7 YEAR ITERATIVE IMPROVEMENTS IN LABORATORY WORK - CONSTRUCTIVE ALIGNMENT

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ABSTRACT

Most agree that laboratory work is essential for engineering learning. The purpose of laboratory work is usually to the deepen understanding of the material and/or to prepare students for the workforce. However, having well thought out experiments certainly does not guarantee that those goals are met. In order to meet those goals constructive alignment is of utmost importance. Having appropriate learning outcomes, appropriate assignments corresponding to the laboratory work and having it aligned to coverage in lectures is crucial to reach constructive alignment. Having an appropriate group size in the laboratory work is also vital. The group size needs to fit the number of tasks in each experiment but also to fit the assignment format to ensure active engagement of all members. This paper presents an experiment on improving laboratory work component of an undergraduate Fluid Mechanics course in Mechanical and Chemical Engineering at University of Iceland. The experiment spans the years from 2015 to 2021, where several adjustments in the laboratory were tested. The measurements tools include i) midterm and ii) end of term student teaching quality surveys with Likert scale questions and open-ended replies, iii) a survey specially made by the author to target the laboratory work (with Likert scale questions and open-ended replies) and iv) a focus group interview on the same subject. The experiment sparked because a large portion of students complained that the workload of the laboratory work was immense and in no correlation to the ECTS units given for the course. This turned out to be a valid point. More seriously students also complained that they did not see the purpose of the laboratory work and that they learned nothing from it. By making adjustments to the alignment of material coverage and laboratory work, by reducing idle time in the laboratory, by adjusting the laboratory work assignment, by making sure the group size was manageable and more significant improvements were seen in reduced student workload perception, student perceived learning, student enjoyment of the laboratory and students saw the purpose of the laboratory. Since workload perception may differ from actual workload it may be assumed that with better structure and learning, workload perception was reduced with the same learning objectives. Some of those results have been published in two papers in the journal International Journal of Engineering Education but this paper emphasizes the newest developments since their publications and more detailed cumulative analysis.

KEYWORDS

Laboratory Work, Formative Assessment, Assignments, Group work, Constructive alignment, Standards: 1, 2, 3, 6, 7, 8, 10, 11, 12.

INTRODUCTION

The laboratory work in an undergraduate Fluid Mechanics course in Mechanical and Chemical Engineering at the University of Iceland had been the same for decades when the author of this paper started teaching the course. She initially just taught the course as traditionally done but heard students complain about immense workload and not seeing the purpose of the laboratory work. This surprised her since she considered the laboratory work crucial to help students gain deeper understanding and intuition on Fluid Mechanics. Simultaneously she was being introduced to student centered learning and the vast literature on scholarship of teaching of learning, so she was determined to find the reason for this mismatch in instructor's intensions and students experience and fix it all. Little did she know that 7 years later that journey was still ongoing. This paper shortly discusses this journey with the emphasis on the newest improvements.

LITERATURE REVIEW

Laboratory work is considered essential for engineering studies (Feisel & Rose, 2005) as by doing properly designed hands-on experimentation students learning is aided (Buntine et al., 2007). Constructive alignment i.e., having appropriate learning outcomes, assessment that supports learning and learning activities that support learning, is essential for learning to occur (Biggs, 1996). The purpose of laboratory work is either to support learning or prepare students for working in the industry or in many cases covers both aims. Where the purpose is to aid learning (as is in this case) it is of utmost importance that the laboratory work is linked with the coverage of material in the course (Hunsu, Abdul, Wie, O. Adesope, & Brown, 2015). If it does not, then the learning activity of laboratory work is ill fit to support learning.

Lack of alignment in material coverage in a course and in its laboratory work is common. This is due to logistical reasons i.e., laboratory equipment is expensive meaning few or only one set of each is available, and laboratory work requires more time involvement of instructors and lab technicians than other forms of learning, meaning laboratory hours are limited and difficult to fit into an already packed schedule. Most deal with this lack of alignment by having thorough laboratory instructions (Lal et al., 2020; Nikolic, Ritz, Vial, Ros, & Stirling, 2014) but many experience that they are useful but insufficient (Helgadottir, Palsson, & Geirsdottir, 2022). Whittle and Bickerdike (2015) used online multimedia sources followed by quizzes, Cranston and Lock (2012) use three plenary minilectures during the laboratory session and Rodgers et al. (2020) use 6-9 minute videos to successfully prepare students for laboratory work on material not covered yet in lectures. However, it must be best, if possible, that students have been acquainted with the material beforehand and those preparation videos can rather be used as a further support for students. COVID-19 has sped up some technological improvements in teaching and now videos have become the new norm. Chew et al. (2021) report making 450 short videos to prepare students for laboratory work with good success. 80% of students were pleased with this format. This was done to make up for school closures due to COVID-19, but post COVID-19 could be used to supplement onsite laboratory work and particularly to aid preparation for students for laboratory work.

Usually, laboratory reports are the assignment formats due after each laboratory session, however, homework (Hunsu, Abdul, van Wie, Adesope, & Brown, 2015), quizzes or assignments (Kresta, 1998) based on experiments, real time visual comparison of students' results and results from other students (Cranston & Lock, 2012), oral presentations (Grant, 1995), blogging (Hicks, Bruner, & Kaya, 2017), turning in single sections of lab reports (Heslop, 2017), synopsis reports (Hoffa & Freeman, 2007) and portfolios (Chen, DeMara, Salehi, & Hartshorne, 2018), have been reported in the literature. Mastering report writing is essential for graduating engineering students but their learning in field of the laboratory work is not increased by writing a report on it rather than completing other well thought out assignments forms (Helgadottir, Palsson, & Geirsdottir, 2020).

Manageable workload is crucial for students to be able to acquire the material covered in a course (Entwistle, 2009; Kember, 2004). Workload prediction is complicated but a well-studied field (Chamber, 1992), with the exception that there is a gap in the literature when it comes to workload in laboratory work. One can assume though that most alternative assignment formats to report writing reduce the workload of students (Chen et al., 2018; Heslop, 2017; Hoffa & Freeman, 2007). Workload perception is not necessary the same as actual workload even though having time is crucial for feeling manageable workload (Chamber, 1992; Prosser & Trigwell, 1999). Other factors like well-structured courses, students being able to ask questions, examples students can relate to, even workload, and more have shown to lead to students experiencing lower workload even though the time they spend on the course might be higher.

METHOD

Student teaching evaluation surveys are used at University of Iceland both midterm (formative) and end of term (summative for administrators, promotions and tenure and formative to improve the course next year). The multiple Likert scale questions there are not tailored to the laboratory work which is only part of the course so only the open-ended replies in those surveys have turned out to be useful in exploring the effects of making changes in the laboratory work of the course. Students tend to only address what they are particularly pleased or dissatisfied with in open-ended replies so those give an indication of what brings up strong emotion among students. More detailed answers are only achievable by asking them specifically which is why in 2015-2021 (apart from 2020 since COVID-19 restrictions greatly affected laboratory work) the author of this paper made a special laboratory work focused survey for students. The number of students in the course in each year varied from 29 to 76 with 43 being the average. The participation in the laboratory focused survey varied from 40.8% to 61.1% during that time. In 2018 to get more detailed analysis a one-time five student focus group interview was held and analyzed with a thematic approach, which results confirm other results but will not be presented in detail here. In this paper the results of the laboratory work focused survey of all years is combined getting a more detailed analysis of the effects of each change in the laboratory and significantly more replies than results only based on each year. The focus is also on new additions in 2021. The interested reader is pointed to Helgadottir et al. (2020) for more detailed analysis, year by year, of the effects of different assignment format used in 2014-2018 and pointed to (Helgadottir et al., 2022) for more detailed analysis, year by year, of the alignment of lecture and laboratory work in 2014-2019.

A list of how the laboratory work was in each year is given in Figure 1. To explain, 2015 represents previous setup but 2016 and later altered setup, with the exception that in 2020 due to COVID-19 restrictions the laboratory was altered so much it is not considered beneficial to include the results in this study. In the old schedule 5 sessions, each 3 hour long were held every week in October (so starting in week 6 or 7 of a 14-week semester). Five groups worked concurrently, each on separate experiments, rotating each week. Students often worked on experiment covering material that had not been introduced in lecture beforehand. Online PDF instructions were, however, available. In the new set up 6 sessions were held, each 1 hour long, only one group at a time meaning idle time waiting for instructor to assist was eliminated. This meant the content of the experiments was not reduced in the new schedule. All groups worked on the same experiment in the same week that was 1-2 weeks after coverage of the material connected to the experiment in lecture. This meant students had been familiarized with the material before working on an assignment based upon it as is crucial for constructive alignment as is known to be essential to support learning (Biggs, 1996). This also meant the experiments were not evenly distributed during the semester but rather in weeks 3, 4, 9, 10, 11 and 12 of a 14-week semester. In the new laboratory schedule adding a new group means adding one hour to the time the laboratory technician and instructor need to be present. In the new schedule the time needed for laboratory instructions, therefore, fluctuates more with enrollment. Making sure the number of students in each group fits tasks in experiment and is appropriate for the assignment due after each experiment, is essential for student learning.

Figure 1. Summary of the arrangement in laboratory work in each year.

2015	2016	2017	2018	2019	2020	2021
5 sessions	6 sessions	6 sessions	6 sessions	6 sessions	Not in this study included due to COVID-19 restriction effects	6 sessions
3 h each	1 h each	1 h each	1 h each	1 h each		1 h each
Each group working on separate exp. per session	All groups working on the same exp. in the same week	All groups working on the same exp. in the same week	All groups working on the same exp. in the same week	All groups working on the same exp. in the same week		All groups working on the same exp. in the same week
5 groups working concurrently	1 group working at a time	1 group working at a time	1 group working at a time	1 group working at a time		1 group working at a time
Timing of exp. not linked to coverage in lecture	Exp. 1-2 weeks after coverage of material in lecture	Exp. 1-2 weeks after coverage of material in lecture	Exp. 1-2 weeks after coverage of material in lecture	Exp. 1-2 weeks after coverage of material in lecture		Exp. 1-2 weeks after coverage of material in lecture
		Postlab	Postlab	Postlab		Postlab
Reports	Worksheets, 1 report	Short reports	Excel sheets	Excel sheets		Excel sheets
				Reflective questions		Reflective questions
						Preparation and postprocessing videos

A few changes were made after the initial changes in 2016. A postlab discussion was added in 2017 and later, where the results of all groups were compared in a lecture following each experiment. This meant constructive alignment was further improved and by adding discussion and reflection, so students' learning was likely to be deepened (McKeachie & Svinicki, 2014). Reflective questions were added to the postprocessing in 2019 and later to further push students to the higher level of thinking according to Blooms taxonomy (Bloom, 1989). The search for the most fitting assignment output for analyzing the results has led us from full reports (2015) to worksheets (2016), to short reports (2017), to Excel sheets (2018 and later). The full reports were traditional laboratory reports. The worksheets had the same contents as the lab reports without the continuous text i.e., it was premade by instructor with blanks for students to fill in. The short reports put the focus on analysis of results, but other traditional laboratory chapters could be incomplete. The excel sheet was premade by instructors, students filled in their results and special emphasis was on analysis. This made it easy for instructors to write a Python code that automatically compared the results of all groups and did statistical analysis of their results. This was essential to efficiently prepare the postlab discussions previously mentioned. In 2021 at most 4-minute-long preparation videos for each laboratory session were added to Canvas as additional laboratory preparation for those that considered the laboratory PDF instructions insufficient. In addition, at most 2-minute-long videos on postprocessing of each experiment were added to supplement the previously mentioned laboratory instructions.

RESULTS AND DISCUSSION

Overall results 2015 – 2021 combined

The estimated time students needed to spend on the course in the previous format was 180 hours before the change in the laboratory work and 170 after the change (Sigurdsson, 2011). A 6 ECTS unit course, as Fluid Mechanics is, should be between 150 and 180 hours of work for students. It was, therefore, before the change right on the maximum limit but below it after the change. This is reflected in students' perception of workload. Before the change 28% of students considered the workload too much, 44% a lot and 28% just right. After the change in 2016 17% considered it too much but also only 17% considered it just right, the rest considered it a lot. The change in setup, therefore, reduced the number of students that considered it too much but also those that considered it just right. This turned out to be because the worksheets were considered too time consuming. So, the reduced attendance requirement which should have led to lower workload did not lead to an overall workload reduction in the laboratory work because the worksheets surprisingly took longer to complete than full laboratory reports. In all the following years the percentage of students considering the workload fitting ranged from 64 – 87% and even a few students reported it being low. The new schedule, therefore, is experienced as appropriate workload for students. Students in 2018, 2019 and 2021 were asked how much time it took them to complete each Excel sheet and on average it took them less than 2 hours.

Before the change students wanted to spread experiments more evenly over the semester and few realized aligning them with lectures was beneficial. Many wanted a numerical project, i.e. computational simulations of flow, instead of experiments since they did not see its purpose. After the change (in total 103 replies) over 93% of students prefer the new schedule, less than 3% would like some other form with alignment of lectures and laboratory, and less than 4% of students mention some other schedule without alignment but rather having the laboratory work more evenly spread out over the semester. After the change, no student suggested numerical work instead of laboratory work, indicating that they now see its purpose. I believe the reason all students realized the purpose of the laboratory work after the alignment, but some did not before the alignment, is because now students had learned about the material in class prior to the experiment and could, therefore, relate to it. Prior to the alignment they just followed a recipe, often without understanding, making it hard for them to fully grasp the purpose of the laboratory. In the focus group students particularly mentioned that they felt they learned more from this set up rather than laboratory work in other courses where this alignment was missing.

Using two sided Welch t-test (Derrick, Toher, & White, 2016) it can be stated with 5% certainty that students report learning more in 2016 than 2015 and more in 2017 than in any other year. They also enjoyed the laboratory work more in the improved laboratory schedule than previously except for 2016 when the worksheets were too time consuming. When asked if they learned from the assignment format there is not any statistical significance between the replies in all years even though the assignment formats altered significantly. Students in 2018, 2019 and 2021 were asked if they believed they learned more Fluid Mechanics from the Excel sheets than writing a report and they moderately agreed (3,29 on a 5-point Likert scale with sample variance 1,03). It can, therefore, be stated that the new schedule is an improvement and preferred by students. However, the assignment format has little impact on how much students perceive learning but does impact how much workload they perceive and how much they enjoy the laboratory work.

The assignment format also impacts how easily the instructor can compare the results of all groups which is essential for a successful postlab discussion. After the postlab discussion was added (in total 92 reply) students reported learning from the combined analysis of all groups and discussion i.e., it received 3.97 with a sample variance 0.8 on a 5-point Likert scale. The students in 2019 and 2021 (in total 47 answers) very much agreed to learn from the thought-provoking reflections for each experiment (Likert score 4.53 out of 5 with standard variance 0.34) and enjoying them (Likert score 4,06 out of 5 with standard variance 0,76).

Taking the average over all years (total 136 replies) of the number of students they consider ideal in a group is 3.87 which is consistent with the number of tasks in the experiment and with the consensus in the literature of an ideal group size between 3 and 4. Being able to make sure the group sizes don't exceed this is sometimes challenging but essential for student learning.

In addition to the quantitative data presented here numerous open-ended replies support that the changes in the laboratory work were significant improvements to students experience and learning.

To emphasize, constructive alignment is achieved by having learning outcomes that fit the course and the curriculum, assessment that supports learning, and learning activities that support learning. In this paper the learning outcomes of the laboratory work are not covered, but they have been scrutinized. The assignments of the laboratory work were also iterated to better support learning as explained above and in detail by Helgadottir et al. (2020). The largest gap needed to be bridged to reach constructive alignment in the course, however, was to make sure that the learning activities of the laboratory work supported learning of the material covered in the course. When students had not learned about the material before participating in an experiment (as in the previous set up) then the laboratory work did not support their learning and a learning opportunity was missed. When they had been familiarized with the material the laboratory work covered then, contrary to previously, the laboratory work further enhanced their learning. The postlab discussions were an additional learning activity that further supported their learning on the material covered in each experiment by digging deeper and giving them a different perspective. Therefore, aligning the coverage in lecture and the laboratory work schedule was essential to make the learning activity, i.e. laboratory work, support learning, and therefore crucial for reaching constructive alignment.

Analysis of additional developments in 2021

In 2021 short preparation videos for the laboratory work and analysis were added to the PDF instructions over 74% of students in 2021 felt the preparation videos for the laboratory work were very useful, just over 16% found it rather useful and less than 10% were neutral. No student did agree with finding it not useful. In 2021, just over 45% of students found the videos explaining the analysis of the results very helpful, 35.5% rather helpful, just over 16% were neutral and just over 3% found them rather useless. Students were also asked if the online

PDF instructions were useful. Over 45% strongly agreed, over 45% rather agreed, 6.5% were neutral and just over 3% found them rather useless.

The focus group of 2018 said one of the benefits of the laboratory was that the instructor was present during the laboratory work. They said this was because then the link between lectures and laboratory work was stronger and, therefore, their learning. In 2021 due to a significant increase in number of students (the total hours of the laboratory were 96 hours) the instructor did not attend the laboratory work but rather an excellent teaching assistant. Students were asked if they thought it would have been better if the instructor had attended the laboratory work and 2/3 of students either strongly or moderately agreed with this statement even though over 80% of all students found the teaching assistant either very or moderately helpful. Having an instructor rather than a teaching assistant attend laboratory work is uncommon so this is an issue that needs to be further investigated in the literature.

LIMITATIONS AND FUTURE DEVELOPMENTS

The main limitation of this study is that even though this study covers many years the total number of students is rather low, it has not been applied to other courses, the statistical analysis is basic and learning and workload measures are based on students' perceptions rather than concrete measures. Despite this it is a solid foundation for future research on this subject.

Shibl, Anwar, Wegdan Wagdi, and Ali (2020) describe how they use the CDIO approach to alter laboratory in Fluid Mechanics to enhance learning. In the future it would be interesting to make similar adjustments to this laboratory work component and rigorously measure its effects and compare to the previously acquired data.

As brilliantly suggested by one of the reviewers it would be beneficial learning experience for students to let them prepare their own worksheets. Then they would need to think about what would be the clearest way to present the material for a user and that would push them to a higher level of learning according to Bloom's taxonomy (Bloom, 1989). This would, however, mean that the automatic extraction of data using the python code script to read the Excel sheets, which was essential to make preparation of the postlab sessions fast and efficient, would fail and the preparation would become much more time consuming. However, a middle ground could be found i.e., letting students prepare their own worksheets for some of the experiments and giving them standardized forms for other experiments. Thus, a balance in workload of the teacher and challenging students could be reached.

CONCLUSION

In this paper a 7-year long journey of improving a laboratory work section of a course and monitoring its effects, is analyzed. Teachers experienced that students felt the laboratory work component too time consuming, that their learning was minimal and undervalued its purpose. By minimizing workload yet maintaining the similar tasks and learning outcomes and analyzing the course with respect to constructive alignment, students' perception of the course shifted significantly. Now the workload was acceptable, their learning was increased, they realized the laboratory work's purpose and even enjoyed it. In the coming years it would be interesting to explore with letting students make some of their own worksheets to push them to a higher level of learning. This would require finding ways to make the postlab preparation less time consuming for the instructor despite the worksheets differing from group to group.

This paper shows clearly how using ideas from the literature on constructive alignment can improve student perception of workload and learning. By doing so their satisfaction is improved and they gain insight on purpose of laboratory work. This paper also demonstrates how rewarding even small improvements in teaching can be for students and teachers. It, however, also demonstrates that improvements in teaching are (and should be!) a never-ending story.

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