

**AC 2009-345: STUDENTS' ATTITUDES AND THRESHOLD CONCEPTS
TOWARDS ENGINEERING AS AN ENVIRONMENTAL CAREER: RESEARCH
BY PARTICIPATORY DESIGN OF AN EDUCATIONAL GAME**

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Students' attitudes and threshold concepts towards engineering as an environmental career: Research by participatory design of an educational game

Abstract

The overall purpose of the research described in this paper is to research the attitudes and threshold concepts (key concepts or gate keeper concepts) of beginning engineering students towards the relationship between environment/ecology and engineering specifically towards choosing: either (a) engineering as a career to make an environmental impact or (b) choosing environmental and ecological engineering as a specific engineering profession. The project is situated in the context of life cycle analysis and the environmental impacts of design, manufacturing, use and disposal of products. The study employs also an innovative research design: The researchers investigate students' conceptions and attitudes (and change of both) by asking students to co-design an educational game with them – through a series of workshops. Of particular focus will be the change of students' conceptual understanding of core environmental and ecological concepts during the design process. We report the results of a survey of 1700 first-year engineering students at the Purdue University, West Lafayette campus. The survey tested student knowledge of environmental issues, their prioritization of sustainable development in various contexts, and also explored student attitude toward change. The results of this survey are combined with high school academic performance data and demographic data to determine how formal curricula and other factors such as personal experience influence a student's environmental knowledge. We observe positive correlations between the high school science courses or high school environmental education, and the average environmental knowledge scores. There is no difference in average knowledge scores when comparing male and female students. In addition, we report the results of an analysis of students' data as collected within the workshops. The study reveals several areas of troublesome knowledge of students.

Introduction

In its report entitled “The Engineer of 2020: Visions of Engineering in the New Century”, the National Academy of Engineering (2004) reported by the year 2020 “the world’s population will approach 8 billion people”¹. Not only will urban areas and developing nations experience significant increases in population centers, populations found in these areas will place considerable demands on the world’s natural resources. The tension found between ever-increasing global populations with decreasing availability of natural resources, provides members of the engineering community with substantial opportunities for the development of meaningful solutions addressing environmental issues.

One of the most pressing issues faced by local and global citizens is that of environmental education. How do we educate current and future citizens about the preservation and management of natural resource? The value and importance of environmental education has been endorsed both in the United States and internationally (e.g. United Nations Educational, Scientific and Cultural Organization, 1975, 1978; North American Association for Environmental Education, 1999). Despite this, ‘two-thirds of adult Americans consistently fail simple tests of environmental knowledge’².

It can only be imagined, how much high school and beginning college students know about environmental and ecological engineering and are aware that engineering is a major career choice for students who want to make an environmentally and ecologically sustainable impact.

The following examples demonstrate that engineering skills and knowledge are essential to environmental protection and enhancement. First, would a person switch from a standard residential home to an “energy efficient home”, if s/he knew that the carbon footprint, use of energy, and greenhouse gas emissions of constructing the home were substantial compared to the energy consumed while residing in the home? Consider another example: If one already owns a mobile phone, how to quantify the impact of upgrading the phone every year or two?? The growing number of electronics devices do not harm the environment during use, but their lifetimes are so short and there are so many of them that disposal is an issue.

The questions embedded in these scenarios are not just for the individual end user; the questions aim at the core of engineering and highlight that the design, manufacturing, use, and disposal of products, in short the product life-cycle, has an equal if not higher impact on the environment than end users’ actions.

Objectives of the Study

The objectives of this study are to research the attitudes and threshold concepts (key concepts or gate keeper concepts) of beginning engineering students towards the relationship between environment/ecology and engineering, specifically towards choosing either (a) engineering as a career to make an environmental impact or (b) choosing environmental and ecological engineering as a specific engineering profession. The project is situated in the context of life cycle analysis and the environmental impacts of design, manufacturing, use and disposal of products.

The study is theoretically grounded in (1) ‘social cognitive career theory’ (SCCT) and the (2) theory of “threshold concepts” (TC). SCCT maintains that people’s interests in certain careers stem partly from their self-efficacy (beliefs about personal capabilities) and outcome expectations (beliefs about the out-comes of engaging in particular courses of action)^{19, 20, 21}. TC argues that there are key concepts, once understood change the way in which students view a discipline¹¹. This study researches students’ change of attitudes and conceptions especially in regards to outcome expectations (as defined by SCCT), meaning: how well do students understand that their environmental/ecological impact is extremely high by choosing an engineering career and which concepts seem to be “threshold” concepts?

This study will address the following questions:

- What is the knowledge level of first year engineering students in regards to environmental and ecological issues, in particular environmental engineering?
- What are threshold or gatekeeper concepts, which help students to transform existing knowledge into deeper conceptual understanding?
- What is the baseline conceptual understanding of ecological and environmental engineering and life cycle assessment?

The study employs also an innovative research design: The researchers investigate students’ conceptions and attitudes (and change of both) by asking students to co-design an educational game with them. Of particular focus will be the change of students’ conceptual understanding of core environmental and ecological concepts during the design process.

The expected outcome of this study: A better understanding of students’ attitudes and threshold concepts towards environmental engineering and a baseline to design new interventions to support a stronger view of engineering as a career for environmental impact.

Literature Review

Conceptions and attitudes of engineering students towards environmental/ecological issues

Through documentaries like “An Inconvenient Truth” and other venues, public awareness on ecological and environmental issues increased in the last years. Available data in reports such as, “Environmental Literacy in America: What 10 Years of NEETF/Roper Research and Related Studies Say About Environmental Literacy in the U.S” show mixed results: On the one hand, the report shows a “confused public that performs poorly on basic environmental literacy questionnaires”, on the other hand “95% of this public supports environmental education in our schools”³.

Earlier work on environmental literacy in the field of engineering showed a similar pattern amongst engineering students: In a worldwide survey amongst engineering students, Azapagic et al. (2005)¹⁸ found (a) unsatisfactory knowledge, and at the same time (b) a general belief that environmental issues are very important. Although reports exist in the engineering education literature, especially on individual lesson design⁴ and curricula design⁵, there is a gap in the literature and a general lack of more detailed research into the conceptions and attitudes of

students towards environmental and ecological issues, especially how both relate to engineering careers.

Threshold Concepts and attitudes

Conceptual change is among the conceptions of learning that have recently been most closely embraced by the educational psychology and learning sciences communities⁶. Humans naturally build simplified and intuitive theories to explain their surroundings. The cognitive process of adapting and restructuring these theories based on experience and reflection is referred to as conceptual change. Most research indicates that conceptual change arises from interaction between experience and current conceptions during higher-order cognitive activity, especially when cognitive conflict arises⁷. Cognitive conflict or ‘troublesome knowledge’⁸, however, is not always sufficient for engaging conceptual change. Students often ignore, reject, exclude, or reinterpret anomalous data or they hold them in abeyance⁹, which is largely due to beliefs and attitudes¹⁰.

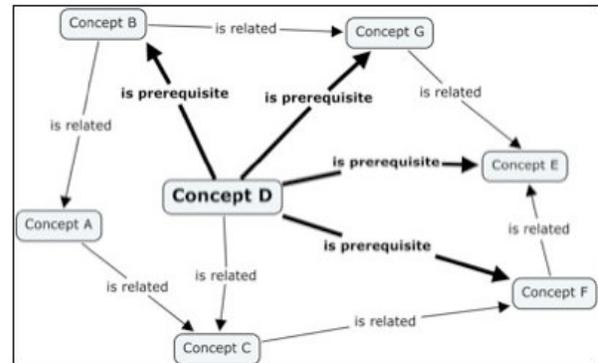


Figure 1: "Concept D" as a Threshold Concept

The new emerging theory of threshold concepts¹¹ argues further that there are hierarchies within concepts, in which certain concepts are threshold or gatekeeper concepts. Attributes, of threshold concepts are (a) transformative (transforming the understanding of a domain), (b) irreversible (change of perception is unlikely to be forgotten), (c) integrative (exposes other relationships), (d) bounded (context-specific) and (e) troublesome (counter intuitive)¹².

As depicted in Figure 1, ‘concept D’ is such a threshold concept, meaning if concept D is not understood properly, it is most likely that concepts B, G, E, and F will not be properly understood, since concept D is the prerequisite for these other concepts. Given such complex and concept-rich domains as in engineering, threshold concepts become increasingly important: Results of ‘threshold concept’ research can inform teachers and administrators on where to set priorities and allocate resources to maximize impact on students’ learning.

Participatory design

As stated, the study uses participatory design of a game as one of its design features. Törpel (2005) stated “participatory design of computer applications is about the direct participation of those who will be affected by the development of a particular computer application in the decision-making, design and/or development process”¹³. In this proposed project, students are collaborative co-designers of an educational game from which other students benefit. The concept of participatory design, used primarily in product design, has long roots in educational design and research practice as well^{22, 23, 24}.

Stemming from a constructivist paradigm¹⁴, the role of computers as “mindtools” or “cognitive tools” is emphasized: meaning to utilize the computer as a partner for the intellectual and social endeavors of the learners rather than utilizing the computer as a glorified teacher¹⁵. As Jonassen

et al. (1993) report, instructional designers learned far more by designing CAI (computer-assisted instruction) than the target audience will probably ever learn by using the designed CAI¹⁶. Both concepts argue for a reciprocal relationship between learners and content, and highlight the notion of “designers as learners” and “learners as designers”. Additionally, as the rich teach-back literature¹⁷ shows, learners are especially successful when teaching newly acquired knowledge and skills to other learners.

Method

The research team utilized the theoretical frameworks of participatory design-based research, comparative design-based research, threshold concepts and attitudes, as the basis for this research project. This framework is depicted in Figure 2 and provided researchers with:

- A novel way to elicit students’ attitudes and conceptions (especially threshold concepts) about ecological and environmental engineering.
- The opportunity to ensure that end-users were actively involved throughout the game design process, so end-user needs and expectations were met.
- The ability to pinpoint students’ threshold/gatekeeper concepts concerning ecological and environmental engineering, informing teachers and instructors where to set priorities and allocate resources to maximize impact on students’ learning.

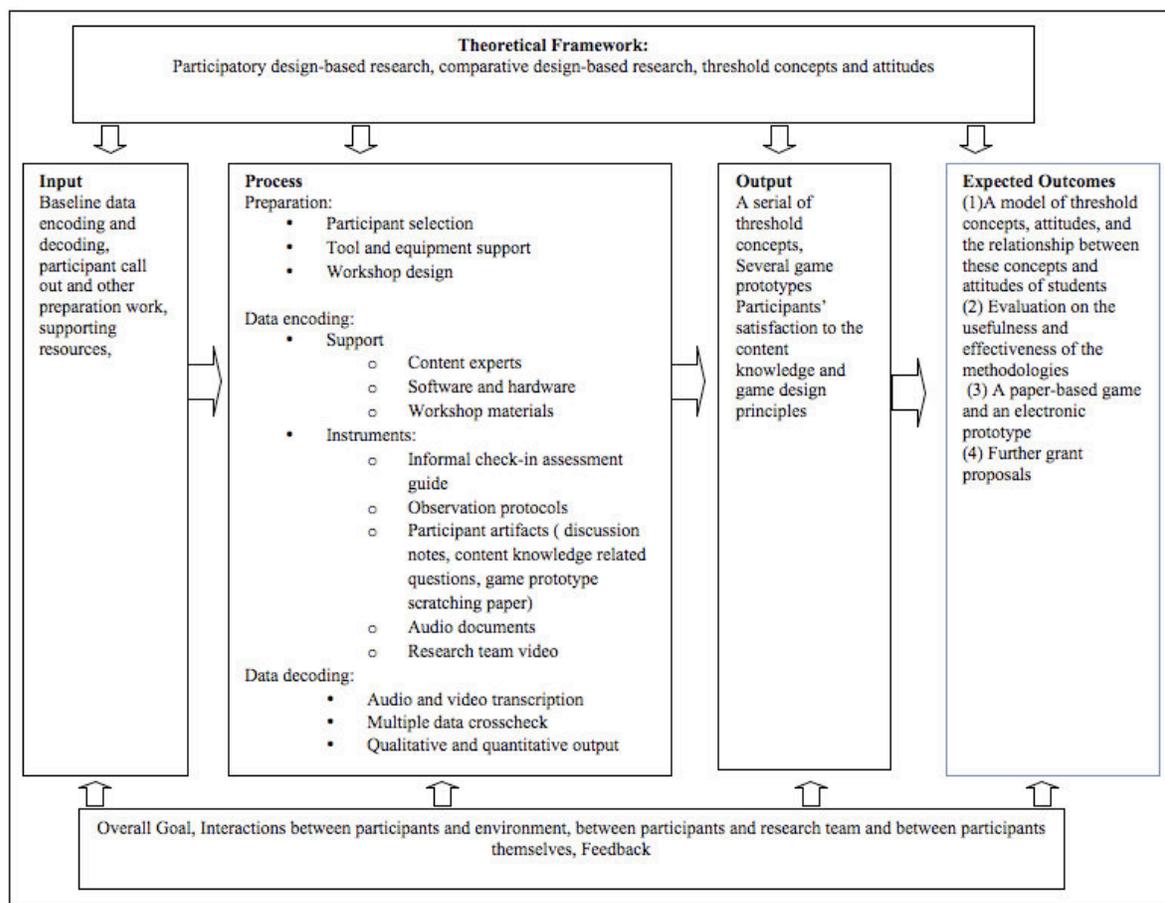


Figure 2: Research logistics conceptual framework

The research team continually reviewed overall research goals, provided participants with feedback, and monitored interactions between members of the study participants and the research team. The research team implemented these processes in order to maintain quality and consistency throughout the game design process. Baseline data analysis, participants call-out and selection and resource support provided sufficient inputs and the process phase consisted of preparation work, data encoding and decoding.

Preparation phase

The research team administered a survey encompassing student demographic information, as well as their initial understanding on ecological and environmental engineering, as a basis for selecting student participants. For the purpose of avoiding bias and increasing reliability and validity in the data collection process, participants were selected based on the following rules:

- Prospective participants were recruited from the students enrolled in ENRG10000, which was the beginning engineering course for all first year engineering college students.
- Students taking courses of the professors in the research team were ruled out.
- A stratified sampling strategy was utilized so that each participant team had mix of demographic background.
- Six teams of 4 students were recruited for the final game design workshops.

The research team developed four (4) workshops, hosted a wikispaces environment, and designed two (2) online activities. The game design workshops provided a venue in which study participants could interact amongst themselves, as well as be observed by research team members. The wikispaces facilitated team member communication. The online activities supplemented information presented in the face-to-face workshops. Research team members also used the workshops to develop observation data, collect team artifacts, such as drawings, reflections, and provide teams with assistance when needed.

The themes of the workshops varied corresponding with the research process. The first workshop focused on Life Cycle Assessment (LCA) content knowledge. Research team members also presented an overview on game design principles. The second workshop began with a review of LCA and was centered on game design model and principles. The design of the third and fourth workshops enabled students were structured as “working sessions.” Each team used their workshop time to develop game prototypes and provide one another with peer evaluation.

Data collection phase

The duration of this phase was seven month (Survey collection: August 2008; Workshops: November 2008 – February 2009). The research team used a multitude of data sources when triangulating study data (See Figure 3). The data collecting process was centered on a series of game design workshops, which consisted of four face-on-face workshops and two online activities. Six (6) teams of four (4) students participated in the workshops and various instruments were utilized to collect data.

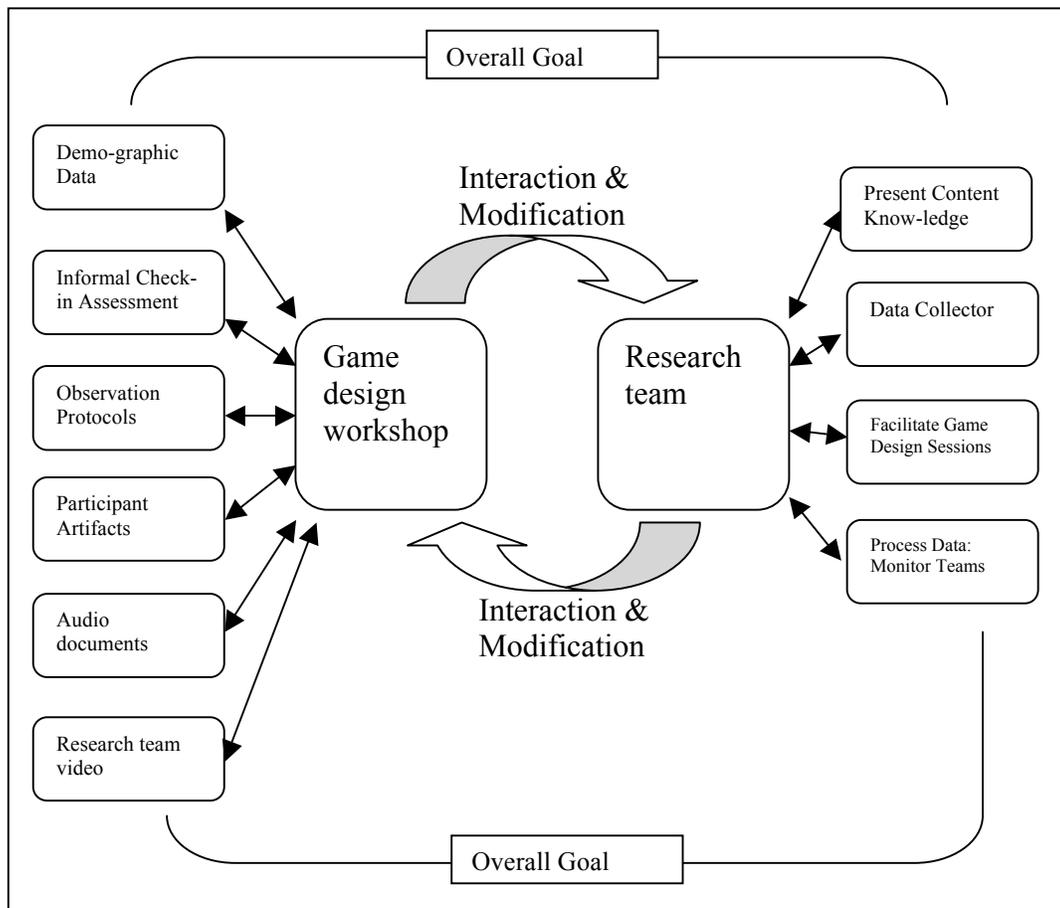


Figure 3: Data encoding model

As previously mentioned, the research team introduced LCA content knowledge during the first workshop. Participants were then encouraged to answer five (5) questions highlighting basic knowledge of LCA, such as their personal definition of LCA and understanding of environmentally friendly products. (See Appendix A - Example 1). These five questions served as the basis for the research team check-in assessment, and were presented in an informal manner to the research subjects. The research team structured this activity in such a way to alleviate participant stress. Once the participants answered these five questions, their answers, reactions, and initial attitudes regarding ecological engineering and documented and analyzed.

During each workshop, the research team also implemented an observation protocol. This protocol was intended to document participants' reaction, attitudes, the extent to which participants understood the LCA content knowledge and game design principles. Research team members also collected paper artifacts, such as team notes and outlines and drawings. During the team meetings, the research team deployed audio recording devices and recorded team conversations, such as prototype brainstorming.

Research team members gathered after every workshop section and videotaped their opinions of the strengths, weaknesses and suggestions of each workshop section.

Challenges of data collection

1. Loss of some participants threaded the consistence of team participation and the final project. Due to the small size of each team, 2 or 3 loss in one team, which was quite normal for research, caused us combine two teams together after the first workshop;
2. It was hard to keep the gender balance as there were much fewer female students in the college of engineering;

Findings

Survey Data

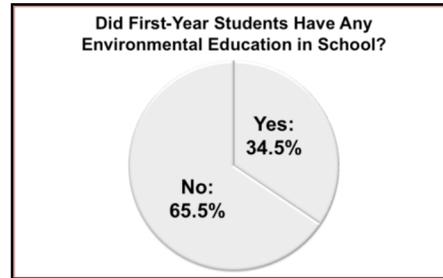


Figure 4: Environmental Education

Two-third of the first-year students indicated that their high school experience did not include any environmental education (see Figure 4).

As Figure 5 shows, First-Year students demonstrated a much higher knowledge level in the category of “environmental issues”, which includes acid rain, water pollution, air pollution, global warming. Students demonstrated less knowledge in environmental tools, sustainable development, and legislature and policies governing environmental issues.

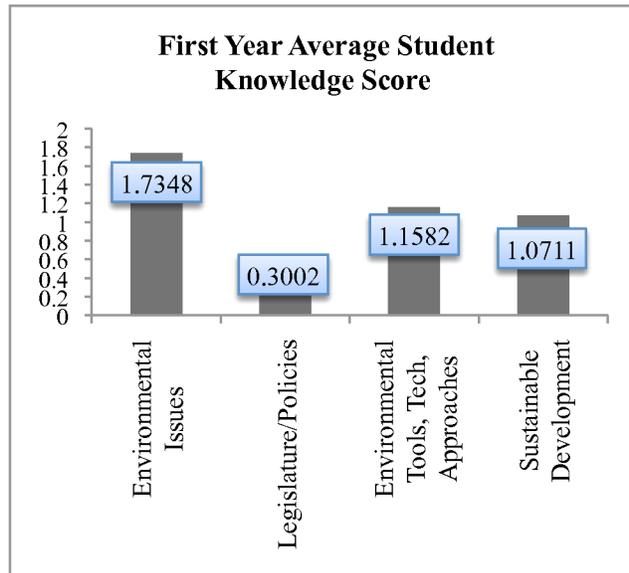


Figure 5: Knowledge on Environmental Issues

Items in “environmental issues” are frequently in the media or are items, which do not need much specialized information to understand such as ‘water pollution’. So it could be argued that the less common sense the terminology, the more specialized prior knowledge is required to understand the concepts, the least likely students were aware or knew about the particular environmental issue. In other words: students’ awareness of environmental challenges is much higher than knowledge on how to take up these challenges.

Correlating the research results of Figure 4 (Environmental education in high school) with research results of Figure 5 (knowledge in environmental engineering issues), the research team compared the average knowledge score in each category of environmental engineering issues for

students who answered “Yes” versus students who responded with “No.” on environmental education. The comparison is shown in Table 1. Students who declared to have received environmental education in high school do indeed demonstrate statistically significant higher scores in all knowledge categories.

Table 1
The Correlation Between High School Environmental Education and Student Knowledge of Environmental Engineering Issues (N=1360)

	1	2	3	4	5
1. Prior Environmental Education	--				
2. Environmental Issues	.272**	--			
3. Legislative Policy	.196**	.466**	--		
4. Environmental Tools, Technologies, Approaches	.096**	.601**	.471**	--	
5. Sustainable Development	.161**	.595**	.497**	.715**	--

** Correlation is significant at the 0.01 level (2-tailed).

Pearson correlations (two-tailed) were calculated for the range of cumulative semester hours of high school math and average score in each of the four categories of environmental knowledge, or for the range of cumulative semester hours of high school science and the average score in each of the four categories of environmental knowledge. Information about specific math or science courses (e.g., trigonometry versus calculus, biology vs. chemistry) was not available.

The range of cumulative semester hours of high school math was 0 – 16 with an average of 7; the range of cumulative semester hours of high school science was 0-19, with an average of 9. Correlations were declared significant at the 0.01 level or the 0.05 level. Please refer to Table 2 for a listing of the correlations.

The number cumulative semester hours of high school math is not positively correlated with student scores in any category of environmental knowledge. However, the number of semesters of high school science is positively correlated with student scores in all categories of environmental knowledge. A cautious interpretation would indicate that typical high school science courses include chemistry, biology, and physics and therefore could possibly include case studies or examples related to the environment.

Table 2
The Correlation Between High School Math and Science Education and Student Knowledge of Environmental Engineering Issues (N=1360)

	Semesters of High School Math Taken	Semesters of High School Science Taken	1	2	3	4
Semesters of High School Math Taken	--					
Semesters of High School Science Taken	.268**	--				
1. Effect of Environment	-.101**	.180**	--			
2. Legislative Policy	-.069*	.123**	.466**	--		
3. Environmental Tools, Technologies, Approaches	-.028	.103**	.601**	.471**	--	
4. Sustainable Development	-.070**	.155**	.595**	.497**	.715**	--

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Gender differences

Given the greater participation of women in environmental engineering degree programs (as mentioned earlier in this paper), the researchers explored gender as a factor that may impact environmental knowledge scores. The data were subject to Levene's Test for Equality of Variances. In all cases, there was no significant difference in the knowledge scores of male and female students.

Qualitative Results

The qualitative research questions were: (1) What are threshold or gatekeeper concepts, which help students to transform existing knowledge into deeper conceptual understanding? (2) What is the baseline conceptual understanding of ecological and environmental engineering and life cycle assessment?

The following themes emerged by analyzing the non-numerical data. The research team employed a grounded theory approach, which includes open coding (applying key phrases to all textual information) and axial coding (grouping of the key phrases to larger units). Quotation marks indicate direct quotes by the students.

Results of LCAs are surprising and 'troublesome'

During the workshops, the students read, interpreted and discussed a variety of different LCAs, which the research team selected. From the verbal and non-verbal reaction of the students, the research team was able to conclude, that results from the LCAs were surprising for students and made them question their previous conceptions. For example, the LCA on coffee consumption revealed very little variance of environmental impact of different forms of coffee, but adding a dairy product (such as milk or cream) made a large impact.

Compromising functionality for environmental concerns

Students felt comfortable talking about their perception of engineering, as a domain, which thrives for optimal or best performance and functionality. They expressed that the particular focus on LCA would mean that “functionality is made secondary” or that they would have to “only think of the environment”, which students expressed as a puzzle or contradiction to their understanding of engineering. The LCA is perceived as a borderline engineering related task. The researchers did not see much evidence that environmental issues are perceived as a required component of what makes a product ‘functional’. A different version of the same argument surfaces, when students express LCAs are more valuable for end-users and less valuable for engineers (“convince someone that one product is more ecologically friendly than the other [...] and trying to persuade them that buying a greener car is better”).

‘Just information’ – no means to tell how to act

Students were quick to determine, that to measure the environmental impact of a “course of action” or “process”, “merely gives you quantifiable results for a certain action”, but the LCA itself was perceived as not providing a roadmap, courses of possible actions nor even options for a decision (“by no means does it tell you what to do”) also it was acknowledged that it needs to be decided “which factors are most/least important”. Students understood LCA as a sophisticated form of analysis, yet they did show little understanding that the LCA is part of a larger picture within an engineering process, a starting point for creativity or problem solving. The analysis was perceived as an unrelated or stand-alone event in regards to other forms of engineering such as design or development.

Cradle to cradle/cradle to grave – how it is made

A small number of students expressed that a LCA is connected to the larger process of making products (“the most important aspect of LCA is actually how a product is made”, yet “it is hard to explain energy/fuel cost in production of products [emphasis by student]. The emphasis on the production is particularly seen in the context of “decomposing a product”, so individual components can be addressed to decrease the environmental impact of a product.

Intertwined process – Uncertainty and less-optimal-data-environments – no single component alone

LCAs are highly complex and much data, assumptions, and analysis is invested to create LCAs. For some students the most troublesome component for LCAs is the complexity. This shows itself either in realizing (a) the LCA alone have many components: “they are all multi-faceted; there is not one factor alone that determines whether a product or method is better” (b) that producing a LCA report required “a compilation of multiple tests”, (c) concerns about the accuracy of the analysis “understanding how the tests were done and under what circumstances so you can accurately interpret an understand the numbers” and no clear cut answer of how to trust whom or the results, etc., and (d) a feeling of overwhelmed with the amount of knowledge and information which is needed “I really don’t know all of the raw materials used in making a product”.

Summary and Conclusion

This study reveals trends across a large body of first-year engineering students at a R1 university: Students across the board are aware of environmental issues, yet when it comes to specific

legislature, environmental engineering tools/approaches and sustainable development strategies, students' awareness and knowledge are considerable lower.

The research results of the second part of the study, the qualitative study, reveal interesting components of students' conceptual understanding of LCA and its relationship to engineering. Particularly the artificial separation between functionality and environmental friendliness of a product and the difficulty of students to connect the results of LCA to the larger engineering process give insights into difficulties and troublesome knowledge for students.

Findings contribute to the small body of existing research in environmental engineering education research. In the next phase, particularly the qualitative findings need to be further studied by transforming them into a valid survey to be employed over a large body of students. A cross-institutional approach is also considered as a next step.

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