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Integrating environmental sustainability in undergraduate mechanical engineering courses using guided discovery instruction

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ABSTRACT

In this paper we discuss a guided discovery instruction approach for integrating environmental sustainability in undergraduate mechanical engineering courses. To validate the proposed approach, we conducted two studies with students in a computer-aided design and prototyping course. The first study verified the feasibility of incorporating guided discovery instruction for teaching environmental sustainability using a structural shape synthesis design task. The second study compared the influences of the guided discovery instruction approach and traditional lecture-based instruction on students' understanding of environmental sustainability concepts. Results show the guided discovery instruction approach facilitated a better understanding of interactions among design parameters and the resulting environmental impact. We also found that students in the guided discovery instruction group gave more prominence to modifying design parameters specific to mechanical engineering concepts taught in the course. These findings suggest that using guided discovery instruction to teach environmental sustainability in undergraduate mechanical engineering courses is beneficial for promoting students' understanding of complex relationships between domain-specific design parameters and environmental sustainability.

1. Introduction

Incorporating ES learning has become one of the primary goals of engineering curricula (Accreditation Board for Engineering and Technology, 2013). In a survey of institutions with engineering programs conducted in 2009, 80% of respondents reported some level of activity with regards to ES (Murphy et al., 2009). There is also a growing demand in industry for engineers with skills in sustainable technologies. A survey by the ASME and Autodesk research has shown that approximately 60% of the 4000 respondents from engineering organizations expected an increase in their organizations' involvement in sustainable design the following year (American Society of Mechanical Engineering, 2010). Along similar lines, the Green Technologies and Practices survey conducted by the United States Department of Labor in 2011 indicates that three-quarters of business establishments use at least one green technology or practice (Bureau of Labor Statistics and United States Department of Labor, 2011). To promote engineering students' ES skills, they need to learn to consider ES as an integral part of the engineering design process. This requires ES to be integrated into the fundamental engineering courses in a manner that enables students to explore complex relationships between domain-specific design parameters and the resulting ES outcomes. To this end, instructional approaches in such courses need to facilitate deep understanding of such relationships and support conceptual change in students' mental models of ES.

Building on theories in constructivism, guided discovery has been advocated as an effective approach for promoting conceptual understanding of theories and principles (de Jong, 1991). Different from lecture-based instruction that directly provides target information to students, guided discovery instruction encourages students to construct knowledge through guided inquiry processes (de Jong and Lazonder, 2014). The discovery learning process resembles real-world science knowledge acquisition, where students go through the hypothesis generation, planning, experimentation, and evaluation stages (Rivers and Vockell, 1987). The presence of guidance is indispensable in discovery learning: students achieved greater learning gains in classrooms with a greater degree of

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List of acronyms & abbreviations

Al	Aluminum 2036
ANCOVA	Analysis of covariance
ASME	American Society of Mechanical Engineering
C#	design constraint number #
CAD	computer-aided design
CI	cast iron GGL-NiCuCr
CNC	computer numerical control
CS	carbon steel 35S20
EI	cradle-to-gate environmental indicator
ES	environmental sustainability
ESBP survey	survey on students' background in environmental sustainability and perception of environmental sustainability concepts
ESDQ	environmental sustainability design questionnaire
ESIP survey	survey on students' perception of instruction approaches used in teaching environmental sustainability
FEA	finite-element analysis
HSS	high speed steel
LCA	life cycle assessment
ME	mechanical engineering
ME444	undergraduate mechanical engineering course on computer-aided design and prototyping at Purdue University
RQ#	research question number #
S1	study 1
S2	study 2
Wt	weight

guidance compared with unguided discovery or direct instruction approaches (Furtak et al., 2012).

Previous research has shown that guided discovery instruction can be a more effective means for learning relationships across concepts compared to direct instruction (Alfieri et al., 2011). This is relevant for ES learning as it also involves understanding complex and often implicit relationships across domains. To this end, our work focuses on developing a guided discovery instruction approach for teaching ES within existing undergraduate ME courses. Using the proposed guided discovery approach, we conducted two studies with students in an undergraduate ME course and explored the following research questions.

RQ1: Is there a need for contextualizing ES learning to specific undergraduate ME courses?
RQ2: What are students' perceptions on using the guided discovery instruction approach to teach ES in undergraduate ME courses?
RQ3: What are the influences of the guided discovery instruction approach and traditional lecture-based instruction on students' understanding of ES?

The contributions of this paper, include (1) a guided discovery instruction approach for teaching ES in undergraduate ME courses, (2) an example application of the instruction approach using a shape synthesis design task that allows students to explore interdependencies in ES and domain-specific design variables, and (3) study setup, analyses, and results comparing guided discovery and lecture-based instruction for teaching ES in an undergraduate CAD and prototyping course.

2. Related literature

In this section we review previous work that has developed ES-focused instruction approaches within engineering curricula. We also discuss previous research on guided discovery instruction.

2.1. Instruction approaches for integrating ES learning in engineering curricula

ES has been incorporated into engineering curricula by developing new engineering courses focused on ES (e.g., courses on sustainable product design and renewable energy), integrating ES concepts into traditional engineering courses, introducing self-directed learning modules on ES (e.g., Autodesk Sustainability Workshop (Faludi and Menter, 2013)), and allowing students to opt for ES-related electives offered in other departments.

Pioneering efforts in sustainability learning focused on developing holistic approaches to increase awareness of interdependencies at the system level. Tilbury (1995) states that environmental education for sustainability should focus on developing closer links between environmental quality, ecology, socio-economics, and the underlying political threads. Reorienting education for promoting sustainable development is discussed by Fien and Tilbury (2002). Their primary focus is the development of an educational system for learning the knowledge, skills, perspectives, and values, that motivate people to lead sustainable livelihoods. Similarly, Ashford (2004) argues that sustainability learning should be interdisciplinary in nature to broaden the “design space” for engineers.

Previous research has also focused on developing courses, workshops, games, and practical experiences that promote active learning of ES concepts (Brundiers et al., 2010; Dieleman and Huisingh, 2006; Brewer et al., 2011; Gennett et al., 2010). Such efforts make ES learning more immersive, which is seen as an important focus for sustainability education (Pappas et al., 2013). Approaches such as learning through reverse engineering products (Hesketh et al., 1997) and cyberlearning modules based on constructionism (Kim et al., 2017) have also been explored for better integrating ES concepts into product design. Project-based learning and problem-based learning have also been used by researchers to integrate ES in university curricula (Steinemann, 2003; Ameta et al., 2010; Bernstein et al., 2012). A comparison of goals and approaches in problem-based learning adopted by multiple universities is discussed by Huntzinger et al. (2007). A majority of such approaches focus on introducing systems-level problems, such as spill cleanup (Hmelo et al., 1995), water conservation (Steinemann, 2003), and energy management (Bremer et al., 2010). Therefore, they are more suitable for teaching systems modeling and life-cycle thinking, rather than teaching relationships between specific design parameters and the resulting environmental performance. To bridge this gap, researchers have argued ES learning should be integrated into fundamental engineering classes.

Peet et al. (2004) noted that students find it difficult to integrate sustainable development into engineering practice unless the learning activities are incorporated in regular course work. Olsen et al. (2015) agreed that ideally engineering students should learn to consider sustainability in everything they do. However, the authors argue that time constraints, consideration of sustainability as a soft skill, organizational challenges, and academic cultural hurdles preclude this possibility. Kumar et al. (2005) concluded that sustainability education should be integrated into the design and