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Educational initiatives

The role of paradigms in engineering practice and education for sustainable development

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ABSTRACT

Engineers have always had to deal with complex challenges. However, a profound change has occurred over the last two decades with a realization of the need to transition from a focus on technical issues to sustainability problems that require an integrated, adaptive and participatory approach. Such an engineering approach does not only necessitate new methods and tools, but also the consideration of epistemology to deal with different kinds of knowledge and high uncertainties. The concept of paradigms can support the case-specific analysis of concrete solution strategies based upon an understanding of the epistemological dimension of sustainability issues. A systematic and integrated discussion of paradigms and their interactions in engineering practice is currently lacking in the scientific literature. This paper examines the role of paradigms in engineering practice and presents a system science approach for the analysis of paradigms. A case study on sustainable flood management and a literature analysis are provided to show the relevance of multiple paradigms in sustainable development issues. Engineers should be aware of paradigms and their respective application context, as well as the particular role of the “community involvement” paradigm for sustainable development. We propose an iterative learning approach to continuously deepen students' understanding of participatory processes and develop their ability to facilitate stakeholder processes. An overview and some reflections on the experiences of the authors in the teaching of these new paradigms at McGill University, Canada, and the University of Osnabrueck, Germany, are provided. In particular, group model building exercises were found to provide students with important experiences regarding stakeholder interaction in the safe space of the classroom.

1. Introduction

Engineering practice and education need to be revised continuously to address technical and methodological innovations, and to react to the challenges and demands of changing environments and societies. Engineering is not built upon a specific set of theories, but its concepts, methods and tools are evaluated in terms of their usefulness to solve contemporary engineering problems. In this way, the classical engineering fields of civil and mechanical engineering have been expanded by the fields of electrical, chemical, biological and ecological engineering, amongst others. This practical orientation has made engineering a very effective and flexible problem solving approach. Koen (2003) defines the engineering method as “the use of heuristics to cause the best change in a poorly understood situation within available resources“. This definition highlights that engineers often cannot build upon a complete knowledge of a particular system, and have thus developed heuristics to find the best possible solutions. Heuristics can be understood to be anything that provides a plausible and tested aid or direction in the solution of a problem, such as the application of an empirical equation or the use of safety factors.

This nature of the engineering method is also reflected in the evolution of engineering curricula. In recent years, traditional engineering education in such areas as material science and construction has been complemented with education in ecology, economics, stakeholder participation or ethics in order to react to new challenges in the engineering profession (cf., Bordogna et al., 1993; Woodruff, 2006). One of the more recent challenges in

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engineering practice and education is the consideration of sustainable development issues (as well as related issues such as climate change, increasing complexity, etc.). Sustainable engineering comprises a life-cycle perspective and consideration of ecological, economic, and socio-cultural aspects (Maydl, 2004; Halbe et al., 2014; Inam et al., 2015). The implementation of engineering for sustainable development requires a multi- and interdisciplinary approach, knowledge integration, higher levels of thinking, and the ability to organize dialogues with a range of stakeholders (Kumar et al., 2005; Woodruff, 2006; Bergeå et al., 2006; Bagheri and Hjorth, 2007). Sustainability related tasks often have the character of 'messy' problems which are indicative of the diverging opinions regarding the definition of the problem and potential solution strategies (cf., Ackoff, 1974; Vennix, 1996). Dealing with such complex problems requires higher levels of reasoning that builds upon an acceptance of incomplete knowledge and context-dependent evaluation of available data (King and Kitchener, 2002). Systems thinking, epistemological reflection, and real world experiences are seen as critical ingredients for higher levels of reflection (Bergeå et al., 2006).

This article suggests paradigms as a helpful concept for engineering students and practitioners to reflect on the linkage between epistemological aspects and case-specific solution strategies. Paradigms comprise our basic assumptions about how the world works, including perceived risks, our goals, and the solution strategies we consider. An ignorance of underlying paradigms can lead to miscommunication and subsequent management problems. For example, the prevalent "predict and control" paradigm in engineering can constrain participation of stakeholders to merely information provision or consultation events, which can frustrate stakeholders who expect to be more meaningfully involved (Tippet et al., 2004). The relevance of paradigms in engineering education and practice have been explored by some scholars (e.g., Mulder, 2006), but a systematic approach for the comprehensive analysis of their relevance and interactions in real-world issues is currently lacking.

This article presents a method for the case-specific elicitation and analysis of paradigms, and an approach to teach the relevance of paradigms at the university level. Problem-based learning is a suitable approach to develop expertise in dealing with complex problems (cf., Savery, 2006), and is thus chosen to support students in the development of a deeper understanding of the context-dependence of knowledge and context-dependent application of paradigms. Following Sheppard et al. (2009) who described an ideal learning trajectory to be "spiral, with all components revisited at increasing levels of sophistication and interconnection", we propose an iterative approach that starts with lectures to introduce concepts and methods, and continues towards group exercises that combine role-playing games and participatory model building (using systems thinking) to sensitize students to different worldviews and their handling in participatory processes. Finally, students explore the applicability of concepts and methods in real world problem situations. Here, students learn how to facilitate multi-stakeholder processes by systematically collecting and analyzing their problem frames and moderating group discussions.

The article is structured as follows: First, a definition of paradigms and a methodology for their case-specific elicitation and analysis are presented. A case study on flood management provides an example of the application of the methodology and reveals the interrelatedness of paradigms that often occur in sustainability issues. Further, a literature review examines the prevalence of each of these paradigms in engineering practice and education. Based on the experiences of the authors, a combination of lectures, exercises and projects are finally proposed to teach these innovative concepts and methods at the university level.

2. Paradigms in engineering for sustainable development

Several new paradigms have been proposed for sustainable engineering. For example, Brandt et al. (2000) highlight the paradigm of clean technology that is aimed at the minimization of resource consumption and wastage during production processes and the product life-cycle. However, relying on only technical solutions is not sufficient to solve sustainability problems since human aspects of engineering systems (e.g., organization of a company, awareness of stakeholders on environmental issues) also need to be addressed. In addition to the human dimension, the inter-linkages between technical systems and ecosystems are another component of sustainable engineering which has resulted in the development of new methods and tools (cf., Mitsch, 1998; Matlock and Morgan, 2011).

The evolution of engineering approaches from a strong technical focus towards a more integrated perspective also requires new approaches in engineering education. This implies changes in the curriculum such as the inclusion of topics like listening and communicating to communities (Lucena et al., 2010), or material and energy flow analysis (Briefs and Brandt, 2002). Mulder (2006) proposed a sustainable technological development paradigm that advocates that engineers should join public debates and closely interact with stakeholders (e.g., customers and politicians, amongst others). Thus, participatory approaches and project-based learning need to be included in engineering curricula (see also Lenschow, 1998). Several pedagogical approaches have been developed in the field of education for sustainable development, such as interdisciplinary learning, or problem-based learning (Dale and Newman, 2005). Problem-based learning is a widely applied learning approach in education for sustainable development that "empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" (Savery, 2006, p. 12). Problem-based learning aims at motivating students and fostering deep learning and professional development, which can also be a first step towards a new culture within university departments that profoundly affects research and community activities (Hadgraft, 1998). Litzinger et al. (2011) also highlight that effective learning experiences need to be integrated across the entire curriculum. Wals (2014) concludes that such systemic changes in higher education institutions (HEI) are beginning at a broader scale by integrating sustainability elements in existing curricula or even designing new curricula. A paradigm change from prescriptive education to empowerment-oriented education (Læssøe, 2010) does not necessarily require an immediate removal of existing structures which would face substantial barriers (cf., Lozano, 2006; UN-DESD, 2006). Sterling and Thomas (2006, p. 349) underline the importance of even small and stepwise change through "curriculum ideas that any HEI can begin to implement, ideally as a precursor to deeper change".

Paradigms describe the often unconscious assumptions of people about the nature of the world ("worldview") and potential ways to take action. New paradigms emerge due to the inability of conventional approaches to address contemporary challenges. As shown by the examples above, sustainable engineering requires profound changes in engineering practice and education. However, the meaning of the term 'paradigm' is unclear in the literature, and denotes different aspects such as the need for a broader perspective on engineering problems, new skills or methods. In addition, most articles highlight the shortcomings of conventional engineering and advantages of a paradigm change rather than offering a more differentiated picture of the application areas. Therefore, a more systematic analysis of paradigms is helpful to (a) establish a thorough definition of the term and, based upon this, (b) develop a

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