

# Constructive Alignment in Science and Engineering: From Principle to Practice

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**ABSTRACT:** This paper reports on an action research study on task design and constructive alignment in an optional module at the Norwegian University of Science and Technology. While students appreciated the two professors' teaching, high failure rates had been an issue for years. This study starts out by exploring potential causes of poor academic achievement. Rather than relying on random interventions, achievement profiles helped to identify crucial issues to inform the selection of measures to improve learning outcomes. A major issue turned out to be students' ability to respond to conceptual questions, partly due to a mismatch between types of tasks in exercises as compared with those encountered at the final exam. A thorough redesign of the course included a voluntary mid-term exam, additions to the weekly exercises and constructively aligning course components. As a result, failure rates dropped markedly over the years, and students' ability to cope with conceptual questions clearly improved.

**Keywords:** Course design, assessment, constructive alignment, science, engineering

## 1.1 Contextual Setting

The overall semester structure features four parallel courses, each with an estimated workload of 7.5 points. The course under scrutiny is termed Stochastic Theory of Sealoads (henceforth "Sealoads") and was taught in the fourth year of a five-year study program. The number of students enrolled varied from one year to the other; however, frequently ranging from 30-40 annually. The contents of the course carried a reputation of great relevance in terms of future employability, so even though the course itself was voluntary, recruiting students was never an issue. A particularly challenging feature of this course was the diverse nature of its two parts, independently taught by the respective professors, who possessed long-term experience as lecturers. The first part focused on statistical methods, while the other addressed stochastic processes, onwards referred to as Part 1 and Part 2. While the first part largely re-addressed and extended key concepts and themes from first-year statistics, the second part introduced several concepts and ideas of which the students possessed little or no prior knowledge. This challenged students in their capacity to engage in deep approaches to learning (Marton, 1976a, 1976b).

Like other universities, this institution had its own quality assurance system in operation, and one would expect that patterns of poor academic performance would be addressed in due time. In particular, the application of course specific reference groups with student representation would seem as a fitting arena to address shortcomings and introduce measures as required. However, since the predominant focus of the reference groups was on teaching rather than on learning, critical issues in need of attention escaped from the agenda. Rather, positive feedback served as re-assuring statements of the state of affairs to the satisfaction of the stakeholders. However, responses concealed students' shortcomings and therefore did not help inform the selection of measures.

This study aims to investigate the nature of learning by examining the course structure: Why did students succeed academically in Part 1, while not to the same extent in Part 2? Based on insights gained to this question, what would be fitting interventions to improve academic achievement, and to what extent did interventions make a difference to learning outcomes? Which were the driving forces to impact learning, and what emerged as effective tools to enhance students' efforts? The study aims to identify major structures to impact learning with a view to aligning course components (Biggs, 1996).

Essential curriculum themes were Monte Carlo simulation, probability distributions for response, parameter-estimation, extreme-value statistics, stochastic processes, auto and cross-correlation functions, spectra and cross-spectra, differentiation of stochastic processes, excitation-response of stochastic processes and response-statistics. Students should have detailed knowledge of principles and methods used to describe stochastic processes, including simple calculations of stochastic

sealoads. They should also master the concepts and terminology used in statistical methods and in the description of stochastic processes.

Teaching methods were lectures along with weekly tutorials and problem-solving exercises, a model widely used in science and engineering education. The course itself served a dual purpose aiming to prepare for engineering practice as well as to promote the acquisition of theory related to physical phenomena. This is an ambitious and challenging combination, particularly when new concepts and ideas appear at short time intervals. The current university exams in some cases typically served as driving forces, prompting students to make strict priorities in terms of time allocation to school commitments and leisure activities. Time pressures typically lead to students becoming strategic in their approaches, causing shallow, memory based learning as a result (Ramsden, 2003).

## **1.2 Theoretical Background**

An algorithmic problem can be solved by using a memorized set of procedures, while a conceptual problem requires the student to work from an understanding of a concept to the solution, where no memorized procedure is likely to be known (Cracolice, Deming, & Ehlert, 2008). This definition is widely used; however, there are also academics suggesting a mix of the two, thus indicating a continuum to facilitate conceptual understanding. Empirical studies still suggest that such transitions may be difficult to plan and predict since there is no way faculty can ensure intended use of learning resources (Case & Marshall, 2004; Gynnild & Myrhaug, 2012).

Certain types of problems appear to be more conducive to academic success compared with other types. For example, one study reported far greater successes among students solving algorithmic problems compared with open-ended questions (Surif, Ibrahim, & Dalim, 2014). Yet another study found that a large fraction of students have "... no choice other than to be algorithmic problem solvers because their reasoning skills are not sufficiently developed" (Cracolice et al., 2008). It has been theorized that conceptual learning is of a different kind compared with memory-based learning (Rillero, 2016), and that limited ability to cope with concepts might have been caused by an overemphasized focus on algorithmic problem solving, but this may not be the full explanation (Igaz & Proksa, 2012).

## **1.3 Methodology**

The two professors teaching and the first author of this paper agreed to form a project team in order to combine research and development in an integrated fashion, commonly known as action research. Assessment data indicated superior performance in Part I compared with Part II, and our first commitment was a search for potential explanations, and second to re-design and align course components to improve learning. Action research is widely used, and the literature offers rich accounts of the method's suitability for learning and change, including benefits and limitations (Zuber-Skerritt, 2002). It involves learning from experiences, and from critical reflection on such experiences in order to reach solutions. Identified problems were addressed by theorizing solutions grounded in data. The purpose of such cause-effect studies is to establish an explanatory understanding as a basis for the implementation of remedial measures. Finally, the study of effects served as a source of learning. The project spanned five years from 2013 through 2017 to observe some of the longer-term effects.

## **1.4 Results and Reflections**

The project featured three major interventions in order to improve learning, and particularly to enhance conceptual understanding in Part II of the course. The assessment regime changed in 2013 making it mandatory to achieve a pass both in Part I and Part II. Candidates could therefore no longer practice instrumental strategies to sub-optimize achievements by addressing exclusively either Part I or Part II. Three years later in 2016, a second intervention took place by introducing a voluntary mid-term exam, addressing exclusively theoretical themes. To boost students' efforts, achieved scores accounted for 30 % towards the final grade, while those who skipped the mid-term achieved scores exclusively by attending the end-of-term exam. Students also knew that similar, if not identical types of problems, as seen at the mid-term might re-occur at the final exam, thus motivating sustained efforts to nurture intellectual growth related to already encountered theoretical issues.

Assessment drives learning (Rust, 2002). Crucially, assessment formats and types of problems operate in tandem to direct and reinforce learning in targeted areas, a fact often underestimated as part of course design processes. In this study, the role of such issues appeared as indisputable. Students were good at doing calculations, while far less successful in solving conceptual tasks as seen in Part II. Table

1 exhibits course design changes based on constructive alignment (Biggs, 1996). This implies concerted efforts to optimize learning outcomes by supporting intended learning outcomes (ILOs).

	Part 1	Part 2
Current exercise design	Emphasis on calculations	Emphasis on calculations
Current exam design	Emphasis on methods & calculations. Tasks closely linked to exercises	Emphasis on concepts and theory. Tasks not necessarily linked to exercises
Revised exercise design	Emphasis on concepts and calculations as seen in ILOs	Emphasis on concepts and calculations as seen in ILOs
Revised exam design	Tasks aligned with intended learning outcomes (ILOs)	Tasks aligned with intended learning outcomes (ILOs)

Table 1 Current and revised problem design in the course under scrutiny

Part II. Previous exam questions were added to the exercises to familiarize students with this type of problems, and to let them get some experience in solving them. Assigned assessment scores ranging from 0 to 100 were converted into letter grades according to the following rules: A (89-100); B (77-88); C (65-76); D (53-64); E (41-52); F (0-40). In Figure 1, the hovering boxes illustrate mean grades for the respective cohort of students, while the score ranges represent the boundaries for the respective grades.

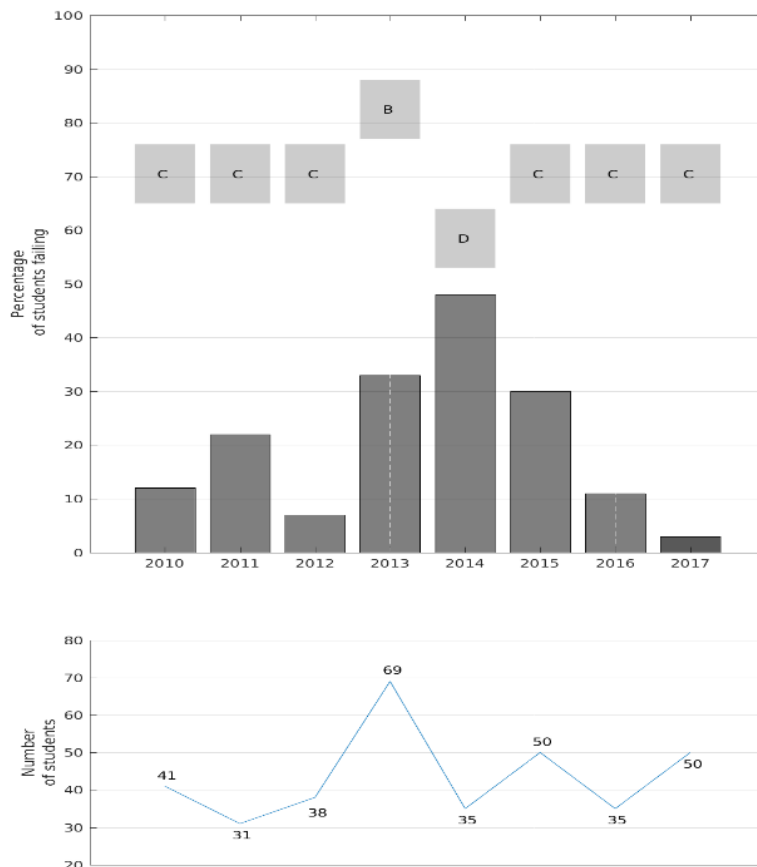


Figure 1 Number of enrolled students by year (bottom figure) and percentage of failures (top figure), 2010-2017

As seen in Figure 1, failure rates peaked in 2014, the year after the introduction of the “pass both parts regime” with a visual decline until 2017. Prior to 2013 candidates could obtain a decent grade by performing well in either Part I or Part II. The “pass both parts regime” motivated learning strategies that included both algorithmic and conceptual tasks, and consequently failure rates dropped, even when candidates encountered demanding theoretical problems.

Theoretically, teaching as task design draws on an activity-based approach to learning. The interest is in the construction of the learning environment rather than on fine-tuning of presentation skills. The key question is what the student does rather than what the teacher does (Biggs, 1999), a position that is supported by a lot of empirical evidence. This study also benefitted from the closer collaboration between the professors in the design of the course as a whole, particularly by aligning constituent parts to given learning outcomes. The graphical presentation in Figure 1 clearly indicates that mean scores converged over time. The somewhat surprising experience caused by the introduction of the pass both parts regime in 2014 is also clearly visible, ensued by increased mean scores in the following years. This makes sense due to the more even distribution of types of tasks in both parts of the course, and by extended opportunities to prepare for conceptual problems in Part II.

The challenge of teaching for conceptual learning requires efforts to expand students’ awareness of aspects of phenomena, and problem design appears as a particularly productive strategy to succeed in this attempt. Unfortunately, competencies in problem design is limited and enjoys little, if any, attention in induction programs for new academics. Research initiatives including the scrutiny of driving forces in the learning environment may shed light on the “hidden curriculum”, a term introduced by Benson Snyder (Snyder, 1971).

This researcher makes a distinction between a formal and a hidden agenda in the academy. Due to time pressures and progression requirements students easily become strategic in their endeavours, and all of a sudden find themselves trapped in competition with peers with a risk of adopting instrumental strategies to learning. Academics therefore need to attend to the effects of their choices in terms of content and problem design strategies. The description of learning outcome may serve as a start, but is far from enough in itself. The very idea of constructive alignment requires increased attention to components of the design process that most directly and efficiently support learning. Presumably, several students are genuinely interested in growth and intellectual excitement in their first year; however, there are competing structures helping to earn good grades rather than spending time on concept learning. For professors, spending time on and well-reasoned problem design appears as one way of combining sustained commitment with rewards in terms of improved grades.

## 1.5 Conclusion

Poor performance and high failure rates are a recurring issues in science and engineering education. Though this study offers no magic stick to remedy all issues, the research team succeeded in coming across explanatory factors of poor academic achievement. First, the nature of the assessment and grading regime enabled candidates to take shortcuts, and thereby get a pass even with exceptionally limited competencies in one part of the course. This illustrates the challenge of validity in assessment design. Second, conceptual learning suffered from poor alignment between theoretical content and an insufficient selection of tasks to prepare for the final exam. The merit of this study lies in the successful analysis of causes, and in the effective implementation of measures to extend and enhance learning. The revision of exercises and constructive alignment of key components of the course boosted motivation, and a mid-term exam enabled a focus shift to enhance much needed conceptual understanding.

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