# IMPROVING STUDENTS ENGAGEMENT WITH ACTIVE LEARNING IN ENGINEERING OPTIMISATION LECTURES

**Gauti Asbjörnsson & Kanishk Bhadani**

Department of Industrial and Materials Science, Chalmers University of Technology, Gothenburg, Sweden

## ABSTRACT

In optimisation, as for learning, the synthesises of previous knowledge and current information is essential to achieve defined objectives. The students' objectives are to fulfil the course's intended learning outcomes and possibly, at the same time, develop their knowledge, skills, and attitudes within the subject. The purpose of this work is to incorporate a more collaborative learning environment with active learning activities in the classroom to improve student learning opportunities, their perception of the course and their interest in the subject of optimisation. Within the CDIO initiative, active learning or experiential learning is stated as a key factor in engaging students directly in thinking and problem-solving activities. This can apply to different teaching activities such as assignments, lectures, and assessments. With active learning, the purpose is to involve students more actively in the learning process instead of relying on passive information transfer. Active learning methods aim to facilitate the students' process of creating their understanding of the topic by reflecting, questioning, conjecturing, evaluating and make connections between ideas whilst drawing on ideas, experiences and knowledge of others. In this work, diverse activities for incorporating more interactive learning in the classroom have been implemented in different course lectures, activities such as think-pair-share, mind maps, multiple-choice questions, incomplete hands and more. An evaluation of the students' perception of the course and the various activities was carried out at the end of the course. The most considerable improvement was with the overall impression of teaching. That improved between the years from 3.10 to 3.57. The most appreciated activity was the think-pair-share approach, which gave the students a cognitive break from the lecture slides to discuss the topic. However, the response rate was limited but did indicate the students' perspective and what was appreciated. The results will provide a good base for future development.

## KEYWORDS

Optimisation, Engineering lectures, Active learning, Standards: 2,8,10

## INTRODUCTION

In optimisation, as for learning, the synthesises of previous knowledge is necessary. The objective might be different for different disciplines, and for the students, their main objective will be different. For some students, the aim might be to get a passing grade, while others aim for the highest grade or something even more long-term. How well they will obtain their objectives depends on their available resources and their capability of putting new information in context. In optimisation, there is even a Teaching-Learning based algorithm (Rao *et al.*, 2011). In the Teaching-Learning based optimisation, the process is divided into two phases: a teacher phase and a learner phase. The teacher phase entitles learning from the teacher, while in the learner phase, the learners interact with each other. In the traditional classroom, the second phase is, however, often left unsupervised.

The reference course in this work is the Engineering Design & Optimization course (PPU191) at the Department of Industrial and Materials Science at the Chalmers University of Technology, held during the first study period (LP1) in the autumn with approximately 40 students each year. This is an elective master-level course at the Chalmers University of Technology and is mainly attended by students from Product Development, Applied Mechanics and Automotive. The course has been developed during the past seven years by several people and follows the principle of the CDIO initiative. A detailed description of the overall experiences from the development, teaching and evaluation of the course has been summarised by Quist *et al*. (2017), focusing on the learning objectives and the project assignments. Video-based learning material has also been developed for the course by Bhadani *et al.* (2017). The course does have a good balance between optimisation's theoretical and practical aspects with a strong industrial connection. The theory is based on the principle of optimal design by Papalambros and Wilde (2017) and is supported by guest lectures and hands-on assignments.

Most pedagogical approaches are focused on the learner perspective, while in practice, lectures are most likely teacher-centred (Felder and Brent 2016), which is often the case for the reference course. The problem was that students were often passively listening and only a handful of students asked questions during the lectures. As a teacher, it was difficult to confirm that the student understood the lecture's topic under these conditions. Active learning has been implemented previously in the course but in the form of assignments and workshops, not actively in the lectures. Wieman (2007) stated that people learn by creating their own understanding, and with learner-centred approaches, such as with interactive lectures, the aim is to facilitate the learning process. Within the CDIO framework, active learning is one of the 12 standards (Malmqvist *et al*. 2019). Active learning is considered to be an experiential learning method and aims to facilitate the students' process of creating their own understanding of the topic. Therefore, the purpose of this work is to incorporate a more collaborative learning environment with active learning activities in the classroom to improve student learning opportunities, their perception of the course and their interest in the subject of optimisation. At the same time, the main aim is to increase student engagement and interaction in class to improve their grade, the course evaluation and the number of master theses on the topic.

## METHODOLOGY

An action research methodology was applied to investigate the application of active learning activities in Engineering Design and Optimisation lectures. Action research is described as a combination of theory and practice; and is an iterative process (Avison *et al*. 1999). For pedagogical action research, the focus is on a reflective part of the underlying pedagogical issue and methodology determining a series of actions to handle the issue. The purpose is to systematically evaluate the teaching to modify current practice (Norton, 2019).

In the following section, the methods related to active learning and the associated topics is described. After that, the implementation of the active learning activities is described. Finally, the evaluation of the implementation and their results are shown. The evaluation consisting of a closed-ended questionnaire was used to evaluate student's perspective on the active learning activities. The survey was conducted at the end of the course for practical purpose and with the expectation that students could provide a holistic perspective of their experience with different active learning activities. The collected data was analysed to produce indicative trends about students' perspective on their experience with different activities in the lectures.

## METHODS

To effectively find appropriate methods, multiple teaching strategies need to be applied. There are several different methods available to support student interactions. However, in order to fully engage students, more aspects need to be considered than just including interactive learning activities. The approach here can be divided into three perspectives: create the right environment for the student interaction, incorporate interactive learning activities in the classroom, and set up systematic feedback for both the students and the teacher.

### *Learning environment*

For an appropriate learning environment, different psychosocial aspects need to be supported to engage the students actively. Zapke and Leach (2010) have formulated different perspectives and actions to improve student engagement. The students need to:

- be able to enjoy the learning process,
- feel confident enough to share and contribute,
- feel support and engagement from the teachers,
- feel challenged but not overloaded,
- see the purpose of the subject and link it to prior knowledge
- interact with others that have different background

All these aspects aim to increase student self-belief and intrinsic motivation to construct their own knowledge (Zapke & Leach, 2010). Creating an appropriate learning environment takes time, and some researchers even state that it takes half a semester before the students feel comfortable participating in interactive activities (Cooper & Robinson 2000). Hockings *et al.* (2008) noted that the student who reflect, question, conjecture, evaluate and make a connection between ideas whilst drawing on ideas, experience and knowledge of others are more deeply engaged. Smith (2000) proposed an informal cooperative learning strategy where the lectures were divided into segments of 10-12 min lectures followed by 3-4 min interaction activities. With the aim of creating a more cohesive and deeper conversation between the students to improve learning. However, there is a risk that it becomes a too predictable routine from some students' perspective (2016).

### *Interactive activities*

The means of creating more student engagement is with interactive learning activities. The interactions allow the students to reflect and re-formulate the information together with another learner. In Cooper and Robinson (2000), multiple small group approaches are described. This includes incorporating learning activities such as:

- Think-pair-share
- Think-pair-square
- Use incomplete hand-outs and slides
- Pose multiple-choice questions
- Quick-thinks – correct errors / compare
- Mind maps

Additional strategies are available for increasing engagement and interaction outside of the lectures (Rodríguez *et al.*, 2019). These may include:

- Flipped classrooms
- Gamification material

- Simulators

Flipped classroom and gamification material has previously been implemented and documented for specific workshops and assignments in the course (Quist *et al.*, 2017) (Bhadani *et al*., 2017).

***Feedback***

Students satisfaction has been found to have a significant correlation with how quickly they got feedback (Felder & Brent 2016) and from the teacher's acknowledgement of their expectations (Zepke & Leach 2010). Feedback to the student can be defined as either directive or facilitative, where directive feedback refers to direct instruction of what needs to be revised, while facilitative aims to guide the student in their own revision (Black & William, 1998). In this course directive, formative feedback has been used. Detailed guidelines on formative feedback to enhance learning have been formulated by Shute (2008) and include aspects such as Focus feedback on the task, Be specific and clear, Keep feedback as simple as possible, Provide feedback after learners have attempted a solution and more.

Communication is vital for both students and teachers. The class is a diverse set of individuals with different experience and cultural background. It is therefore essential at the start of the course to state follow topics to minimise the risk of unconscious bias or any inherent assumptions:

- Clarify the lecturer and TA purposes and roles
- Highlight the code of conduct in the course
- Enquire about their educational background
- Provide a variety of support services

The feedback from different interactive learning activities provides the student with either a confirmation or correction to their answer. It also provides feedback to the teacher on the efficiency of the process of learning. The format of the feedback depends heavy on the format of the activity. This may include:

- Face-to-face communication
- Written summary, highlighting strengths and weaknesses
- Quizzes from Canvas
- Online personal response system for polls, such as Mentimeter
- Minute papers

## IMPLEMENTATION

In the course Engineering Design & Optimization, 9 core lectures are focused on general aspects of optimisation. Those lectures, out of 16 in total, are the focus of this study. In the initial lecture, where the purpose is to introduce the general concept of optimisation, it is important to set the benchmark for the rest of the course. For the first part, the examiner and all TAs are present to go through the way of communication in the course by clearly stating the lecturers and TA roles during the course, the code of conduct and going through the variety of support service and channels for efficient communication between teachers and learner. That is to establish appropriate communication channels and clearly state the expectation of the students work.

During each lecture, two or more interactive activities were performed, and minute papers were available after each lecture. The number of lecture slides was reduced to allow for additional time for interaction and activities during lectures. Essential information was provided on the slides for students not able to attend the lecture. The methods and examples of how they were applied are described here in more details:

### *Think-pair-share*

Think-pair-share was be incorporated in most lectures. The think-pair-share activity's objective is to help the students with the conceptual understanding of the topic or question, encourage student-to-student interaction, and support the students in sharing their ideas with their peers. This was done in combination with other methods such as concepts maps, open questions or compare.

Example: Asking direct questions relating to the reading material such as the definition of monotonicity or contextual question such as for boundary optima in what cases can it be useful to incorporate penalty or barrier functions.

### *Mind maps*

The purpose of the concepts maps is to improve the students' conceptual understanding of optimisation, system structures and identify a logical relationship between different systems and subsystems. Each mind map is followed up with discussions and sharing the results with the rest of the class. This can also provide feedback to the lecturer, such as providing input on more appropriate case examples based on the student's background.

Example: Ask the student to map out their master program's knowledge base and identify the possible application of optimisation within that framework or create a concept map of a multi-objective or multi-system optimisation example and identify possible relationships and shared variables between different disciplines.

### *Open question*

Posting an open question to be answered at the end of the lecture, with think-pair-share or other supporting methods, aims to promote more active participation during class and help the student reflect on the topic from a particular aspect. Collecting the answer from all students at the end of the lecture with tools such as Mentimeter also helps clarify the lecture's efficiency in providing the student with the correct information to answer the question satisfactorily.

Example: Core questions connected to the lecture's main topic, such as: what are the criteria for a well-bounded optimisation problem or what are the characteristics of gradient-free optimisation algorithms?

### *Multiple-choice questions*

Multiple choice questions help highlight general misunderstanding of different topics, provide feedback to the lecturer on the students' understanding of the topic, and incorporate an iterative loop at the end of the lecture to highlight the lecture's essential aspects. It can be incorporated with compare or other similar methods. The questions can be posted during class or on the course webpage.

Example: Topic-specific questions such as identifying the active, inactive or semi-active constraint in an optimisation problem or selecting the correct definition of concepts such as the Lagrangian function.

#### *Incomplete hand-outs*

Incomplete hand-outs aim to promote more active participation during lectures and focus the students' attention on specific aspects of the topic to reduce their cognitive load. However, this can also activate discussions outside of the lecture room for those who cannot attend the lecture if incorporated into the PowerPoint lecture presentation.

Example: leave empty spaces in the presentation on a critical aspect of a definition. For example, suppose the Hessian is positive-definite. In that case, the variable is *blank space* or only provide the first step of calculating, such as determining the step length in a Gradient descent approach.

#### *Minute paper*

The purpose of the minute papers is to assess the students' perspective of what was difficult to understand during the lecture or their understanding of the material read before the lecture. This is also a channel for the students to express issues with the course, lecturer, or fellow students anonymously. The minute papers are available after each lecture for the students, often combined with a specific task or question.

## EVALUATION

The implementation has been evaluated from two different perspectives. The first part includes the comparison between the course evaluation of 2018 and 2019. This is to get more information on the students' perception of the course in general, i.e., if the course has improved their opinion on the lecture structure and the teachers involved compared to last year's participants. The second part is the questions aimed at capturing the students' impressions on the implemented methods. This provides a quantitative comparison between the different approaches and qualitative information about their perception of an engineering course's active learning strategies. Hall *et al.* (2002) have demonstrated an approach to quantify the students' perception when evaluating multiple teaching strategies.

In the course evaluation, the students were asked to give their opinion on if the activation methods supported their learning process during the lecture on a scale between 1 - Disagree completely to 5 – Agree completely. The same applied to the different tools used during the study period as well. Finally, they were asked for suggestions on how this could be improved. Out of 36 students registered for the course, 14 completed the course evaluation, which counts for 39 % of the course participants. In the previous year, 20 answered the course evaluation survey, about 44% of the course participants.

## RESULTS

One of the initial results was clear in the first couple of weeks into the course. The students were not using the minute papers. Instead, the students would come up during the break or after the lecture with specific questions for further explanations. The minute papers were therefore dropped after three weeks. The score results from the course evaluation (Figure 1) show that the students' appreciation for the course structure increased from 3.75 to 4.00, the teaching worked well, changing from 3.10 to 3.57 and the students' appreciation for the course literature increased as well from 3.10 to 3.57. While the overall impression of the course remained similar, changing from 3.70 to 3.71. In general, the student opinion on the course remains similar to the year before.

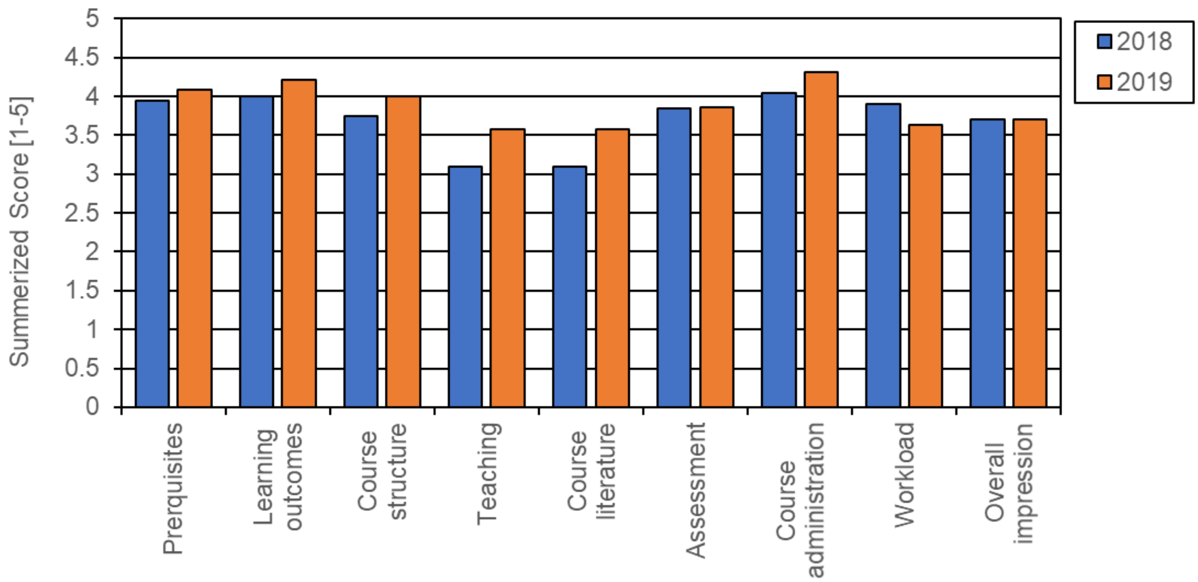


Figure 1. Overall course evaluation for 2018 and 2019.

However, the course evaluation is focused on the course as a whole, not a specific part of it. Areas that the active learning activities should affect did improve compared to the previous year. The most improvements were on the question: if the student perceived that the teaching went well. However, the activation activities were implemented in half of the lecture (eight) and two of the lectures were new compared to the previous year. Making it impossible to make any general assumption of the significance of the implemented methods. The questions specifically related to the implemented methods in the course survey were as follows:

Did the methods help your learning process of different topics during the lectures?

1. Did the Think-pair-share discussions help your learning process?
2. Did the Mind maps help your learning process?
3. Did the Word clouds help your learning process of different topics?
4. Did the True and false statements help your learning process?
5. Did the Multiple-choice questions help your learning process?
6. Did the Incomplete statements help your learning process?
7. Did the calculations in slides help your learning process?
8. Did the calculations on the board help your learning process?
9. Did stating a direct question help your learning process?

Figure 2 illustrates the average points of each question if the student agrees or disagrees with the statement that the method in question supported their learning process. The value five corresponds to "Agree completely" while one corresponds to "Disagree completely". The proportional distribution within each question is also illustrated with the different colours.

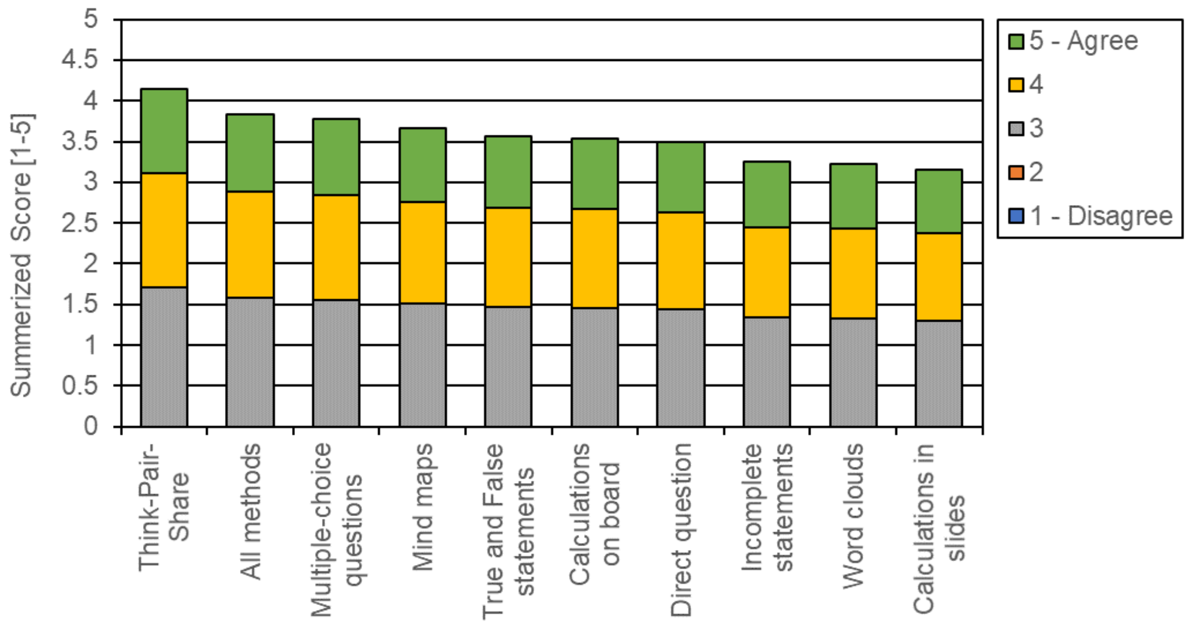


Figure 2. Evaluation of the activation strategies.

In general, the students appreciated the activation methods, and from the evaluation, the think-pair-share was the most appreciated activation method. The think-pair-share activity had an average score of 4.14. After that came the multiple-choice question, the mind maps and the true and false statements. At the lower end of the evaluation of the methods are the calculations on slides, word clouds and incomplete hand-outs. The students also appreciate more having examples calculated on the board instead of being provided in the slides, which would entail more activation during the lecture.

The questions specifically related to the supporting tools in the course survey were as follows:

1. Did support tools work well during lectures?
2. Did Socrative work well during lectures?
3. Did Mentimeter work well during lectures?
4. Did the hand-outs work well during lectures?

Figure 3 illustrates the average points of each question if the student agrees or disagrees with the statement that the tools in question worked well to facilitate their learning process. The value five corresponds to "Agree completely" while one corresponds to "Disagree completely". The proportional distribution of within each question is also illustrated with the different colours.

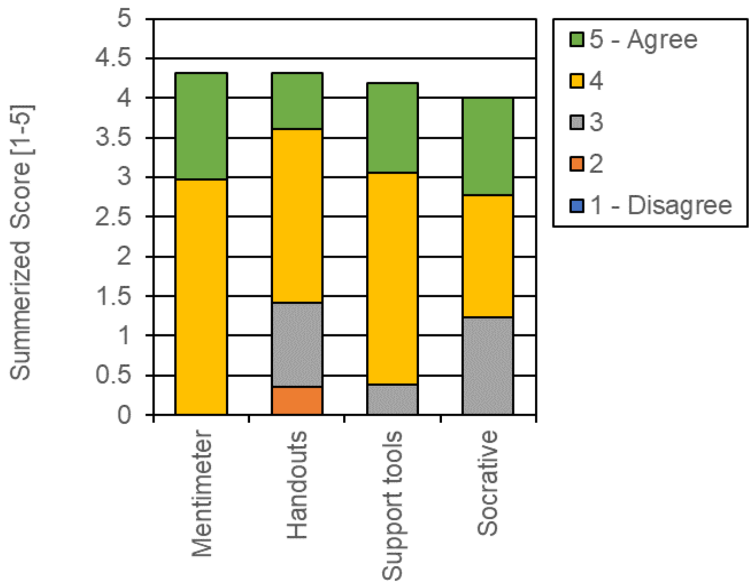


Figure 3. Evaluation of the supporting tools.

The support tools used during the course were all highly appreciated, with all scores above 4. No issues came up during the lectures, and the students had no difficulty with the corresponding app or webpage when answering questions.

The course's final grade is a balance between the format of the content included in the exam and students' preparation for the exam. Since the exam changes every year, it is difficult to use it to measure students' performance. In the previous year, the average student grade, who passed the exam, was 3.9 compared to the average of 3.5 this year. However, the number of students that did not pass the course went from 19 to 5 between the years. In the previous year, ten students didn't even attempt the final exam.

## DISCUSSIONS

During the lectures, I experienced more interaction with the student. The think-pair-share activities created a good discussion environment that was difficult to stop sometimes. Stating a related question on the topic, with true or false statements, multiple-choice questions, incomplete statement, or other means. Gave all the students' possibility to discuss the question or statement, answer the question and then reflect on the results. After the answer was revealed, the second round of discussion usually started by connecting the question to a specific lecture slide. Stating a direct question was difficult and usually resulted in only a few students participating in the activation.

The process of creating and implementing active learning activities was simple. After the initial demos, the lectures' questions were configured on the related app or web page in minutes. In these implementations, both Socrative and Mentimeter were used. The results can be logged to keep track of the students' general development if the same approach is implemented throughout the course. The results from each task will help develop the questions and their format for the course next year. The time it took to conduct those activities requires some alteration of the lecture material in content full lectures. This entails putting an extra focus on the essential part of the theory and directing them to find additional information that is good to know. Creating an efficient pre-lecture preparation material will also help with time allocation.

The lectures' format will be further developed for next year, focusing on think-pair-share activities in each lecture. Activities such as multiple-choice questions and true and false statements will be done regularly to get feedback on the students understanding of the subject during a lecture or from the request reading material. Calculations are an essential part of the course material that needs to be revisited and changed to improve their impact on the learning process.

The implementation's main goal was to increase student engagement and interaction in class to improve their grade, the course evaluation, and the number of master thesis on the topic. During the study, general observations were that active learning does activate the student efficiently during lectures and makes them more engaged both during the lecture and between them. By introducing discussion and reflection during the lecture, the learning process should also improve. The average course grade became lower between the years. However, the percentage of students attempting the final exam and the student that did not pass reduced significantly.  After the course, several students have also approached me with master theses proposals related to optimisation. Five optimisation related design projects were conducted during the following spring, providing additional examples for the course. Compared to one from the previous year.

## CONCLUSIONS

The different active learning activities worked well from the authors' perspectives. The students appeared to be more engaged and interactive during lectures, more students passed the course examination and more applied optimisation in their thesis work. The study was explorative with several different methods tested to see what worked well in this particular situation with this topic and these students. Each year the course content and structure will change slightly based on the course evaluation. However, based on the experience from the implementations, the active learning activities will be an integrated part of the course in the coming years.

## REFERENCES


Avison, D. E., Lau, F., Myers, M. D., & Nielsen, P. A. (1999). Action research. *Communications of the ACM*, *42*(1), 94-97.

Bhadani, K., Stöhr,C., Hulthén, E., Quist, J., Bengtsson, M., Evertsson, M. and Malmqvist, J. (2017). Students Perspectives on Video-Based Learning in CDIO-Based Project Courses. *Proceedings of the 13th International CDIO Conference*, Calgary, Canada.

Black, P., Wiliam, D. (1998). Assessment and classroom learning. Assessment in Education: Principles, Policy & Practice 5(1), 7-74.

Shute, V.J. (2008). Focus on Formative Feedback. *Review of Educational Research, 78*, 153-189.

Cooper, J. & Robinson, P. (2000). Getting Started: Informal Small-Group Strategies in Large Classes. *New Direction for Teaching and Learning, 2000*(81), 17-24.

Felder, R.M. and Brent, R. (2016). *Teaching and Learning STEM: A Practical Guide* (1st ed.). San Francisco, USA: Jossey-Bass.

Hall, S. R., Waitz, I., Broadeur, D.R., Soderholm, D.H. and Nasr, R. (2002). Adoptation of Active Learning in Lecture-Based Engineering Class. *Proceedings of the 32nd ASEE/IEEE Frontiers in Education Conference*. Boston, USA.

Hockings, C., Cooke, S., Yamashita, H., McGinty, S. and Bowl, M. (2008). Switched off? A study on disengagement among computing students at two universities. *Education, 23*(2), 191-201.

Malmqvist, J., Knutson, M., Lundqvist, U., Edström, K., Rosén, A., Astrup, T. F., Vigild, M., Hussman, P. M., Grom, A., Lyng, R., Gunnarsson, S., Huay, H. L.-W. K. and Kamp A. (2019). Towards CDIO Standards 3.0. *Proceedings of the 15th International CDIO Conference*, Aarhus, Denmark.

Norton, L. (2019). Action Research in Teaching and Learning - A Practical Guide to Conduct Pedagogical Research in University (2nd ed.). New York, USA: Routledge.

Papalambros, P. Y. and Wilde, D. J. (2017). *Principle of Optimal Design - Modelling and Computation* (3rd ed.). New York, USA: Cambridge University Press.

Quist, J., Bhadani, K., Bengtsson, M., Evertsson, M., Malmqvist, J., Enelund M. and Hoffenson, S. (2017). CDIO Based Engineering Design and Optimization Course. *Proceedings of the 13th International CDIO Conference*, Calgary, Canada.

Rao, R. V., Savsani, V.J. and Vakharia, D.P. (2011). Teaching–learning-based optimisation: A novel method for constrained mechanical design optimisation problems. *Computer-Aided Design, 43*(3), 303-315.

Rodríguez, M., Díaz, I., Gonzalez, E.J. and González-Miquel, M. (2018). Motivational active learning: An integrated approach to teaching and learning process control. *Education for Chemical Engineers, 24*, 8-13.

Smith, K. (2000). Going Deeper: Formal Small-Group Learning in Large Classes. *New Direction for Teaching and Learning, 2000*(81), 25-46.

Wieman, C. (2007). Why Not Try: A Scientific Approach to Science Education. *Change: The Magazine of Higher Learning, 39*(5): 9-15.

Zepke, N. and Leach, L. (2010). Improving student engagement: Ten Proposals for action. *Active learning in Higher Education, 11*(3): 167-177.

## BIOGRAPHICAL INFORMATION

***Gauti Asbjörnsson*** (PhD) is an Assistant professor at the Department of Industrial and Materials Science at Chalmers University of Technology. His research focused is on modelling and optimisation in minerals processing.

***Kanishk Bhadani*** (MSc) is a PhD student at the Department of Industrial and Materials Science at Chalmers University of Technology. His research focused is on optimisation in minerals processing.

***Corresponding author***
Gauti Asbjörnsson
Chalmers University of Technology
Dept. of Industrial and Materials Science
Hörsalsvägen 7A, 412-58, Gothenburg
Sweden
0046-729819993
gauti@chalmers.se