International Journal of Engineering Education Vol. 38, No. 1, pp. 264–282, 2022
Printed in Great Britain

0949-149X/91 $3.00+0.00

Improving Student Learning Experience in Fluid Mechanics with Lecture/Lab Alignment and Post-Lab Discussion*

ÁSDÍS HELGADÓTTIR
Faculty of Industrial Engineering, Mechanical Engineering and Computer Science, University of Iceland, Reykjavik, 107, Iceland.
E-mail: asdishe@hi.is

HALLDÓR PÁLSSON
Faculty of Industrial Engineering, Mechanical Engineering and Computer Science, University of Iceland, Reykjavik, 107, Iceland.
E-mail: halldorp@hi.is

GUÐRÚN GEIRSDÓTTIR
Faculty of Education and Pedagogy, University of Iceland, Reykjavik, 102, Iceland. Center for Teaching and Learning, University of Iceland, Reykjavik, 102, Iceland. E-mail: gudgeirs@hi.is

The paper explores curriculum development within the laboratory component of a fluid mechanics course taught at the University of Iceland. The paper addresses various steps taken to improve the laboratory work component of the course, such as, shortening experiments, aligning the schedule of laboratory work exercises with lectures, and adding postlab discussions. University midterm and end of term surveys were not effective to measure the consequences of the changes, so an additional survey focused on laboratory work was made. In addition, a student focus group interview was held three years into the study to further confirm and deepen the findings on the effect of the changes made. All measurements indicate an improvement in the laboratory component by using the new schedule, in particular with the synchronization of lectures and experiments and with the addition of postlab discussions, where the results of all lab groups are compared and analyzed. Students reported increased satisfaction with the laboratory work, more appropriate workload, and better understanding of and learning from the laboratory work as compared to the past.

Keywords: laboratory work teaching; fluid mechanics; mechanical engineering education; chemical engineering education; workload; curriculum development

1. Introduction

In this study, the authors seek to arrange the laboratory component in an undergraduate fluid mechanics (FM) course in mechanical engineering (ME) and chemical engineering (ChE) at the University of Iceland (UoI) so that it better supports students learning. The authors intend to address the students' critique that the laboratory work was extremely time consuming and did not add to their understanding of the main concepts of the course. The purpose of the laboratory component of the course is to give hands-on experience with various aspects of FM to provide students with a deeper understanding of the subject. This goal seemed to be not met with the previous arrangement of the laboratory component, so changes were made. The research question for this study can be formalized as follows:

- Do the curriculum changes in the laboratory component address students' concerns about the workload, learning and purpose of the laboratory component?

To give a better idea about the student population participating in the course and this study, the course is mandatory in the third and last year of the BSc degree in ME, in the second year in ChE and is an elective in various other programs, mostly from engineering physics. Student enrollment in the class during the study (2014–2019) varied from 29 to 57.

The paper starts with a literature survey, followed by a description of previous and altered setup of the laboratory component. The assessment of the curriculum development is based on the university-wide midterm and end of term surveys (years 2014–2019), a survey focused on the laboratory component (years 2015–2019) and on a one-time interview with a student focus group about the laboratory component (year 2018). The paper is concluded by a discussion on the results, the gains and drawback of the new schedule, the limitations of this study and by linking this study to the broader spectrum of how faculty scholarship in higher education can develop while working on changes to the curriculum.

2. Literature Review

Laboratory work has always been an essential part of engineering studies, although its significance has varied with time, demographics and focus of study,

---

* Accepted 23 October 2021.

among other things [1]. Research findings agree that, in order to fully grasp the concepts of engineering, reading about the subject in a book is not enough. Despite some contradictory findings [2], most of the literature agrees that experience aids learning [1, 3–9] and that adding well thought out, hands-on experimentation [10] and numerical modeling can benefit student learning.

Feisel and Rosa point out that even though laboratory work has always been considered crucial part of engineering studies their learning outcomes are seldom specified [1]. This fact was largely undetected until online engineering programs sought accreditations, despite it being well accepted in engineering design that expecting acceptable results and evaluating whether a design criteria has been met is impossible if the design criteria itself is not clearly stated. Accreditation Board for Engineering and Technology (ABET) since came up with 13 learning outcomes of engineering laboratories [1] that can be used on engineering study programs . There is a general consensus about those learning outcomes, with a few minor exceptions, but learning outcomes need to be specified for each laboratory course in order to provide a focus for instruction, guidelines for learning, targets for assessment, evaluation for instruction, feedback for continuous improvement and convey instructional intent to others [11].

Traditionally, laboratory work has been hands-on (e.g., [12–15]), but demonstration of experiments also existed. With increased advances in technology, remote (off-site but in real time, e.g., [16]), virtual (numerical simulation, e.g., [17, 18]) and visual (demonstration or a video, e.g., [19–21]) laboratory work has become more common. Multiple articles have assessed the differences between traditional and nontraditional laboratory work (remote, virtual and visual) and most agree that student learning outcomes are comparable [22, 23]. Based on those findings, choosing which type of laboratory work (traditional, remote, visual, or virtual) to use might be more based on non-educational values like cost, availability, tradition and logistics. In the ME and ChE study programs at the UoI, traditional hands-on laboratory work has been taught for decades inside of FM. The equipment for the laboratory component has recently been renovated, and traditional laboratory work will only be used in this class in the near future due to financial and logistical reasons, as well as faculty tradition.

The scheduling of laboratory work in engineering curriculum varies. Many schools have adopted one or more laboratory courses that exclusively cover experiments in various subjects (e.g., [12, 15]). Others have the laboratory section included in the courses covering the subject material in question. In ME at the UoI, the laboratory component of each subject, if included, has been part of the course covering that subject instead of separate laboratory courses covering experiments in all the ME subjects. In ChE at the UoI, laboratory focused courses do exist but do not cover experiments in FM. The experiments in FM do touch on most of the topics covered in lecture, so the curricular development described in this paper, is restricted to changes in schedule and organization rather than to the experiments themselves. Various types of experiments in FM have been documented previously [17, 24–35], and a short description of the experiments currently explored in this FM course is given in the appendix.

The number and length of FM-related experiments covered in ME and ChE varies greatly. In a short literature review, the authors found that the number of FM experiments ranged from zero to eleven [19] (the one with eleven experiments was an outlier though and the experiments were only demonstrated to students) with three or less being most common [12–15, 36–38]. The length of each experiment commonly varies from one to three hours [14, 37–39]. Grant [37] claims that an experiment should not exceed two hours with analysis in order to achieve its purpose and be an effective usage of student's time. In the FM course in ME and ChE at the UoI, students perform six distinct laboratory experiments that have traditionally been three hours long.

Constructive alignment is of utmost importance for learning to occur [40]. This means that learning outcomes need to fit the course and the curriculum, assessment needs to support learning, and most importantly for the focus of this paper, learning activities need to support learning. As the purpose of laboratory work is to help students better grasp the concepts of the subject covered in lectures, it can be assumed that one would like to link an experiment to learning about the subject in class [13]. Due to logistic reasons, this is not always possible. FM laboratory equipment is expensive and only one group can work at a time on each equipment. Fitting all groups within a time slot between coverage in class and finals that is reasonable for students, staff and instructors is often problematic. In laboratory only courses, this obstacle may be avoided by having a lecture course on the subject as a prerequisite. In courses where the laboratory is integrated into a course on the same subject, the timing of the laboratory hours within the term is even harder. Thorough laboratory instructions are essential [41, 42] but hardly enough to overcome this complete lack of student preparedness. Preclass assignments [43, 44] and online multimedia sources [45] followed by quizzes have been effectively used previously to encourage students to prepare for lectures and laboratory sessions in settings where alignment is lacking between laboratory and lectures. Cranston and Lock [14] reported that 2/3 of their students had not yet covered the material for the experiments in lecture at the time they were conducting them in the laboratory section. As a remedy, three plenary mini lectures on the subject are given by the instructor during a three-hour laboratory session. Rodgers, Cheema, Vasanth, Jamshed, Alfutimie and Scully [46] use 6-9 minute videos, first one for each experiment and later three for each experiment, to increase student preparedness for experiments in a course where experiments come before coverage in lecture. Rathod and Kalbande [9] suggest, among other things, adding prelab simulations and prelab demonstration to increase preparedness of students. It is not clear from the paper if this is in settings where lectures and laboratory work are aligned.

The laboratory in FM could be considered to have some components of active learning [47] as it requires students to be actively involved in the experiment and in a later postlab session. Active learning has been shown to increase student learning in science, engineering and mathematics [48]. Problem-based learning is a form of active learning where learning is facilitated by letting students work on problems with multiple possible solutions requiring a multidisciplinary skillset. The problem itself sets the need for seeking, testing, and judging knowledge and deciding on a solution in an iterative process [49]. Problem-based learning, therefore, encourages initiative, judgment skills, interdisciplinary skills, and team work [49] by using both cognitive and collaborative learning [50].

Domin [51] puts laboratory teaching into four categories: expository instruction, inquiry instruction, discovery instruction, and problem-based instruction. In expository instruction, the most common form of laboratory instruction, the procedure is given, a deductive approach is used, and the results are known by both students and instructors. In inquiry instruction, students decide on the procedure, an inductive approach is used, and the results are unknown, requiring students to use higher order mental processes [51]. In discovery instruction, the procedure is given, an inductive approach is used, and the outcome is known by the instructor. The theory and outcome of the experiment is, however, unknown to the students [51]. Problem-based learning strategies have been reported to be used in laboratory work [51–54]. In deciding what type of laboratory instruction to choose, it is important to have in mind the objectives of the laboratory since they will likely be ineffective if they are poorly constructed [55].

Last but not least, appropriate workload is of great concern [56]. In order for students to be able to acquire the knowledge covered in a course, the workload needs to be reasonable [57]. Chambers [58] has given some directions on how to estimate student workload. However, most can agree that predicting student workload is a complicated task. The predictions need to make some assumptions about the time it takes the average student to learn the material presented in the course. Therefore, these kinds of predictions will always be imprecise, especially in engineering, where the number of pages in a textbook may be a poor indication of the time spent on a task since problem solving is the most common learning method. It has been documented in the literature that instructors often underestimate workload and/or do not consider student complaints about workload while planning their courses [59]. There is, however, often a gap between actual workload and the workload perceived by students [56, 60]. Ercan, Karaağaç and Emekli [61] developed a computer application that periodically asks students what they are doing to get a more accurate estimate of actual workload in each course. Souto-Iglesias and Baeza-Romero [62] did a survey with 1400 students at two universities throughout a semester and saw that the distribution of workload was wide. This means that the workload of one year might not accurately predict the next year's workload.

Kyndt, Berghmans, Dochy and Bulchens [63] analyzed what contributes to workload perception by interviewing 40 master's level students, half in civil engineering and half in educational sciences. According to their work, having time is crucial to experience manageable workload but not sufficient. Qualitative factors also greatly influence the perception of workload. Students' motivation, their intrinsic interest on the subject, their ability to plan, minimal memorization, students being able to ask questions, group work where students could choose their partners and share responsibilities, working on practical problems, enthusiastic teachers showing examples students can relate to, and well-structured courses with even workload all contributed to lower student perceptions of workload even though workload was quantitatively higher in some cases. Students often struggled to balance studies and leisure, feeling that time spent on leisure was time lost. Taking time off for leisure, however, led to students feeling more relaxed and gaining a different perspective on their studies.

Even though laboratory work is widely used, the literature on measuring its workload is sparse. Credit systems for courses differ between the USA and Europe. In the USA, contact hour is used to determine the credits for each course, whereas universities in Europe use European Credit Transfer and Accumulation System (ECTS) units, which is based on estimated student workload. Each ECTS unit accounts for 25–30 hours of work [64]. UoI uses the ECTS and the FM course in ME and ChE is a 6 ECTS course, meaning that it should take students 150–180 hours to complete the entire semester. When looking at the workload of the laboratory section, it is important to remember that the laboratory is only one part of the course. Trying to measure its workload is important nonetheless, especially since there are few studies on which to base the estimate. It is clear, though, that decreasing the attendance time for the laboratory component will decrease its workload. Downscaling the post-laboratory report writing will also usually decrease the workload [39, 65, 66].

Serval issues related to the possible quality of laboratory instruction have been discussed above. Students are important stakeholders and sources of information. Student evaluations of teaching (SET) are commonly used in higher education for improving the quality of teaching and other administrative purposes [67]. Research conducted on SETs over the last 30 years suggests that SETs, while they do have shortcomings, provide valuable information regarding teaching effectiveness [68] especially when used along with other assessment tools. Both formative (midterm) and summative (end-of-term) SETs are used at University of Iceland and are an important source of information in this research.

3. Presentation

3.1 Setting the Scene

The FM course, which the FM laboratory component is housed under, is an introductory course to FM. Its objective is to give students a basic understanding of the behavior of static and moving fluids and the mathematical tools to calculate pressure, velocity and more in different scenarios. The course covers topics on incompressible and compressible flow, pipe flow, open channel flow and dynamical analysis. It addresses both practical problems and theoretical analysis using the full Navier Stokes equations. Students who finish the FM course should be able to:

- Understand the properties of fluids which affect flow and pressure.
- Calculate hydrostatic pressure in fluids, both for simple cases and complicated ones with varying densities and fluids.
- Calculate forces and moments in hydrostatic conditions and their effect on fluid boundaries.
- Understand the concept of control volume and its usage in analyzing fluid mechanics problems.
- Apply conservation laws on fluid flow, in terms of mass, momentum and energy.
- Conduct dimensional analysis and apply the rules of similitude on experiments.
- Calculate shear stresses and flow variations in boundary layers, for both laminar and turbulent flow.
- Conduct pressure drop calculations in pipe systems and solve corresponding design problems.
- Analyze compressible flow and supersonic flow, including the effects of shock waves.
- Conduct experiments and measurements on pressure, velocity and force in relation to classical problems in fluid mechanics.
- Analyze their own experiments and explain results in light of theory.

Although the laboratory component of the course is meant to support all the learning outcomes of the course, the two last outcomes are directly linked to only the laboratory component.

Lectures are twice a week for 90 minutes (10 minutes of those are a break) with one 50-minute (10 minutes of those are a break) discussion section added at the end of one of the weekly lectures. Every week, students turn in individual homework that counts towards their final grade in the course. The course is concluded with a final exam.

3.1.1 Laboratory Exercises

The laboratory exercises in FM taught in the ME and ChE study programs at UoI total six and are all mandatory. The exercises were chosen because they touch on most of the material covered in the course that is testable with experiments. The topics covered in the course and not in the laboratory component are either too theoretical (e.g., the Navier Stokes equation) or the laboratory equipment needed for those types of experiments is too expensive for a small engineering department (e.g., supersonic flow). The purpose of the laboratory component is to demonstrate theory and help the students better grasp the material covered in the course. A short description of the steps needed to carry out the experiment is provided for students online. This description also includes a short theoretical background on the subject and how one can verify the theory. All experiments require a set of laboratory equipment which can be quite expensive. Since acquiring more equipment is not an option, only one group can carry out each experiment at a time. This brings up some complications discussed later. The experiments and the online instructions have been essentially the same for years, even though the length of some experiments has been adjusted. A short description of each laboratory experiment is provided in the appendix.

3.1.2 *Previous Setup*

Until 2016, the laboratory component of the class was split into 5 sessions (one of those session included two experiments) of three hours each. The weekly laboratory component started in week 6 or 7 of a 14-week semester. Students worked in groups of 3–7. The group size was determined by the number of students in the class, limited laboratory working hours and laboratory equipment. The total number of groups in 2015 and earlier was always 10. Five groups were working concurrently, one on each experiment, so laboratory sessions were held two days in a row with two instructors present, the lecture instructor or a teaching assistant (TA) and a laboratory technician. Each group turned in a full report after each session.

3.1.3 *Students' Concerns – What Sparked the Changes?*

While the instructors strongly believed in the usefulness of the hands-on experimentation to help understand the theoretical terms presented in lectures, students voiced their dissatisfaction. They claimed that the laboratory component was extremely time consuming and not beneficial enough for their learning.

After hearing repeatedly of the students' dissatisfaction with the laboratory component, the authors decided to seriously address their complaints. Why did this mismatch between the instructors' intentions and students' experiences occur? The search for a solution started quite randomly but became ever more scholarly as the academic staff learned more about and became further engaged in scholarship of teaching and learning (SoTL) [69]. The focus was first put on the most frequent complaint: the workload. As mentioned earlier, workload predictions will always be imprecise. With this reservation, the workload of the course, including the laboratory section, was estimated to be about 180 hours using the approach presented in by Sigurdsson [70]. The course was clearly on the upper side of the workload intended for a 6 ECTS course. The instructors, therefore, wondered if a more practical and less time-consuming setup would be possible.

Students also seemed to find that their learning from the laboratory component of the class was limited. The instructors concluded that the fact that the students often performed experiments before they learned about a subject in lecture was a major contributor to that complaint. This meant that learning activities in the laboratory work component did not align with the learning taking place in the lectures, therefore diminishing the constructive alignment of the course. The students did, and still do, get guidance during laboratory working hours and the online instructions mentioned earlier. Despite this, they seemed to be unable to grasp the concepts.

The instructors set out to explore a laboratory set up that would be within the limits of the units credited for the course and would improve student learning more than in the previous format. The curriculum redesign focused on three main tasks: rescheduling to align coverage in lectures and laboratory exercises, assessment format changes and the introduction of postlab discussions. The changes in assessment were aimed at reducing workload while maintaining the same learning gains. The postlab discussions were meant to further align experiments to lectures to improve learning outcomes. The changes in assessment and its effect on students' experience of workload and learning have been described in a paper by the authors' of this paper [71] and are outside of the scope of this paper. The focus in this paper is, therefore, the rescheduling and postlab discussions.

3.1.4 *Rescheduling Laboratory Classes*

In order to help the students to better grasp the course concepts, the instructors decided to make sure the material had been addressed in lecture before each experiment was performed. The experiments would thus be aligned to the academic lessons to ensure ease of transfer of knowledge. The week the material is covered in class is listed in Table 1. A maximum of one experiment would be covered every week in order to not overload students. This meant that from 2016 onwards, the experiments would be performed in weeks 3, 4, 9, 10, 11 and 12 (see Table 1). This meant, though, that the experiments were not evenly distributed during the semester but rather supported and were linked with the topics dealt with in the class.

For this design to work, taking into account student number and availability of laboratory space and instructors, the length of each experiment

Table 1. Experiments, the week in the semester when material concerning the experiment is covered in lecture and the week when the experiment is performed after rescheduling

Experiment	**Week material covered**	**Week performed, rescheduled**
Static fluid pressure force	2	3
Stability of an object in static fluid	2	4
Reynolds experiment	8	9
Pressure drop in a pipe	9	10
Wind tunnel	10	11
Viscosity of liquids	10	12

was reduced from 3 hours to 1 hour. As only one workstation is available for each experiment, one group at a time was working with an instructor and laboratory technician. Thus, the groups obviously had more help, guidance and opportunity to discuss during the experiment than in previous years. This helped students be more active and productive in the time allotted. This is contrary to previous years when idle time spent waiting for assistance while other groups were being helped was often considerably longer. Therefore, even though the time allotted for the experiments was now 1/3 of the previous time, the tasks in the experiment were not reduced greatly (repetitions of measurements were at most reduced by half, see appendix). To repeat, the laboratory work now consisted of shorter experiments but still with the same main components as previously.

3.1.5 Postlab Sessions

The changes in the laboratory component scheduling now allowed for special postlab sessions that were added in the second year of the rescheduling, where the results of all groups were compared and discussed, and a statistical analysis shown in a lecture following each experiment. The instructor presented the statistical analysis and students discussed it for a few minutes afterwards. No assignment or grade was given for the postlab discussion. The postlab sessions not only lead to some practical outcomes like the detection of a systematic errors in much of the newly renovated equipment but also further strengthened the alignment between lectures and laboratory learning. In addition, it encouraged students to actively share results, something that is known to increase learning [72]. In this new component, all students were dealing with the same issue. This allowed for student discussion, analysis and assessment of laboratory results within the whole class. It also pushed the students into active inquiry based learning and to a higher level of thinking according to Bloom's taxaonomy [73]. When students' learning was pushed to this level, they started asking for more types of learning [55] and more reflective exercises, as mentioned later. The postlab sessions were incorporated into lecture hours with no extra assignment to return. It, therefore, did not increase the students' workload.

3.2 Methodology

After making the changes to the laboratory curriculum, it was important to find out what effects they had. To assess the effects, various types of data were collected. This included the university's midterm and end of term surveys, a survey aimed at assessing the laboratory work only, open-ended questions in the three surveys mentioned earlier and a focus group on the laboratory work component. The midterm and end of term surveys spanned the years 2014–2019. The laboratory work survey spanned the years 2015–2019. The focus group interview was conducted in 2018. Participation in all surveys and the focus group interview was voluntary and did not affect students' grades in any way. The instructors did not know who participated in the surveys.

University midterm and end of term surveys are a part of the centralized UoI quality assurance system and have multiple Likert scale questions and open-ended questions. Neither of those surveys particularly address the laboratory portion of the class, but students can address issues related to the laboratory experience in the open-ended sections, if they feel it is necessary. Both surveys were carefully analyzed, and students' open-ended answers closely read with the research question in mind. Nevertheless, their utility in capturing curriculum changes, especially only to a portion of the class, is limited, and their results will only be briefly referred to and discussed in this paper. In order to measure the effects of the curriculum changes, the laboratory survey and focus group interview were added. A more detailed description of those is given in the following subsections.

3.2.1 Laboratory Work Survey

In order to explore students' attitudes towards the curriculum changes, a specific laboratory work survey was created. A survey was chosen since it gives all students the opportunity to voice their opinion and is easy to monitor. Tailoring it to the laboratory component gave detailed answers to the research question of this paper [74]. The survey was conducted by the first author of this paper and was held about a month after the class had finished and all grades had been submitted. In order to get specific answers about the laboratory component, the instructor asked the students to reply to an online survey focused on the laboratory. The survey was essentially the same four years in a row. It included 5 optional questions on demographics and an open-ended option where students could leave additional remarks. The optional questions on demographics were included in order to see if the students participating in the laboratory survey were a good representation of the demographics of the students who were in the course. Also, since it was expected that student course load during the semester, the number of hours they work external jobs and if they have children to take care of, might limit the time they had for their studies, questions on those issues were included in the survey. In the laboratory survey, all replies were tailored for the laboratory

Table 2. The total number (#) and the percentage (%) of the total number of students who replied to the laboratory survey each year and participated in the focus group interview

	2015		2016		2017		2018		2019	
	#	%	#	%	#	%	#	%	#	%
Laboratory survey	32	56.1	12	41.9	23	52.3	22	61.1	16	53.3
Focus group interview	–	–	–	–	–	–	5	13.9	–	–

component and more easily analyzable for this purpose.

3.2.2 Focus Group Interview on the Laboratory Work Component

Once the university and laboratory surveys of the past 4–5 years had been analyzed, it was considered useful to form a focus group on the laboratory component in 2018 to get more in-depth answers on some aspects of the laboratory work and the research question of this paper. A focus group interview was chosen instead of another survey because of its flexibility. In a focus group interview, the conductor can detect a certain theme or concern immediately and ask the participants to dig deeper into certain aspects and skip other aspects if they turn out to be of less concern to participants [75]. This flexibility is not achievable with a survey where unexpected turns cannot be dealt with immediately because they are only detected once the survey is over, and its results are analyzed. The focus group meeting was held 2 months after the last lecture in the course and about 2 weeks after the laboratory survey took place. All students in the FM course in the fall 2018 received an email asking them to participate. They were told that participation was voluntary and that the results would only be used to improve the laboratory work component in FM. In total, five students participated in the laboratory focus group interview: two students from ME (third year), two students from ChE (second year) and one student from engineering physics (third year). They were representative of the demographics in the course itself. However, four students were female and one male, which does not rightly reflect the gender balance in the course. The focus group meeting was an hour long. It was voice recorded and transcribed verbatim. The first and third authors of this paper were present and asked questions during the focus group interview. The transcript was analyzed with a thematic approach [76].

3.3 Findings

In this section, the main results of the various data collected and used to assess the effects of the changes in the laboratory work are presented. The total number of students and the percentage of the total number of students who participated in the laboratory survey each year and in the focus group interview is given in Table 2.

3.3.1 Laboratory Survey

The laboratory survey asked about student demographics. In general, most participants are full-time students. Most do not have any external work, though some report working full time or more externally. Very few students have children. It is expected that, in general, family life is not influencing students' perception of workload. In most cases, external work is not a large contributing factor to perceptions of workload and study load is, in most cases, as expected for full-time students. The replies to questions on the study program and year were representative of the student composition in each year. Overall, students replying to the laboratory survey were typical students for undergraduate studies in engineering at the University of Iceland.

A comparison between the years of the laboratory survey on preferred schedule, perceived workload and Likert scale questions are shown in Table 3, Table 4, and Table 5, respectively. When the schedule changed significantly in 2016, so did the questions in the laboratory survey on the preferred schedule. The first option shown in Table 3 is the altered schedule (2016 and later) and the second option is the previous schedule (2015 and before). For all years, the option of the original schedule (#2) was in the survey as well as the option to choose a different schedule (#7) and explain further in an open-ended reply. In 2015, the options were to keep it as it was (#2), spread the work session over a longer period (#5) and align experiments to lectures (#6). In 2016 and later, the options were to keep it as it was (#1), change it to as it was previously (#2), concentrate it (#3) or have some other schedule with alignment (#4).

As shown in Table 2 the number of students participating in each laboratory focused survey was low, making statistical analysis limited. Despite that, we did a basic statistical analysis testing if the means of the Likert scale questions presented in Table 5 were statistically different. Using a two sample Welch t-test [77] with the hypothesis that the means of the Likert scale questions are the same, the hypothesis is rejected, i.e. the means are not the same with 95% certainty when comparing how

Table 3. Comparison of replies on the preferred laboratory schedule in the laboratory survey 2015–2019. If a question or option was not included in that year's laboratory survey, it is indicated with –. The laboratory survey question on preferred scheduled in 2015 (before the changes) differed significantly from the same question in that survey in later years. Only two options (#2 and #7 in the table) on schedule were available in the laboratory survey before and after 2015. Before the changes in schedule, two options (#5 and #6) were available that were not available later. After the change, two new options (#3 and #4) were added. If a student did not agree with the given options, they could always use option #7 and leave an open-ended reply

	2015 %	**2016** %	**2017** %	**2018** %	**2019** %
Preferred schedule					
#1: 6 experiments each 1 hour long when material has been covered in class beforehand (as was 2016 and later)	–	50	100	100	93.8
#2: 5 experiments every week, 3 hours each, material not covered before lab (as was 2015 and earlier)	28.1	0	0	0	0
#3: Rather fewer but longer experiments	–	8.3	0	0	0
#4: Some other schedule where material is covered before lab in lecture	–	25	0	0	0
#5: 5 experiments every other week, 3 hours each, material not covered before lab	40.6	–	–	–	–
#6: 3 times over semester, 1–2 experiments at a time after material had been covered in lecture	15.6	–	–	–	–
#7: Other, explained in open ended reply	15.7	16.7	0	0	6.2

Table 4. Comparison of replies on perceptions of student workload in the laboratory survey 2015–2019

	2015 %	**2016** %	**2017** %	**2018** %	**2019** %
Perceived workload					
Too heavy	28.1	16.7	0	0	0
Heavy	43.8	66 7	26.1	9.1	12.5
Just right	28.1	16 7	73.9	81.8	81.3
Light	0	0	0	9.1	6.3

Table 5. Comparison of replies on the 5-point Likert scale questions in the laboratory survey 2015–2019. If a question or option was not included in that year's survey it is indicated with –. Standard deviation is within the parentheses below the Likert scale value

Question	**2015**	**2016**	**2017**	**2018**	**2019**
I learned a lot from the laboratory	3.78 (1.10)	4.42 (0.51)	4.83 (0.49)	4.09 (0.61)	4.19 (0.40)
I enjoyed the laboratory	3.56 (1.16)	4.00 (0.74)	4.13 (0.55)	4.41 (0.59)	4.44 (0.51)
I learned a lot from the coverage on systematic errors in lecture based on the results of the experiments from all groups	–	–	3.74 (1.14)	4.14 (0.56)	4.19 (0.91)

much students perceived learning in 2015 vs 2016. That is to say, students reported learning more in 2016 than in 2015. In fact, with 95% certainty, students reported learning more in 2017 than any of the other years. With 90% certainty, it can be stated that students reported learning more in 2019 than in 2015. As for enjoying the laboratory, students reported enjoying the laboratory more in all years after the change (2017, 2018 and 2019) than before the change (2015) with the exception of 2016, where the difference in the Likert scale means is not statistically different with 95% certainty.

In analyzing the results of the laboratory survey, four main themes were detected: alignment/schedule/transfer, purpose, postlab sessions, and length/workload.

Alignment/Schedule/Transfer

Table 3 shows clear dissatisfaction with the pre-2015 schedule. Less than 30% thought the schedule of the laboratory was appropriate, but most students thought that spreading the sessions out more evenly rather than having fewer aligned with when the material is covered in class was appropriate. What is interesting is that less than 16% of students participating in the laboratory survey in 2015 saw the merit of aligning lecture coverage and the experiments. One student did, however, mention it in the open-ended question.

> "Thought the schedule was fine, but it would possibly be smart to make sessions where the laboratory work and lectures were intertwined. I think they would support each other better." (2015)

In 2016, half of the class liked the new schedule, but a quarter would have liked some other schedule with the main requirement that the material be covered in class beforehand. A few would have liked fewer but longer experiments. In 2017 and 2018, all students replying to the laboratory survey preferred the new schedule. In 2019, all but one student answered the same way. The only student suggesting a different schedule in 2019 would have liked 3–4 laboratory sessions that were longer and more comprehensive. It is interesting to see that, before the alignment had been accomplished, few students realized its benefits. Once it had been established (2016 and later), students wanted to keep it as it was.

> "We saw what we had just learned in lecture and could connect it to something tangible, I think that is very important in engineering studies." (2018)

Purpose

In Table 3, it is striking that almost 16% of the students replying to the survey in 2015 chose the other option and further indicated in an open-ended reply that they did not see the purpose in the laboratory and wanted to have a numerical projects or a visual lab instead of the laboratory. This resonates well with other open-ended replies given that year.

> "Some of the experiments could be demonstrated by the instructor without students doing anything." (2015)

They claimed that the laboratory component was not useful.

> "Too much time goes into figuring out how the equipment works and then repeating the same procedure over and over with a slightly different set up." (2015)

Some students, however, did see merit in the laboratory component.

> "Fluid mechanics is one of the most practical courses in ME, very important to have laboratory work in order to get a deeper understanding of the subject." (2015)

Once the laboratory schedule had been altered, no open-ended replies in the laboratory surveys suggested an alternative to the laboratory work component, and many addressed its importance.

> "The laboratory component gave good insight into the material covered in the course, so it is important to have it included in the course." (2016)

> "FM has the best laboratory work component I have participated in because its focus is on understanding and not postprocessing and 99% precision. This leads to a much deeper understanding." (2019)

As the students started to see the purpose of the laboratory, they perceived the learning from it, and they showed increased satisfaction (see Table 5). This is in agreement with previous findings [10].

Postlab sessions

The postlab sessions were introduced in 2017. In Table 5, it is clear that the students moderately agreed that they learned from the covering the systematic errors from the results of all groups combined in 2017 but strongly agreed in 2018 and 2019. Although there were no open-ended replies concerning the postlab discussions in the laboratory survey, the postlab sessions are likely to have contributed to an improvement (see Table 5) in students' experiences of learning as well as in the general increase in students seeing the purpose of the laboratory component (see Table 3).

Length/Workload

In Table 4, it is clear that the workload in the course before the change was perceived to be too high. This is further supported by multiple open-ended replies.

> "The laboratory work component is good but the workload was so immense that most could not work as well on it as they might have wanted." (2015)

The percentage of students who thought the workload was too heavy during the laboratory sessions went down from 28% in 2015, to 17% in 2016 and zero in 2017–2019 along with the change in schedule. In 2016, less than 17% of students considered the workload just right. The experiments had been shortened, but students complained about the time they needed to put into the experiments, sometimes due to the lack of assistance as an instructor was not present that year.

> "The schedule would have been fine if it had just taken 1 hour, the experiments need to be shortened." (2016)

> "The teaching assistant and the laboratory technician often did not know the postprocessing in detail which slowed us down." (2016)

In 2017–2019, an instructor attended the sessions and made sure the length of each experiment was as intended. This significantly increased the proportion of the students that thought the workload was just right, as was further supported by open-ended replies.

> "I thought the schedule was nice. It was only 1 hour." (2017)

One student, however, wondered if the laboratory sessions should be longer:

> "I think one-hour experiments is a bit too short, but 4 hours is too long. I would have liked to have them 2 hours with a bit more extensive experiments." (2017)

3.3.2 Focus Group

The results of the midterm, end of term and laboratory surveys give an overview of how the majority of students felt about the laboratory component. In order to get a more in-depth understanding of the results, a focus group around the laboratory component was conducted.

The focus group results on group work and workload with respect to assignment format have already been reported in a previous paper [71]. Here, they will be discussed with respect to the new schedule. In the earlier paper, it was also reported that, when the students of the focus group stated what they believed they had learned from the laboratory component, they listed all the learning outcomes of the laboratory component and more. The three themes detected in the focus group not linked to assessment are alignment/schedule/transfer, postlab sessions and length/workload.

Alignment/Schedule/Transfer

All the students in the laboratory focus group interview confirmed the results of the laboratory survey, that they thought the new scheduling of the laboratory component was ideal for their learning. One described the laboratory component as being "concise and fitting." They thought the number of experiments was appropriate for covering most of the material in class. They thought that the link between lectures and laboratory section was essential and that it was important to have covered the material in class before doing the experiment. They also stressed the importance of alignment in time, i.e., that there should not be too much time between coverage in class and the execution of the experiment. Covering the material in lecture a week or two before doing the experiment was considered ideal. By doing that, the participants felt they were able to follow the online instructions and have a clear understanding of what they were doing, in contrary to what they had experienced in the laboratory components of other courses.

> "I remember other laboratory sessions where we did the experiment and a few months later covered the material in class and then finally had an aha moment. 'That is why I was supposed to do this in the experiment.' At the time of the experiment, a teaching assistant told us to do this and then this, but we didn't know why or what we were doing." (focus group 2018)

The importance of fluent transfer of knowledge was also stressed, and all students agreed that it was important for the instructor to be present during the laboratory session and not a teaching assistant, unless the teaching assistant had attended lectures and was well trained in the experiment and, most importantly, in the analysis of the experiment. They said that this allowed the lecturer to point out the link between the experiment and lectures.

> "This is just as we did in this example. This is just as the question that came up in lecture." (focus group 2018)

Postlab sessions

The students in the focus group interview thought going over the results of the experiments from all right after the experiment (postlab sessions) not only helped them further understand the concepts but the transfer of knowledge between the experiment and lecture was aided by the post-lab discussion:

> "I thought it was clever when the instructor came in the next lecture showing us the results of all the groups. Then I thought about the experiment one more time. Also comparing your results with other groups and if what you were getting was somehow odd." (focus group 2018)

On student suggested that more reflective questions could be added to the material.

> "Maybe more questions could be added on why something happens or the reason for something. . . where you have to explain and think outside of the box." (focus group 2018)

Once presented with this idea, other students agreed. Based on this result, it was decided to add reflective questions to the online instructions in 2019.

Length/Workload

The students in the focus group were content with the workload and the length of the laboratory sessions.

> "I thought the number of experiments was fitting. Also because they were so short, it was OK to have this many." (focus group 2018)

They liked the laboratory component and considered it a good way to break up the lecture focused learning. They believed this was because the laboratory work was short, it was clear to them what was expected from them, and the experiments were related to the material covered in lecture. The students thought that the online instructions for the laboratory work were good, easy to follow and fitting in length. Students, however, suggested that the instructions could be improved by pointing out where to find further reading in the book and as mentioned previously, by adding reflective questions for students that force them to think more deeply about the subject.

4. Discussion

Although the midterm and end of term university surveys were not directly useful in analyzing the effects of the changes in the laboratory component of the course, it is worth mentioning that their open-ended replies were useful for sparking for this journey. The open-ended replies in those surveys also significantly improved with the changes in the laboratory work. Judging from all measurements, students generally perceived that the laboratory component was more enjoyable and reported increased learning as the years progressed, with a slight dip in 2018 in the laboratory survey. The change in schedule was met with greater student satisfaction; students feel they learned more from and complain less about workload. The addition of the postlab discussions also seems to enhance their learning. As the years passed, the students seemed to be almost completely satisfied with the new schedule and modes of learning.

In the focus group, general contentedness was with the laboratory component, with a few improvements suggested. The online instructions need more thought provoking questions and a clearer reference to the textbook. The focus group thought the most important part of the laboratory component was how closely it linked to the lectures, no more than a week or two apart and that there was a review in lecture right after the experiment. Furthermore, they considered it important to have the experiments and postprocessing short and that the instructor attends the laboratory work sections. The fact that students think it is important that the coverage in lecture needs to be close in time to the corresponding experiments means that pure laboratory work courses are not very beneficial to their studies.

In this paper, curriculum changes only focused on the scheduling part of the laboratory work and not how the laboratory work was taught, except for more assistance being available in the new schedule. The laboratory work in question in this paper, currently and previously, uses expository instruction, since the procedures are given [71]. The lack of interpretation of results is usually the main criticism of expository instruction [51] but in this laboratory component great emphasis has always been put on the interpretation of results. It may be argued that, because the previous set up lacked links between lectures and laboratory exercises, causing students to be ill prepared for the experiments, the earlier laboratory instruction was more discovery based [51]. It is also worth mentioning that the addition of the reflective questions in 2019 pulled the laboratory component more towards inquiry based instruction [51]. Inquiry based instruction is considered leading to higher order thinking processes than expository and discovery instruction. It would be interesting to see how the ideas of problem-based learning could further increase learning in the laboratory section, but that would mean completely rethinking all the experiments and is outside of the scope of this paper.

If we recall the research question listed at the beginning of the paper:

- Do the curriculum changes in the laboratory component address students' concerns about the workload, learning and purpose of the laboratory component?

The new schedule of the laboratory work component, where an experiment is conducted 1–2 weeks after covering the material in class and with a short review in the following lecture, was able to improve links between lecture coverage and experiments and encourage shared learning in postlab discussions, while also reducing workload. Students like the new schedule more, feel like they learn more from it, feel like the workload is less than previously and seem to be able to see the purpose of the laboratory work, which was not always the case previously. Besides that, the changes in the laboratory section seem to positively affect students and address their concerns. These results are also somewhat supported by other results in the literature [14, 37].

4.1 Next Steps – Changes 2019 and Later

In addition to having a new schedule, the following steps suggested by the data were taken in the fall of 2019. It is crucial to have the instructor attend laboratory section instead of a TA or at least to make sure the TA is very well prepared. The TAs claimed to be well prepared, but the students did not agree. Using TAs has been shown to be fruitful in team-based teaching in laboratories if the leading instructor is a highly skilled teacher [78]. In team-based teaching, multiple teachers are present in the classroom at once. Nikolic, Suesse, McCarthy and Goldfinch [78] conclude that this maximizes resource allocation at little cost to students experience. This was, however, not the experience in our laboratory setting, perhaps because either a TA or a teacher was present in each laboratory session. Technically, this is not considered team-based teaching. It is also important to address group size early and add more laboratory sections to the schedule if the group size is greater than 4 [71]. It would also be an improvement to add learning outcomes for each experiment [1] so students are more aware of what is expected of them. The addition of thought-provoking or reflective questions on the subject, as the focus group of 2018 called for and was done in 2019, was a major improvement. The laboratory survey in 2019 showed that students experienced learning from the reflective questions (M = 4.50 SD

= 0.52 out of 5 on a Likert scale) and enjoyed tackling them (M = 4.25 SD = 0.93 out of 5 on a Likert scale). In addition to student approval, the reflective questions are clearly pushing the laboratory work to be more inquiry based instruction, which has been linked to higher order learning [51]. Adding to the written online instructions, more direct references to the chapters in the book as the focus group asked for was done in 2019 and should be an improvement. In 2021, four-minute preparation videos for each experiment were added to the online material. Also, two-minute videos to aid filling in the Excel sheet for each session were added to the online material. Students seemed to like this addition, but it remains to be seen in the laboratory focused survey at the end of the semester how much they consider those two changes help.

4.2 Drawbacks of the Curriculum Changes

The new schedule has a lot of advantages but is not without flaws. One flaw is that, even though the time the students spend on the laboratory work has been reduced, the amount of time the instructor spends has increased because now only one group works at a time. In the new schedule, the instructor needs to be present for a total of 48 hours for the laboratory work sections each term (4 hours each session, 2 times a week for 6 weeks) as opposed to 30 hours previously (3 hours each session, 2 times a week for 5 weeks). If the number of sessions each week needs to be increased to make sure the number of students in each group does not exceed four, then even more of the instructor's time is required. This may occur more frequently in the new schedule since the new schedule accommodates 8 groups, whereas the old accommodated 10 groups. This occurred in the fall of 2021 when 79 students signed up for the course meaning the number of groups, and therefore the attendance of instructor in the laboratory, needed to be doubled from the setup described in this paper. Having the assignment format reduced from a full report [71] does, however, reduce the time for grading and may compensate for the extra time spent attending the laboratory work section up to a point. Despite the extra work for teachers created along with the new schedule, their primary reward is in increased student learning and satisfaction.

Having the experiments one to two weeks after the material on the experiment is covered in lecture means that the experiments are not evenly distributed throughout the semester, and some experiments are quite late in the semester. Even though this may be inconvenient, it seems like the students feel the drawbacks from this scheduling is fully compensated for by the gains.

4.3 Limitation to Study and Further Thoughts

There are a few limitations to the analysis in this paper. Relatively few students participated in the study, and it has not yet been replicated in other courses. It is, nevertheless, an ongoing study, where data has been collected repeatedly over 6 years and results have been used to constantly to improve student learning experiences. Only one focus group was conducted towards the end of the study. This study has limited statistical analysis. The study measures the students' perceptions of their learning and workload but does not measure those factors directly. Reducing the amount of time students spend on laboratory work obviously reduces their workload. It also seems logical and is supported by other studies in the literature [13, 14, 37], that aligning the laboratory work to the lectures would increase their learning. Directly measuring whether learning increased with the changes is difficult though because the cohort of students varies from year to year, as does their academic proficiency. Reusing questions for the final exam in the course is not an option since students have access to all previous exams. However, it has previously been shown that positive perceptions of laboratory work does increase learning outcomes [10]. Despite the limitations to this study, the authors of this paper believe that its findings clearly show how aligning laboratory work with lectures and reducing the number of hours in the laboratory can increase learning if done in a well-designed manner. We also believe that this study can be a solid starting point for further study on the subject.

Findings in the literature suggest that there is a lack of clear laboratory learning outcomes that needs to be address by teachers responsible for laboratory instruction and at the program level to better ensure constructive alignment. The learning outcomes in this course were listed in section 3.1 of this paper. They fall into the categories of instrumentation, models, data analysis, and communication of the ABET (Accreditation Board for Engineering and Technology) laboratory learning outcome established in 2002 [11]. An analysis of the learning outcomes for our laboratory demonstrates that, although learning outcomes on teamwork and sensory awareness are not specified, these are indeed an important part of the course. The learning outcomes in our course should be updated accordingly. The learning outcome ABET requires for accreditation are under constant review and the laboratory learning outcomes are now incorporated into the general learning outcomes of a program. As analyzed in our previous paper on assignments in laboratory work [71], students themselves list the learning outcomes of the laboratory component when asked what they gain from it even when returning different assignments than lab reports. Their learning on fluid mechanics is the same from these alternative assignment formats but they do not get trained in report writing. Report writing is an essential skill for engineers, but as long as students do get sufficiently trained in report writing in their bachelor studies, it does not need to be addressed in every single course in the study program.

When starting this journey, the first and second authors of this paper where normal academic staff members in engineering. They were experiencing a mismatch in teachers' intensions and students' perceptions, causing wide student dissatisfaction, which is common [79]. In dealing with the issue, they learned that it must be tackled in a systematic and scholarly way, as with all their research. While digging into the problem, their approach changed as their educational knowledge and experience increased. At first, they thought the traditional midterm and end of term surveys would be sufficient to guide them in solving this issue. They quickly realized that the surveys needed to be more focused on the laboratory component in order to shed light on the issue. It became clear to them that forming a special laboratory survey was necessary. They even foolishly thought that one iteration of improvements, based on previous literature, would be sufficient. However, they learned, a bit by trial and error, that the laboratory survey and the solutions needed to be adjusted yearly, mostly in the second year.

The addition of the postlab discussions came from both the literature [72] and students asking for more ways of learning and more reflective thinking. The focus group interview was a new research method for the engineering academic staff, as they were not familiar with qualitative research methods in engineering. The focus group interview, although challenging for first timers, turned out to be fruitful for digging deeper into the unknown issues and confirming previous findings. For an outsider, the improvement process may seem random at times and, admittedly, would look different if we were planning this research now that we have acquired more knowledge and experience in research in higher education. However, this journey was fruitful both because students now have an improved laboratory component and because, with our attempts, we have become familiar with the higher education research literature, which will benefit us in improving our teaching in the future. Furthermore, we have felt compelled to share our findings as they may be useful for others in similar situations and contribute to higher education research literature [71]. We wouldn't be surprised if our journey of improvement may be considered to be rather typical journey of academic staff developing from sincere teachers to full on SoTL [80].

5. Conclusion

In this paper, we have discussed the procedures and outcomes of a curriculum development project. Aligning experiments to lectures and adding postlab discussions increased student satisfaction and learning, while being less time consuming for students. Other important issues in the laboratory work component were that the instructor was present during the experiments and adding more thought provoking questions into each experiment's online instructions.

Finding a solution to a teaching problem that fits both students and instructors is, in most cases, feasible. When searching for such a solution, it is crucial to do so in a scholarly manner. One needs to bear in mind the intended learning outcomes and an appropriate workload for students. Searching the literature for existing solutions is crucial, as is measuring all possible aspects and changes. Reaching such a solution takes both time and labor, but the possibility of vast gains makes it worth the effort.

Acknowledgments – The authors of this paper would like to thank the students of the fluid mechanics course at Mechanical Engineering and Chemical Engineering at the University of Iceland between 2014 and 2019 for their participation in the three surveys. We would like to particularly thank the 2018 focus group for their participation and helpful comments.

Funding details – The research of Á. Helgadoóttir was supported by The University of Iceland Research Fund 2019.

Declaration of interest – The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

1. L. D. Feisel and A. J. Rose, The Role of the Laboratory in Undergraduate Engineering Education, *Journal of Engineering Education*, **94**, pp. 121–130, 2005.
2. R. S. Castillo, T. Waltzer, and H. Kloos, Hands-on experience can lead to systematic mistakes: A study on adults' understanding of sinking objects, *Cognitive Research: Principles and Implications*, **2**, pp. 1–12, 2017.
3. L. E. Carson and J. F. Sullivan, Hands-on Engineering: Learning by Doing in the Integrated Teaching and Learning Program, *International Journal of Engineering Education*, **15**, pp. 20–31, 1999.
4. A. Hofstein and V. N. Lunette, The laboratory in science education: Foundations for the twenty-first century, *Science Education*, **88**, pp. 28–54, 2004.

5. D. Satterthwait, Why are ‘hands-on’ science activities so effective for student learning?, *Science Teaching – The Journal of the Australian Science Teachers Association*, **56**, pp. 7–10, 2010.
6. T. Kostulski, and S. Murray, *The National Engineering Laboratory Survey – A Review of the Delivery of Practical Laboratory Engineering Educaiton in Australian Undergratuate Engineering Programs*, Labshare, 2010.
7. T. d. Jong, M. C. Linn and Z. C. Zacharia, Physical and Virtual Laboratories in Science and Engineering Education, *Science*, **340**(6130), pp. 305–308, 2013.
8. J. Bernard, Insightful learning in the laboratory: Some experiences from 10 years of designing and using conceptual labs, *European Journal of Engineering Education*, **35**(3), pp. 271–287, 2010.
9. S. S. Rathod and D. R. Kalbande, Improving Laboratory Experiences in Engineering Education, *Journal of Engineering Education Transformations*, **29**(4), pp. 51–60, 2016.
10. M. A. Buntine, J. R. Read, S. C. Barrie, R. B. Bucat, G. T. Crisp, A. V. George, I. M. Jamie and S. H. Kable, Advancing Chemistry by Enhancing Learning in the Laboratory (ACELL): a model for providing professional and personal development and facilitating improved student laboratory learning outcomes, *Chemistry Education Research and Practice*, **8**, pp. 232–254, 2007.
11. K. R. Most and M. P. Deisenroth, ABET and Engineering Laboratory Learning Objectives: A Study at Virginia Tech, American Society for Engineering Education Annual Conference & Exposition, Nashville, Tennessee, June 22nd – 25th, 2003.
12. R. H. King, T. E. Parker, T. P. Grover, J. P. Gosink and N. T. Middelton, A Multidisciplinary Engineering Laboratory Course, *Journal of Engineering Education*, **88**, pp. 311–316, 1999.
13. N. J. Hunsu, B. Abdul, B. J. V. Wie, O. Adesope and G. R. Brown, Exploring Students’ Perceptions of an Innovative Active Learning Paradigm in a Fluid Mechanics and Heat Transfer Course, *International Journal of Engineering Education*, **31**, pp. 1200–1212, 2015.
14. G. Cranston and G. Lock, Techniques to encourage interactive student learning in a laboratory setting, *Engineering Education – a Journal of the Higher Education Academy*, **7**, pp. 2–10, 2012.
15. R. F. Schkoda, T. A. Schweisinger and J. R. Wagner, An improved undergraduate mechanical engineering laboratory structure and curriculum: design and assessment, *International Journal of Mechanical Engineering Education*, **40**, pp. 182–196, 2012.
16. P. Gibbings, Qualitatively Different Ways Students Experience Remote Access Laboratories, *International Journal of Engineering Education*, **30**, pp. 1120–1129, 2014.
17. M. M. Felling, R. H. Page, H. H. Korst and R. A. White, An Experimental Analysis and Demonstration of the Non-Steady Flow in a Shock Tube, *International Journal of Engineering Education*, **14**, pp. 59–66, 1998.
18. M. S. Glessmer and C. F. Janßen, Using an interactive Lattice Boltzmann Solver in Fluid Mechanics Instruction, *Computation*, **5**, pp. 1–22, 2017.
19. S. Kresta, Hands-on Demonstrations: An Alternative to Full Scale Lab Experiments, *Journal of Engineering Education*, **87**, pp. 7–9, 1998.
20. T. Abdel-Salam, P. J. Kauffmann and G. Crossman, Does the lack of hans-on experience in a remotely delivered laboratory course affect student learning?, *European Journal of Engineering Education*, **31**, pp. 747–756, 2006.
21. V. Gynnild, D. Myrhaug and B. Pettersen, Introducing innovative approaches to learning in fluid mechanics: a case study, *European Journal of Engineering Education*, **32**(5), pp. 503–516, 2007.
22. J. R. Brinson, Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research, *Computers & Education*, **87**, pp. 218–237, 2015.
23. E. K. Faulconer and A. B. Gruss, A Review to Weigh the Pros and Cons of Online, Remote and Distance Science Laboratory Experiences, *International Review of Research in Open and Distributed Learning*, **19**, pp. 155–168, 2018.
24. J. Hillard, K. Branch and A. Butterfield, Teaching fluid dynamics with the ball-in-tube device, *International Journal of Mechanical Engineering Education*, **43**, pp. 15–22, 2015.
25. C. Y. Liu, A Compact Mini Smoke Wind Tunnel, *International Journal of Applied Engineering Education*, **7**, pp. 120–124, 1991.
26. M. Trinder and M. Jabbal, Development of a smoke visualisation system for wind tunnel laboratory experiments, *International Journal of Mechanical Engineering Education*, **41**, pp. 120–124, 2013.
27. N. Amini, A. Sekaran, M. Schwaenen, A. Vijaykumar and D. Ranjan, An experimental investigation of the free jet flow from a radially lobed nozzle using hot-wire anemometry, *International Journal of Mechanical Engineering Education*, **40**, pp. 261–275, 2012.
28. M. Metghalchi and M. P. Grassman, Application of a Two-Dimensional Laser Doppler Velocimetry System in Undergraduate Fluid Mechanics Course, *International Journal of Engineering Education*, **11**(4–5), pp. 369–373, 1995.
29. A. T. Al-Halhouli, H. I. Abu-Mulaweh, M. Hammad, M. Alhusein and B. Shannak, Experimental apparatus for measurements of two-phase slug flow pressure drop in a T-junction, *International Journal of Mechanical Engineering Education*, **36**, pp. 184–192, 2008.
30. S. L. Tuttle, An experiment for teaching hypersonic aerodynamics to undergraduate mechanical engineering students, *International Journal of Mechanical Engineering Education*, **28**, pp. 151–162, 1997.
31. C. Y. Lam and C. Y. Liu, An Experimental Facility for Compressible Flow, *International Journal of Engineering Education*, **15**, pp. 58–63, 1999.
32. M. Atilhan, F. Eljack, H. Alfadala, J. E. Froyd, M. El-Halwagi and V. Mahalec, Inquiry Guided Learning in a Chemical Engineering Core Curriculum, *The International Journal of Engineering Education*, **30**, pp. 1450–1460, 2014.
33. R. Absi, C. Nalpas, F. Dufour, D. Huet, R. Bennacer and T. Absi, Teaching Fluid Mechanics for Undergraduate Students in Applied Industrial Biology: from Theory to Atypical Experiments, *International Journal of Engineering Education*, **27**, pp. 550–558, 2011.
34. W. Sano, Z. Szabo, D.-A. Borca-Tasciuc and T. Borca-Tasciuc, Introducing nanotechnology into the thermal and fluids curricula: pool boiling heat transfer in nanofluids, *International Journal of Mechanical Engineering Education*, **40**, pp. 276–288, 2012.
35. O. V. Fedina, A. R. Zakinyan and I. M. Agibova, Design of science laboratory session with magnetic fluids, *International Journal of Mechanical Engineering Education*, **45**, pp. 349–359, 2017.
36. J. S. Lyons and J. S. Brader, Using the learning cycle to develop freshmen’s abilities to design and conduct experiments, *International Journal of Mechanical Engineering Education*, **32**, pp. 126–134, 2005.
37. A. D. Grant, The Effective Use of Laboratories in Undergraduate Courses, *International Journal of Mechanical Engineering Education*, **23**, pp. 95–101, 1995.
38. A. Cancela, R. Maceiras, A. Sánchez, M. Izquierdo and S. Urréjola, Use of learning miniprojects in a chemistry laboratory for engineering, *European Journal of Engineering Education*, **41**(1), 2016.

39. B. Chen, R. F. DeMara, S. Salehi and R. Hartshorne, Elevating Learner Achievement Using Formative Electronic Lab Assessments in the Engineering Laboratory: A Viable Alternative to Weekly Lab Reports, *IEEE Transactions on Education*, **61**, pp. 1–10, 2018.
40. J. Biggs, Enhancing teaching through constructive alignment, *Higher Education*, **32**, pp. 347–364, 1996.
41. S. Lal, A. D. Lucey, E. D. Lindsay, D. F. Treagust, J. M. Long, M. Mocerino and M. G. Zadnik, Student perceptions of instruction sheets in face-to-face and remotely-operated engineering laboratory learning, *European Journal of Engineering Education*, **45**(4), pp. 491–515, 2020.
42. S. Nikolic, C. Ritz, P. J. Vial, M. Ros, and D. Stirling, Decoding Student Satisfaction: How to Manage and Improve the Laboratory Experience, *IEEE Transactions on Education*, **58**(3), pp. 151-158, 2014.
43. C. E. Heiner, Preparing students for class: How to get 80% of students reading the textbook before class, *American Journal of Physics*, **82**(10), p. 898, 2014.
44. A. J. Cann, Increasing Student Engagement with Practical Classes Through Online Pre-Lab Quizzes, *Journal of Biological Education*, **50**(1), pp. 101–112, 2016.
45. S. R. Whittle and S. R. Bickerdike, Online Preparation Resources Help First Year Students to Benefit from Practical Classes, *Journal of Biological Education*, **49**(2), 2015.
46. T. L. Rodgers, N. Cheema, S. Vasanth, A. Jamshed, A. Alfutimie and P. J. Scully, Developing pre-laboratory videos for enhancing student preparedness, *European Journal of Engineering Education*, **45**(2), pp. 292–304, 2020.
47. C. C. Bonwell and J. A. Eison, *Active Learning – Creating Excitement in the Classroom*, Washington: Information Analyses – ERIC Clearinghouse Products, 1991.
48. S. Freeman, S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt and M. P. Wenderoth, Active learning increases student performance in science, engineering, and mathematics, *Proceedings of the National Academy of Sciences*, **111**(23), pp. 8410–8415, 2014.
49. J. E. Mitchell, A. Nyamapfene, K. Roach and E. Tilley, Faculty wide curriculum reform: the integrated engineering programme, *European Journal of Engineering Education*, pp. 1–19, 2019.
50. M. L. Dahms, C. L. Spliid and J. F. D. Nielsen, Teacher in a problem-based learning environment – Jack of all trades?, *European Journal of Engineering Education*, **42**(6), pp. 1196–1219, 2017.
51. D. S. Domin, A Review of Laboratory Instruction Styles, *Journal of Chemical Education*, **76**(4), pp. 543–547, 1999.
52. J. Macias-Guarasa, R. San-Segundo, J. M. Montero, J. Ferreiros and R. Cordoba, Tools and strategies for improving PBL laboratory courses with a high student-to-faculty ratio, *Proceedings Frontiers in Education 35th Annual Conference*, Indianopolis, November 2005, pp. F2C-7.
53. K. E. Bledsoe and L. Flick, Concept Development and Meaningful Learning Among Electrical Engineering Students Engaged in a Problem-Based Laboratory Experience, *Journal of Science Education and Technology*, **21**, pp. 226–245, 2012.
54. D. J. Hartman and M. Gindy, Comparison of Lecture- and Problem-Based Learning Styles in an Engineering Laboratory, *Transportation Research Record*, **2199**(1), pp. 9–17, 2010.
55. W. McKeachie, and M. Svinicki, *McKeachie's Teaching Tips: Strategies, Research and Theory for College and University Teachers*, 14th ed., Wadsworth, Cengage Learning, 214.
56. D. Kember, Interpreting student workload and the factors that shape students' perceptions of their workload, *Studies in Higher Education*, **29**, pp. 166–184, 2004.
57. N. Entwistle, Chapter 3. How students learn and study, in N. Entwistle, Teaching for Understanding at University: Deep Approaches and Distinctive Ways of Thinking, Palgrave Macmillan, 2009.
58. E. Chamber, Work-load and the quality of student learning, *Studies in Higher Education*, **17**, pp. 141–153, 1992.
59. A. Alshamy, Credit Hour System and Student Workload at Alexandria University: a possible paradigm shift, *Tuning Journal for Higher Education*, **4**(2), pp. 277–277, 2017.
60. S. Kolari, C. Savander-Ranne and E.-L. Viskari, Learning needs time and effort: a time-use study of engineering students, *European Journal of Engineering Education*, **33**(5–6), pp. 483–498, 2008.
61. T. Ercan, F. Karaağaç and A. E. Emekli, A desktop application to learn the actual workload of the students, *Procedia – Social and Behavioral Sciences*, **1**(1), pp. 136–140, 2009.
62. A. Souto-Iglesias and M. T. Baeza-Romero, A probabilistic approach to student workload: empirical distribution and ECTS, *Higher Education*, **76**, pp. 1007–1025, 2018.
63. E. Kyndt, I. Berghmans, F. Dochy and L. Bulckens, "Time is not enough." Workload in higher education: a student perspective, *Higher Education Research & Development*, **33**(4), pp. 684–698, 2014.
64. Erasmus, *ECTS Users Guide*: European Union Publication Office, https://ec.europa.eu/education/ects/users-guide/docs/ects-users-guide_en.pdf, 2015.
65. M. J. Heslop, Developmental laboratory report-writing programme based on progression throughout the year: how to make better use of staff/student time and increase student satisfaction, *Education for Chemical Engineers*, **2**, pp. 62–71, 2017.
66. D. W. Hoffa and S. A. Freeman, The Impact of Laboratory Report Format on Student Learning, *International Journal of Engineering Education*, **23**, pp. 105–113, 2007.
67. F. Hammonds, G. J. Mariano, G. Ammons and S. Chambers, Student evaluations of teaching: improving teaching quality in higher education, *Perspectives: Policy and Practics in Higher Education*, **21**(1), pp. 26–33, 2017.
68. S. Darwin, Moving Beyond Face Value: Re-envisioning Higher Education Evaluation as a Generator of Professional Knowledge, *Assessment & Evaluation in Higher Education*, **37**(6), pp. 733–745, 2012.
69. V. D'Andrea and D. Gosling, *Improving Teaching And Learning In Higher Education: A Whole Institution Approach*: McGraw-Hill Education, 2005.
70. B. Sigurdsson, Mæling náms í ektum – undirstaða gæðastarfs?, *Vefritið Netla*, pp. 1–12, 2011.
71. A. Helgadottir, H. Palsson and G. Geirsdottir, Balancing Student Workload with Learning Outcome – The Search for Suitable Assignment Format for a Fluid Mechanics Lab, *International Journal of Engineering Education*, **36**(6), pp. 1924–1937, 2020.
72. E. Dallimore, J. Hertenstein and M. Platt, How do students learn from participation in class discussion?, *Faculty Focus*, https://www.facultyfocus.com/articles/effective-teaching-strategies/students-learn-participation-class-discussion/, 2017.

73. S. W. Bloom, The medical school as a social organization: the sources of resistance to change, *Medical Education*, **23**(3), pp. 228–241, 1989.
74. B. K. Daniel and T. Harland, *Higher education research methodology. A step-by-step guide to the research process*, Routledge, 2018.
75. M. V. Panyan, S. A. Hillman and A. M. Liggett, The Role of Focus Groups in Evaluating and Revising Teacher Education Programs, *Teacher Education and Special Education*, **20**(1), pp. 37–46, 1997.
76. J. Creswell, *Research design: Qualitative, quantitative, and mixed methods approaches (4th ed.)*: Sage, 2014.
77. B. Derrick, D. Toher, and P. White, Why Welch's test is Type I error robust, *The Quantitative Methods in Psychology*, **12**(1), pp. 30–38, 2016.
78. S. Nikolic, T. F. Suesse, T. J. McCarthy and T. L. Goldfinch, Maximising resource allocation in the teaching laboratory: understanding student evaluations of teaching assistants in a team-based teaching format, *European Journal of Engineering Education*, **42**(6), pp. 1277–1295, 2017.
79. M. G. Crisp, S. H. Kable, J. R. Read and M. A. Buntine, A disconnect between staff and student perceptions of learning: an ACELL educational analysis of the first year undergraduate chemistry experiment 'investigating sugar using a home made polarimeter', *Chemistry Education Research and Practice*, **12**, pp. 469–477, 2011.
80. R. A. R. Gurung and B. M. Schwartz, *Optimizing Teaching and Learning: Practicing Pedagogical Research*, Wiley-Blackwell, 2008.

Appendix

A short description of each experiment was given in a paper by the authors of this paper [71] and for clarification repeated below. An image showing each experimental set up has been added to the description. All the laboratory apparatus was purchased from Armfield Limited, but most have been adjusted since. An explanation of those adjustments has been added to the description below.

In the **static fluid pressure force** experiment, students increase the water level in a tank and simultaneously add a load to a lever. The momentum of the added load, along with the distance from the lever to the center of gravity of the area under water, is used to determine the static fluid pressure force on that area. Fig. 1 shows the experimental setup of the static fluid pressure force experiment. The original length scale on the apparatus, shown at the middle of Fig. 1, is both coarse and too short. Therefore, a new measurement system to measure the height of the water level, was added to experimental setup. The measurement system consisted of a bent rod with a pointed pin at one end and connected to a Verner caliper at the other end. Due to capillary effects, it is clearly detected when the pointed end touches the water level. The Verner caliper used had accuracy of 0.1 mm. The apparatus had originally no system to provide water. This was solved by adding a 5L bottle connected to the apparatus with a small soft tube. When water is supposed to flow into the apparatus the bottle is put at a higher elevation than the apparatus. When water is supposed to flow out of the apparatus the bottle is put at a lower elevation than the apparatus.

In the **stability of an object in static fluid** experiment, a raft floats on still water. By measuring the center of gravity, the center of buoyancy and the angle of tilt produced while a load is offset from the center of the raft, the distance from the center of gravity to the metacenter is determined. Fig. 2. shows the experimental setup of the stability of an object in static fluid experiment. The Plexiglas container holding the still water that the raft floated in was made by the laboratory technician.

In the **Reynolds experiment,** students observe flow in a transparent pipe with an indicator showing

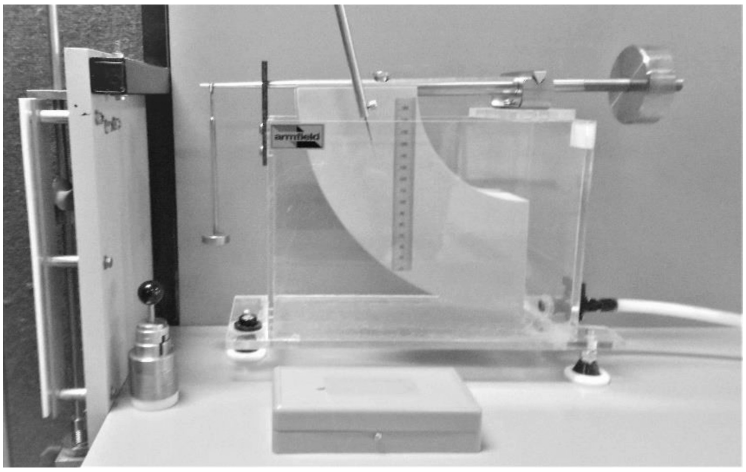

Fig. 1. Experimental setup of static fluid pressure force experiment.

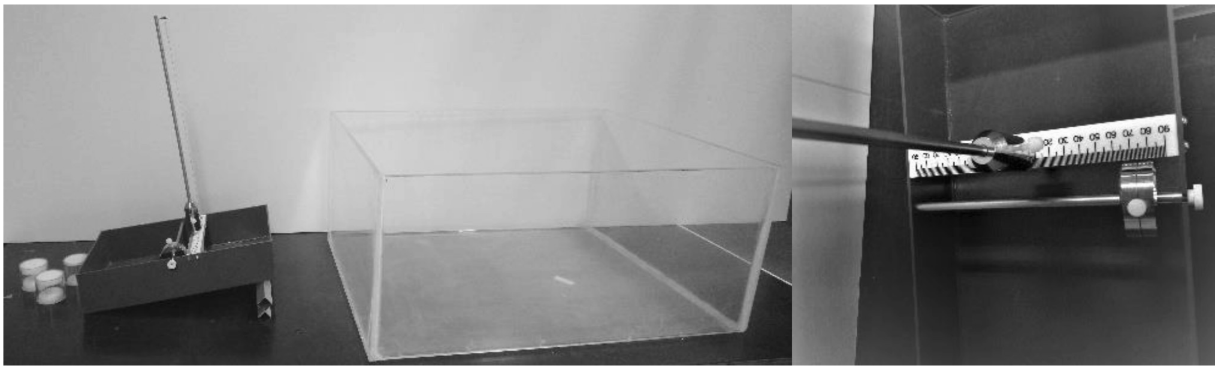

Fig. 2. Experimental setup of the stability of an object in static fluid experiment. The picture on the left shows a zoom into the load on the raft that is moved side by side.

Fig. 3. Experimental setup of the Reynolds experiments.

the streaklines. The transition between laminar, transient and turbulent flow is determined by varying the volume flow rate. Measuring the volume flow rate, the transition Reynolds number is determined. Fig. 3 shows the experimental setup of the Reynolds experiment. Originally, the apparatus was supposed to stand on a pump with water circulating. We decided to mount the apparatus on the wall and connect it to the laboratory sink. Water could then be controlled by using the faucet on the sink. The wastewater went down the drain. This was done because prolonged circulation of the water made the visibility of the ink difficult since the amount of ink present in the water increased with each cycle, making the water more and more colored. Since the ink in the tube was used to show if the flow was laminar or turbulent, it became nearly impossible to detect the streakline after a short while. It should probably be noted that Iceland has no water shortage, and this set up might not be advisable where water conservation is important.

In the **pressure drop in a pipe** experiment, students work with a pipe bench. They measure the pressure drop in a pipe for various flow velocity and compare these to the theoretical values using the Moody diagram. In longer (earlier) experiments, three pipes were explored but the shortened experiments used two pipes. Fig. 4 shows the experimental setup of the pressure drop in a pipe experiment. This apparatus came on wheels and tilted slightly. At its tallest, it was at approximately the hip height of a person meaning that students would need to kneel or bend while working on the experiments. We considered this to be bad working conditions and mounted the pipe bench the wall at a height that allowed students to stand during the experiment. The pipes where then at the height of most student's torsos or heads. Instead of using the pump provided to insert air into the manometer, we use airpipes in the laboratory.

In the **wind tunnel** experiment, the drag force on various objects in a subsonic wind tunnel is measured and compared to the theoretical values. In longer (earlier) experiments four objects were explored: sphere, disk, concave hollow half sphere and convex hollow half sphere. In the shorter (later) experiments, only the sphere and disk were used.

Fig. 4. Experimental set up of the pressure drop in a pipe experiment.

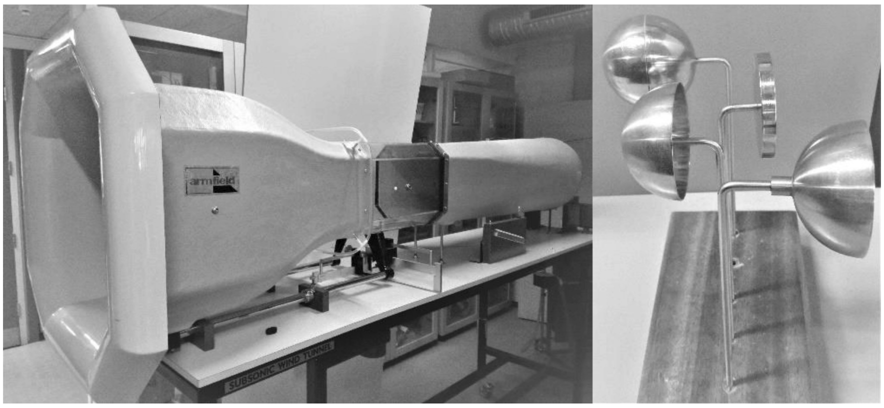

Fig. 5. Experimental setup of the wind tunnel experiment. On the left figure the four objects inserted (initially) to the wind tunnel are shown. The stick is always located downstream of the object.

Fig. 6. Experimental setup of the viscosity of fluids experiment.

Fig. 5 shows the experimental setup of the wind tunnel experiment and the objects inserted into the wind tunnel. The wind tunnel was renovated within the last 5 years, but the objects inserted into the wind tunnels are from previous versions of wind tunnels from Armfield (probably up to three decades old). Apparently, the pin holding the objects has changed between those two versions of wind tunnels from Armfield. This meant that the laboratory technician needed to adjust the mount where the objects were inserted. The scale measuring the force on the objects inserted need to be adjusted as well.

In the **viscosity of liquids** experiment, the viscosity of three liquids, unknown liquids are determined by measuring the terminal velocity of tiny spheres free falling in still liquids. Terminal velocity is achieved when the drag force on the spheres and gravity are in equilibrium. From the measured viscosities, students determine what liquids are used in the experiment. Fig. 6 shows the experimental setup of the viscosity of liquids experiment. This is the only apparatus that has not been recently renovated, meaning that it might be up to three decades old. The liquids used are glycerin, castor oil and engine oil.

Ásdís Helgadóttir is an associate professor at the Faculty of Industrial Engineering, Mechanical Engineering and Computer Science Department at the University of Iceland. She obtained her PhD in Mechanical Engineering from University of California Santa Barbara in 2010 and has focused her research in numerical methods, in particular with applications in fluid mechanics, heat transfer and bio engineering. After becoming a faculty member, her interest in improving teaching has grown. In 2019, she obtained a Postgraduate Diploma in Teaching Studies in Higher Education and by using the skills she learned there, she has started to scholarly and systematically tackle the obstacles she faces in her own teaching. In November 2021 Ásdís was chosen to be one of 11 founding members of the Icelandic Teaching Academy.

Halldór Pálsson is a professor at the Faculty of Industrial Engineering, Mechanical Engineering, and Computer Science at the University of Iceland. He received his MS degree in 1995 and his PhD degree in 2000, both in the field of Mechanical Engineering from the Technical University of Denmark. He has worked on mathematical modeling of various physical problems, including heat transfer, structural engineering, and electromagnetism. His main research interests include heat transfer and fluid mechanics with emphasis on numerical and mathematical modeling, systems related to geothermal energy utilization, as well as models used in bio engineering.

Guðrún Geirsdóttir is an associate professor at the Faculty of Education and Pedagogy and the head of the Center for Teaching and Learning at the University of Iceland. She obtained her Master of Science degree in Curriculum and Instruction from Pennsylvania State University 1996 and her PhD in Education from Iceland College of Education in 2008. Since 2000, she has led the Center for Teaching and Learning, organized and run a postgraduate diploma program in higher education and encouraged SoTL approaches at different organizational levels within the University of Iceland.