Same goal, but different paths - Learning, explaining and understanding entropy

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Abstract— Engineering students train to discuss conclusions and results in different ways as part of their education. This is often done in connection to learning disciplinary knowledge where comparisons with and connections to previous courses play an important role. Students from different programs can have distinctly different repertoires of concepts and experiences when starting a course. This influences their learning on the course and how they communicate afterwards. We explore this issue in relation to engineering students’ explanations about entropy and how these change during a course in thermodynamics. A questionnaire study was done during the spring semester 2014 with students enrolling in a course on chemical thermodynamics. Students were asked to explain the concept of entropy and list scientific concepts they relate to entropy both before and after the course. A qualitative analysis was done for the 73 students who answered the questionnaire both before and after the course. Analysis showed that disorder was the most common aspect in student explanations, both before and after the course, but that many students used the concept in a more critical and reflective manner after the course. We also found that student explanations develop in richness by involving more aspects after the course. This development is dependent on the resources students bring with them when enrolling in the course. This is especially clear for students from the Master Programme in Chemical Engineering, who to a larger extent use microscopic elements, such as interaction between particles, in their explanations already before the course.

Index Terms—Academic integration, student retention.

I. INTRODUCTION

THERMODYNAMICS is recognized as one of the foundations for much of of engineering. Understanding thermodynamics, and the concept of entropy, is important in coming to terms with contemporary societal challenges, such as energy usage and global warming. However, Ugursal and Cruickshank found in an international study that engineering students considered course in thermodynamics not-so-interesting or even boring and of average or higher difficulty compared to other courses [1]. In addition, findings from science education research show that thermodynamics can be challenging to learn [2, 3]. This motivated our exploration of engineering students’ interpretations of the entropy concept as reflected in their explanations. This paper will expand on previous findings [4] through an analysis of differences between students from different engineering programs. Implications of the findings for teaching and educational development are discussed.

II. TEACHING AND LEARNING OF THERMODYNAMICS

Science education researchers have explored the teaching and learning of thermodynamics and recent reviews give a good introduction to the field [2, 3]. In this section we present two themes of particular interest to our study.

A. Talking about thermodynamics and entropy

There have been many different suggestions regarding what teaching approaches to use for coming to terms with students’ difficulties with thermodynamics, and entropy in particular. Arguments have been raised for the need of qualitative and metaphorical ways to introduce and discuss entropy [5, 6]. A dominating metaphor in teaching of entropy is entropy is disorder. This metaphor has met with considerable criticism [6, 7], not least due to its subjective character. Other examples of proposed metaphors are entropy is spreading of energy [5] and entropy is freedom [6]. Different interpretations of and metaphors for entropy are likely to affect how students learn and talk about entropy.

B. Different disciplinary traditions

Different ways of approaching a subject have been exemplified in the field of thermodynamics by Christensen and Rump [8]. Their study explores similarities and differences in engineering, physics and physical chemistry thermodynamics courses. These courses have partially different content, but Christensen and Rump found differences in how central, shared concepts were interpreted and represented. For example, considerations of the microscopic nature of matter were strongly present within the chemist tradition.
III. METHODOLOGY

This study draws on data from two questionnaires and follow-up interviews. Some results from the questionnaire study have been published and additional details on that part of the methodology can be found in our journal article [4].

A. Context of the study

The initial study was conducted in the spring 2014 before and after the course Chemical Thermodynamics. This course is given during the fourth semester on four different master of engineering programs with different amounts of previous courses in chemistry and other subjects. These are Chemical Engineering (55 ECTS of previous chemistry courses), Environmental and Water Engineering (10 ECTS), Materials Engineering (5 ECTS) and Molecular Biotechnology Engineering (20 ECTS). The course follows a traditional structure with lectures, problem-solving sessions and laboratory exercises. Atkins' physical chemistry [9] was used as course literature.

B. Questionnaire data collection

Paper-and-pen questionnaires were handed out at the first and last lectures of the course. The first questionnaire was answered by 130 of the 190 students registered to the course. 96 students answered the second questionnaire. In the questionnaire students were asked: What is entropy? Give a brief explanation that reflects your understanding. They were also asked to list the scientific concepts they connected to entropy. The two questionnaires were matched for 73 students, which allowed for comparisons. Further details about this study and results from it are reported elsewhere [4].

C. Questionnaire data collection

All questionnaire answers were transcribed and entered into a spreadsheet. The explanations about entropy were initially assigned to different categories by one of the authors. Two authors then refined the categories and coded all answers. The categories were not mutually exclusive and many explanations were coded in multiple categories.

D. Follow-up interviews

Three follow-up interviews were held with students from the questionnaire study during spring 2015. Three pairs of students were guided through different exercises by one of the authors. These interview sessions were video recorded. Relevant parts of the interviews were transcribed and are currently being analysed. Preliminary findings from this analysis are used in this study.

IV. RESULTS

Our analysis of student explanations of entropy identifies six overarching, non-exclusive, themes. These are:

- Microscopic interpretations of entropy
- The disorder metaphor for entropy
- The spreading metaphor for entropy
- Problematic connections between entropy and energy
- Teleological understanding of the second law of thermodynamics
- Literal statements, often using mathematical formalism
- Concrete example

The dominant theme was the disorder metaphor, which is well in line with previous research on teaching of entropy. This theme was present in 67% of the student answers before the course and in 77% after the course.

A. Evolving explanations

The student explanations generally evolved during the course. This was especially pronounced in how they related to the categories regarding disorder, spreading and microscopic interpretations. Figure 1 shows a summary of this for the whole population. The left part of the figure shows the distribution of the student population between different types of answers, labelled by those of three categories present in their explanations. The three most common types of explanations before the course were only coded as involving the disorder metaphor (38% of the respondents), a combination of the disorder metaphor and microscopic interpretations (23%) or none of these aspects (20%). Most students were also using more aspects in their explanations after the course. Students without any of these aspects in their initial explanations to a large extent started using the disorder metaphor after the course. The majority of the students, labelled as Changers in the figures, changed which aspects they used in their second explanations. The students that did not change used aspects are labelled as Stable.
After the course, 21% of the students used a combination of the disorder metaphor, the spreading metaphor and microscopic interpretations in their explanations. The students who use the disorder metaphor in combination with other aspects after the course are often doing this in a problematizing fashion. They acknowledge that disorder might be a problematic metaphor, but still find it useful for their explanation.

B. Comparing programmes

Our original analysis hinted at program related differences, both in initial explanations and in the development after the course. This has been explored further through separate analysis of the two programs with the larger numbers of enrolled students - Chemical Engineering and Environmental and Water Engineering.

The results for Environmental and Water Engineering students are presented in Figure 2. The students on this program mainly used the disorder metaphor or no aspect at all before the course. After the course we see that students either have adopted the disorder metaphor or come to expand their explanations by adding microscopic interpretations and possibly also the spreading metaphor. Many of these students also reflect on problems with using only the disorder metaphor in their answers after the course.

The results for Chemical Engineering students are presented in Figure 3. The students on this program use microscopic interpretations in their explanations to a larger extent, already before the course, which corresponds to the fact that they have the most extensive training in chemistry before this course.

There are two different paths of development found for the explanations of the Chemistry Engineering students after the course. Some students exhibit the same changes as seen for the whole population, where explanations include more aspects and problematize disorder. However, some of the Chemistry Engineering students have abandoned the disorder metaphor in their explanations afterwards and rely on microscopic interpretations, in some cases together with the spreading metaphor.

C. The role of disorder

The entropy metaphor is present in most student explanations both before and after the course. We also find that student use of it generally becomes more reflective and problematizing after the course. In relation to this, it is interesting to note that none of the students listed disorder as a scientific concept related to entropy. This indicates that they are aware that disorder is just a metaphor, but that they find it useful for their explanations, and perhaps also for their learning. This interpretation is strengthened by results from the follow-up interviews, where students in all interviews recognized disorder as a most useful concept when talking about entropy, but at the same time as a very unscientific concept.

D. Exam results

Our initial study [4] found no correlations between student exam scores (or their points on one entropy-related exam question) and their responses to the questionnaire items. In the present study, we have explored other possible variables, such as the number of categories students engage in the explanations, but still find no significant correlations to exam scores. The only statistically significant difference found within this population was related to programme belonging. Students on the Environmental and Water Engineering
programme performed significantly better (p=0.03) on the exam than students overall. The mean score on the exam for this programme was 11-15 points higher than the mean score for other programmes. Although the students from this programme to a large extent only draw on the disorder metaphor in their explanations of entropy and only have 10 ECTS of previous chemistry courses they still perform most successfully on the exam.

The lack of correlation between questionnaire responses and exam results finds support in physics education research, according to which the connection between conceptual understanding and problem-solving skill has been found to be weak [10]. On this note, in the follow-up interviews, the students expressed that problem-solving skills and conceptual understanding are both important to develop, but did not see them as related to one another, apart from being able to assess the plausibility of calculated results.

V. IMPLICATIONS FOR PRACTICE

These results give interesting insights into how student explanations evolve during the course and also reflect some of their learning processes. This has some important implications for practice, both regarding entropy and engineering education on a larger scale.

A. Use the disorder metaphor, but with care

Our study confirms the dominant role of the disorder metaphor in teaching and learning of entropy. The students use it, but often in a reflective and more problematizing way after the course than before. The evolution of student explanations indicates that the disorder metaphor provides an accessible entry point for students to start discussing, and learning, about entropy. At the same time, most students are well aware that disorder is not a scientific concept. Although the use of the disorder metaphor has been criticized [7], our findings indicate that it is an important tool in the teacher tool kit when teaching about entropy, but that it should be used with care.

B. Problematize representations of knowledge

In a broader perspective, our findings indicate the importance of using multiple aspects in explanations during teaching. Illustrations, metaphors and analogies resonate differently with students, depending on factors such as programme belonging or personal background. Multiple representations provide multiple entry points to the subject for the students. At the same time, it is important to recognize, as has been argued by e.g. Styer [6], that all metaphors have shortcomings.

C. Recognise differences in the student population

Students from different programmes can bring different knowledge and experiences to a course, as exemplified in Figures 2 and 3. Instructors should recognize this and make sure that the course content is accessible to all participants.

D. Consider how to best probe understanding

Our study shows that the traditional written exam only probes some aspects of student understanding about a subject. This informs the discussion about appropriate methods of examination that covers the diverse skills students are expected to learn during their engineering education.

REFERENCES