The why, what and how of teaching: an engineering design perspective

Daniela Pusca & Derek O. Northwood

University of Windsor
Windsor, Ontario, Canada

ABSTRACT: The why, what and how of teaching are examined from the perspective of teaching engineering design in an integrative learning environment. Why is the guiding vision and relates to why one reads or studies particular topics. It is the starting point of the learning process. Once why has been established, a backward design approach is utilised to formulate the what and how. What relates to the development of discipline-specific skills and competencies. The what for engineering design is considered from the perspective of the ability to a) generate new design solutions; b) improve existing design solutions; and c) manage design. How is the creative strategy that effectively supports transformative learning and can involve three other ws; namely, who, when and where. Successful engineering design education requires the active participation of students in all stages of the educational process.

Keywords: Engineering design, teaching, backward design, creative strategy, integrative learning, transformative learning

THE WHY, WHAT AND HOW OF TEACHING

In an opinion piece on integrative learning, Jessica Riddell has explored the why of teaching from her perspective as a professor of English [1]. Why - the guiding vision - is considered by Riddell to be the starting point of all our endeavours as learners. Riddell has given an eloquent description of the why in an integrative learning environment:

My present integrative self collaborates with students as they build their capacities to lead enriching and diverse lives. In this model, our learning goals focus on process. Together we build a guiding vision of why we read literature; namely, how studying Shakespeare’s plays, for example, challenges us to see the world through new lenses in order to develop both an in-depth understanding of ourselves and a deep appreciation for the disciplinary field. Our point of entry into strange and unfamiliar texts is to discover resonance with our lived experiences. Exploring our affective responses is the first step in a progression towards a more sophisticated critical approach, gradually moving away from what we already know into a realm of new knowledge(s) [1].

Riddell also acknowledges the need to consider the what and how of teaching. What is related to …building students’ capacities to master discipline-specific skills and competencies [1]. The how of teaching is related to …creating the conditions that most effectively support transformative learning [1].

Todd Henry in his book The Accidental Creative also emphasises the importance of first answering the why [2]. When faced with any problem/project, one must first ask why is one undertaking the work, i.e. teaching, and what purpose does it serve [2].

Further, Henry cites Jim Collins in his book How the Mighty Fall in which Collins claims that the first signs of the decline of many great companies is when they fail to recognise the why behind their day-to-day activities [3]. Henry also describes three other ws; namely, who, when and where [2]. These three ws might be considered to be part of how. Henry considers the how to be the creative strategy, and emphasises that one must make certain that why and what are aligned [2].

Figure 1 is a schematic summary of the why, what and how and their teaching/learning objectives.
Figure 1: Schematic of the why, what and how.

**WHY AND BACKWARD DESIGN**

Understanding the why first, is also the underpinning of backward design or understanding by design (UbD) [4-7]. As noted by Grant Wiggins and Jay McTighe in their book, *Understanding by Design* [4]:

> Teachers are designers. An essential part of our profession is the design of curriculum and learning experiences to meet specified purposes [4].

Wiggins and McTighe advocate a backward design approach to curriculum planning:

> One starts with the end - the desired results (goals or standards) and then derives the curriculum from the evidence of learning (performances) called for by the standard and the teaching needed to equip students to perform [4].

Wiggins and McTighe acknowledged that the logic of backward design had been clearly and succinctly described by Ralph Tyler in 1949 [8]. Tyler identified four fundamental questions, which must be answered in developing any curriculum and plan of instruction, namely:

1. What educational purposes should the school seek to attain?
2. What educational experiences can be provided that are likely to attain these purposes?
3. How can these educational experiences be effectively organized?
4. How can we determine whether these purposes are being attained? [8]

A comparison of the four questions posed by Tyler [8] with Figure 1 readily shows that Question 1 is the why in Figure 1, i.e. the guiding vision of Riddell [1]. Question 2 and Question 3 correspond to the what and how, respectively, in Figure 1. Question 4 relates to assessment and understanding. Wiggins and McTighe have described understanding as:

> Understanding is revealed as transferability of core ideas, knowledge, and skill, on challenging tasks in a variety of contexts [4].

The assessment of understanding is also a backward design process. As succinctly described by Tyler Coolidge Wood:

> ...we need to figure out what understanding looks like and develop the evidence we need to show the students have understood, then design the assessments before the actual lesson [9].

The importance of answering the why question first cannot be overemphasised [1][2][4]. Wiggins and McTighe in Chapter 1 of their book, *Understanding by Design* [4] use a quote from Stephen R. Covey [10] to begin the chapter:

> To begin with the end in mind means to start with a clear understanding of your destination. It means to know where you’re going so that you better understand where you are now so that the steps you take are always in the right direction [10].

Tyler’s original (1949) rationale and his four fundamental questions for curriculum development [8] has been subject to criticism but still ranks as one of the most influential writings in curriculum development [11]. In the 1970’s, Tyler started a revision to his 1949 rationale, but it was unfinished. Recently, Stanley [11] has examined the Tyler Rationale and the 1970’s revision and has concluded:

> The most notable change in Tyler’s 1970’s proposals for curriculum development was a greater emphasis on the learner as a source for deriving educational purposes. This change indicated Tyler’s increased commitment to the active participation of the student in the educational process [11].
As already discussed, Riddell strongly emphasises the importance of active student participation, i.e. integrative learning [1]. Both student and the teacher are learning. In a learning-centered campus, student learning is the most significant goal of the university [12]. Thus, students should always be kept first in mind when addressing the why question, as well as the what and the how.

THE WHY, WHAT AND HOW OF TEACHING ENGINEERING DESIGN

A key challenge for the instructor in engineering design education is to correctly address the question: why should students study the topic of engineering design? At the University of Windsor, this guiding vision is that the students will develop:

An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, economic, environmental, cultural and societal considerations.

In considering the what, which is the development of discipline-specific skills and competencies, the authors have considered engineering design from three perspectives:

- ability to generate of new design solutions;
- ability to improve existing design solutions;
- ability to manage design.

Table 1 summarises what methods and techniques have been integrated in the context of teaching and learning at both the undergraduate and graduate levels. The question what, in the authors’ opinion, should also consider the intent associated with the adopted approach; namely, whether one is preparing undergraduates for graduate school, the workplace or both. Tomiyama et al argued that there is a critical difference:

The key point in design education is to learn how to design. On the other hand, industrial focus in design of products and systems is design itself[13].

The engineering design stream for undergraduate courses offered from the first year to senior year follows the curriculum requirements regarding learning outcomes. The main goal in the teaching and learning process during the first and second years is to guide the students in the engineering design process for product design, and the main goal for the students is to learn the basics of the engineering design process and engineering design tools. These design methodologies …focus more or less on functional design and embodiment design, rather than how to achieve concrete performance goals such as cost, quality, and time, and as mentioned by Tomiyama et al, find less industrial application [13].

This is because …innovation in functional design and embodiment design is less necessary, since industry requires mostly design improvement, with a focus on reducing cost, and increasing quality and variety of products, to meet changing market demands. Design methodologies that are taught in the junior years find less industrial application since that they do not emphasise innovative design, but they have educational value, in helping students to easily understand fundamental concepts and to organise knowledge related to product development activities.

In Table 1, under how, the authors briefly summarise the creative strategies used to support a transformative learning process. As noted, since how involves three other ws; namely, who, when and where [2], the last column in Table 1 outlines the level (undergraduate or graduate) and engineering programme of the students.

Integrative learning as used in the case of engineering design courses is about making connections between academic knowledge and engineering practice, and this requires active involvement of both the student and the instructor. As mentioned by Loris Malaguzzi:

Learning and teaching should not stand on opposite banks and just watch the river flow by; instead they should embark together on a journey down the river. Through an active, reciprocal exchange, teaching can strengthen learning how to learn [24].

To support integration, the design courses require students to work on engaging problem-based projects that can be mainly classified in two categories:

- Service learning: students’ projects address identified community needs or global issues;
- Applied research projects: students’ projects address specific business or industry problems.

These projects allow students to take different perspectives on an issue, and/or to draw on learning from earlier courses to solve a problem. As part of these experiences, students are also asked to prepare e-portfolios in Blackboard, the current learning management system employed at the University of Windsor. This practice allows the students to
reflect on their learning process, and reason on the connection between their work, the learning outcomes, and the skills gained.

Table 1: What and how in engineering design.

<table>
<thead>
<tr>
<th>What</th>
<th>How</th>
<th>Who? When? Where?</th>
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| • For the generation of new design solutions | Design based on creativity [14] | - Brainstorming  
- Analogy  
- Biomimetics | First year: general engineering, teamwork |
| | Mechanical design process [15] | - Needs assessment  
- Problem formulation  
- Abstraction and synthesis  
- Analysis  
- Implementation | First year: general engineering  
Second year: mechanical, automotive, industrial engineering |
| | Case based reasoning [16] | - Case studies | Second year, third year, fourth year: mechanical, automotive, industrial engineering |
| | Systematic engineering design and practice [17] | - Planning and task clarification  
- Conceptual design  
- Embodiment design  
- Detail design | Graduate level: mechanical, industrial engineering |
| • For analysis of attributes and functions to improve existing design solutions | Axiomatic design (AD) [18] | - Independence axiom  
- Information axiom | Graduate level: mechanical, industrial engineering |
| | Quality function deployment (QFD) [19] | - House of quality tool | Fourth year and graduate level: mechanical, automotive, industrial engineering |
| | Failure mode and effect analysis (FMEA) [20] | - Design FMEA  
- Product FMEA | Fourth year and graduate level: mechanical, automotive, industrial engineering |
| | Design for X (DFX) [21] | - Variety  
- Quality  
- Manufacturing and assembly | Fourth year and graduate level: mechanical, automotive, industrial engineering |
| • For design management | Concurrent engineering (CE) [22] | - Product lifecycle management  
- Product data management  
- Product manufacturing management | Fourth year and graduate level: mechanical, automotive, industrial engineering |
| | Design structure matrix method (DSM) [23] | - Network modelling tool for managing complex systems | Fourth year and graduate level: mechanical, automotive, industrial engineering |

The role of the e-portfolio is to make students more self-aware about their studies, so that they can answer the questions: why they need to study a certain topic; what design method or technique is suitable for a specific requirement; and how it might be solved. Students’ engagement in activities that encourage learning by doing, followed by reflection on what was done, has been shown to better prepared students for the workplace [25-27].

The advances in digital engineering, virtual engineering and globalisation in product development, are important factors that must be considered when shaping the content of engineering design courses and implementing design theories and methodologies to address the what and how, and to better prepare graduates for the market demands. The overall skills, knowledge and abilities acquired during the learning experience at each degree level must resonate the employers’ expectations. Pusca and Northwood have emphasised elsewhere that …the content of engineering design education should be continuously revised to ensure that graduates possess the knowledge, skills and capabilities required for a global engineer [28]. There should be communication and collaboration between educators, students and industry...
representatives, so that the needs of each party can be addressed. The results of this collaboration can be used as inputs to both formulate the why as the guiding vision, and to shape the skills as required by today’s global market.

In a continuing effort to address the existing gap between school and workplace, several initiatives have been implemented that have had a positive effect in design education:

- Experiential learning and co-operative education [29];
- Active learning and students engagement through hands-on activities that require the use of the same digital tools used by practicing engineers to create virtual or physical models [27];
- Integration of information and communication technologies [30].

CONCLUDING REMARKS

Teaching engineering design in an integrative learning environment has been examined from the viewpoints of why, what and how. Why is the guiding vision, i.e. Why study engineering design?, and is the starting point for the learning process. Why has been defined, in part, with respect to students’ (graduates’) capabilities to design systems, components or processes to specific needs and requirements. What is the development of the discipline specific skills and competencies. How is the creative strategy that is adopted and which supports transformative learning.

When developing the what and how, the authors have considered whether they are preparing undergraduates for graduate school, the workplace or both. The overarching guidelines for success in the learning process are that one must first define the why, and then ensure that there is an alignment between the why and what. Only then can one design the creative strategy that leads to transformative learning. The importance of first answering why was simply expressed by John Lennon in the lyrics to the song, how?

How can I go forward when I don’t know which way I’m facing [31].

REFERENCES


**BIOGRAPHIES**

Daniela Pusca, PhD, is a Learning Specialist in Engineering Education in the Department of Mechanical, Automotive and Materials Engineering at the University of Windsor, Ontario, Canada, and she is teaching engineering design courses. She has earned her doctorate in technological equipment design from Cluj Napoca University (Romania) and a BSc in mechanical engineering from Lucian Blaga University of Sibiu (Romania). She is a licensed Professional Engineer in Ontario (PEng). Her educational background is mechanical engineering and engineering education. From 1986 until 1999, she was a lecturer at Lucian Blaga University of Sibiu, where she was teaching machine design courses and was involved in research projects on a wide range of topics. In 2000, she became part of the Mechanical, Automotive and Materials Engineering Department at the University of Windsor. She has written numerous research papers on innovative educational practices, and has published over 50 papers in refereed international journals and conference proceedings in the field of engineering design, engineering technology and engineering education, and she is a member of World Institute for Engineering and Technology Education (WIETE).

Professor Derek Northwood is Distinguished University Professor and Professor of Engineering Materials in the Department of Mechanical, Automotive and Materials Engineering at the University of Windsor, Ontario, Canada. Professor Northwood has earned a doctorate in crystallography from the University of Surrey (UK) and a BSc (Eng) in engineering metallurgy from the Imperial College, University of London (England). He is a licensed Professional Engineer in Ontario (PEng) and is a Chartered Professional Engineer (CP Eng; NER) in Australia. In the 40+ years as an academic, Professor Northwood has held various administrative positions including Department Head, Dean, Associate Dean of Research, Director of the Office of Research Services, President of the Industrial Research Institute, and, Research Leadership Chair, both at the University of Windsor and Ryerson University, Toronto, Canada. Professor Northwood has taught, researched and facilitated joint research and educational programmes at 14 universities worldwide, including the UK, USA, Australia, Taiwan, China, Singapore and Canada. He has published over 650 papers in refereed international journals and conference proceedings on a wide range of topics including materials and their applications, and engineering and technology education. He has been elected Fellow of five international professional societies in Australia, Canada, the UK and USA; namely, Fellow of the Royal Society of Canada (FRSC); Fellow of the Institution of Engineers Australia (FIEAust); Fellow of the World Institute of Engineering and Technology Education (FWIETE); Fellow of the Institute of Materials, Minerals and Mining (FIMMM); and Fellow of ASM International (FASM).