Volume 19, Number 2, 2017

Global Journal of Engineering Education

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

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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 disciplinary-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 Fail* 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.

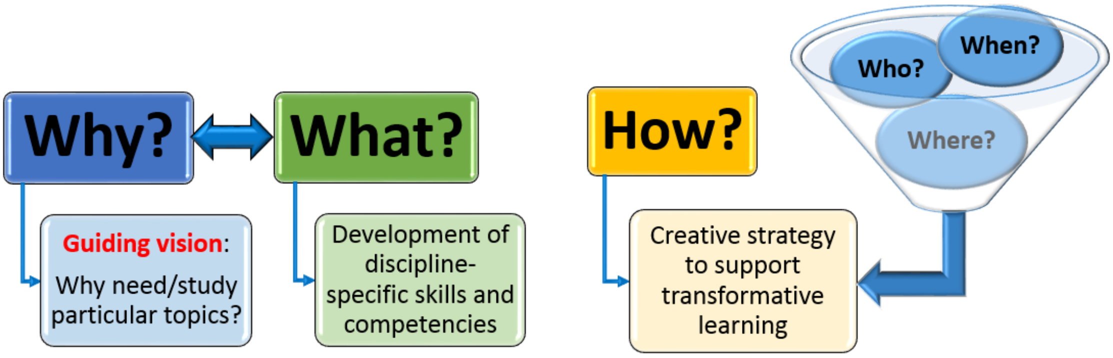

Figure 1: Schematic of the *why*, *what* and *how*.

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.

What		*How*	*Who? When? Where?*
• 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].

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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 an earned 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).