A high level of student engagement and motivation was achieved according to formal and informal feedback. A detailed learning diary for individual students as well as keeping minutes of group meetings were important elements of knowledge-scaffolding. This was also a useful tool to insure group members engaged equally with the task. A number of graduates who took this module realized the usefulness of this learning experience when they started working for the industry.

Acknowledgments

Contribution and support from Paul Brown, Martin Pierce, Ian Cross, Jasper Baker, David Iles, Bob Otter, Tom Wyatt, and Dominic Fox are gratefully acknowledged.

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