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Increasing Bloom's Hierarchical Learning in Aerospace Engineering – a Case Study of Forensic Engineering Course using a "Chain of Events"

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An often heard complaint is the inability of students to apply their learning at a higher level in Bloom's taxonomy. However, the challenge in teaching basic forensic engineering principles to students and achieving a higher Bloom's learning hierarchy is time. As a Master's elective course within a two-year Aerospace Engineering curriculum, limited time is allocated (84 hours). Teaching students the fundamentals of Forensic Engineering, applying them, and synthesize the knowledge in four class hours, plus self-study, over seven weeks is challenging. As such the lecture setup needs to address theory, application, and synthesis in a fundamental, educationally constructive approach. By having a multi-step group exercise which is running concurrently alongside the academic theoretical and hands-on lectures, the students are challenged to apply the concepts learned and synthesize their knowledge. This paper presents a case study: the "Chain of Events" group exercise, which students are required to perform as part of the forensic engineering course. The exercise was mainly developed to bridge the learning gap from application to creation by a problem-based-learning exercise. Furthermore, the exercise prepares students for the hands on exam whereby an actual crash is recreated. Within this paper the Forensic Engineering learning outcomes, the set-up of the "Chain of Events" exercise, its results and the evaluation of student performance and satisfaction will be described.

I. Nomenclature

n	=	number of students
p	=	probaility-value or test significance
$S.D.$	=	Standard Deviation
U	=	Mann-Whitney test statistic
z	=	standard score

II. Introduction

The Forensic Engineering course discussed throughout this paper is an elective course with a 84-hour study load in the two-year master program at the Faculty of Aerospace Engineering of Delft University of Technology in The Netherlands [1]. The master degree has a work load of 3360 hours and allows students to specialize in one of four resarch groups: Aerodynamics & Wind Energy, Flight Propulsion & Performance, Control & Operations, Aerospace Structures & Materials and Space Engineering. With approximately 1300 bachelor and 1300 Master students the Faculty of Aerospace Engineering is the largest in western Europe. At the Bachelor level the educational goal is to strive for a broad academic background with wide aerospace domain knowledge. Students are taught to be academically intellectually skilled with a good attitude to analyze, apply, synthesize and design. For the Master's program the learning is focused

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towards an expert having deeper engineering knowledge and understanding in a specific sub discipline. Student are taught to be academically intellectually skilled to model, analyze, develop, research and solve.

The Faculty of Aerospace Engineering is a member of several education networks such as CDIO and GE3 and has an active learning philosophy embedded in its curriculum. Similar to other universities worldwide project-based-learning, an effective organization form of Problem Based Learning (PBL) is a corner stone in the engineering curriculum. These projects enable students to synthesize knowledge by for example, a Design Synthesis Exercise or Capstone project[2][3]'. Project-based-learning programs have been embraced as effective multifaceted educational means to develop engineering student's skills. The improvement of student knowledge, motivation and skillfully to apply knowledge in a new situation [4]. It allows to increase Blooms' hierarchal level of learning [5] and achieves higher learning outcomes [6].

However, Project-Based-Learning is time intensive and requires a lot of scheduled on-campus time during a semester or educational block and are often allocated more credits than electives. Project-Based-Learning is therefore primarily suited for mandatory undergraduate courses. For a typical lecturer teaching an elective in the master, achieving the synthesis of knowledge seems to be unachievable for students from a scheduling point-of-view. This is why for electives that combine knowledge and skills it is better to abandon the project setting but maintain the Problem Based Learning strategy in order to achieve higher levels of learning. This does not mean that students do not work together but the structure in which they work together is more loose.

In order to be effective, lecturers need to devise a problem based learning experience which addresses several learning outcomes during the course and enables students to go to the Blooms' hierarchical creation level. As stated by De Graaff and Kolmos in their work on PBL [6], PBL is characterized by a logical course structure and design, i.e. offering the right information at the right time, self-directed learning groups with lecturers facilitating the discussion and activities, and an assessment testing students' competence and progress rather than testing the student for "isolated factual knowledge".

III. The Forensic Engineering Course

The Forensic Engineering course is open to all Aerospace Engineering Master students and runs in the third quarter of the first year master's program. At this time the students already possess a Bachelor's degree in either Aerospace or Mechanical Engineering. The course is taken by 20-40 students each year, some of whom take it as an supplementary course. Although Forensic Engineering is an Aerospace Materials & Structures elective only 40% of the students originate from this track. All other Aerospace Engineering tracks are represented resulting in Forensic Engineering having a diverse students group with various backgrounds in different aerospace topics.

The Forensic Engineering course was set up to teach students forensic methods and principles based on air safety investigations. The accident and incidents diversity of the past hundred years holds a wealth of information and educational value. In certain cases the aircraft accident can be related to an engineering failure by which a forensic investigation can disclose the root cause. In other instances human error is a more prominent cause, but more often it is a combination thereof. Only a non-biased investigation approach will result in a substantiated conclusion and recommendation to prevent re-occurrence. As such the course objectives and setup are tailored to achieve the learning outcomes using problem based learning. Furthermore, by active learning and specific exercises students are enabled to enhance their critical thinking and collaborative working skills.

A. Learning Objectives

The main Forensic Engineering learning objectives are to teach the students the theory, experience and apply the different skills of a forensic investigation, see Fig. 1. The student are instructed on approaches that will help in determining what, how and why it happened. As the course is based on aircraft accident investigation the learning objectives have been formulated specifically to address aircraft accident investigation topics. In the Aerospace Engineering study guide the following Forensic Engineering learning objectives have been formulated; after the course students will be able to:

- Describe and explain the accident investigation goal, identify and analyze the different investigation phases.
- Demonstrate and apply accident investigation techniques.
- Select and use forensic investigation techniques to determine failure causes.
- Have knowledge of constructing and testing hypothesis and the ability to go through a verification process.
- Write an Annex 13[7] accident investigation report with fact, analyses and conclusion including the formulation of recommendations to prevent re-occurrence or diminish the consequence of future events.

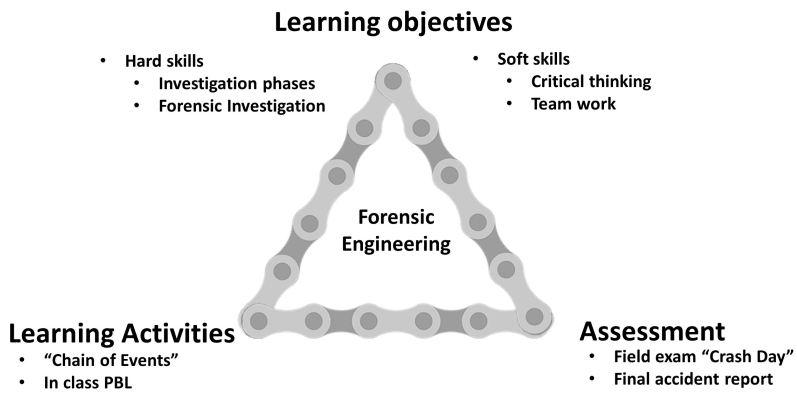

Fig. 1 The Forensic Engineering constructive alignment triangle showing the connection between learning objectives, learning activities and assessment.

Apart from the learning objectives the course also aims to improve the critical thinking and collaborative working skills of students. Both skills are necessary for the Forensic Engineering course as team work and critical thinking are necessary to solve the problems given during the lectures. As Critical Thinking Skills is defined by Halpern in 1999[8] where it is stated that: "Critical thinking refers to the use of cognitive skills or strategies that increase the probability of a desirable outcome. Critical thinking is purposeful, reasoned, and goal-directed." She also expresses the opinion that these skills are transferable across the whole academic landscape. This means that students are not limited to only their engineering knowledge and skills. Critical thinking requires an ability to acquire and synthesize knowledge from all relevant fields in order to reach the desired goal. This type of thinking demands that students go outside their comfort zone and evaluate thought processes and outcomes themselves. Trevelyan has already stated that this may pose an obstacle for engineers: "Critical thinking and presenting logical arguments can be more challenging for engineers than for those with a background in humanities"[9]. He makes this claim based on an article by Ahern et al.[9] in which they provided evidence that staff in engineering academia have the least developed ideas on critical thinking compared to other disciplines in academia. Trevelyan[10] puts the blame for this short-coming partly on the way engineers are taught. They have often been stimulated to build on their natural strengths in STEM courses at school, fields in which logical thinking is made easy, facilitated by formulas.

B. Learning Activities

The theory and practical hands-on learning activities are aimed to prepare students for the final practical exam for which a simulated accident scene investigation is created named "Crash Day". The general setup of the forensic engineering course is given in Fig. 2. In week 2 the course instructors make student teams based on students knowledge background (Master track) ensuring a diversity of aerospace specializations being present in each group. From this point onward the students will perform the hands-on PBL assignments as a set group. This allow students to get familiar with each other and learn each other's strong points and weaknesses over the remaining six lecture weeks. This will also increase group cohesion in tackling problems in a stressful situation which the "Crash Day" exam is for most students.

In week 1 student are introduced with the basic concepts in accident investigation. During the following lectures the primary phases of an aircraft accident investigation are explained: starting from the 'Data Collection' (fact-finding) phase through the 'Analysis' phase (hypotheses) and the final 'Reporting' phase (conclusion). Each phase is dealt with in a separate lecture with theory being presented in a classroom setting. If possible a small in-class exercise is given to allow students to apply the knowledge acquired. During the subsequent lecture a more elaborate PBL exercise is given which is done by each student team separately to increase learning level.

An example of one of these more elaborate PBL exercises is the field mapping exercise in week 2, where students are taken outside and presented with a simulated drone crash. The crash scene is prepared by the instructors in a small field and represents a scenario which corresponds to the drone damage. The purpose of this exercise is not to solve the event but focus on data collection, measuring and practicing writing down factual observations. Students are asked to make debris field map with a provided set of tools and equipment (which are the same tools that are later used in the final exam) and report on this. During this exercise students have a chance to get acquainted with the tools and debris mapping.

Another example of an extensive PBL exercise is the so-called "eggsercise", which was developed to teach students logic, critical thinking and hypothesizing. During this exercise the students are given an evidence folder containing pictures of broken eggs and additional images with information which is not described. It is the students task to use the information provided in the evidence folder to come up with plausible scenarios and conditions for the ill-fated eggs that are consistent with the evidence at hand. The student are required to use the (limited) information they have to form hypotheses and (cor)relate this with the information they have available. This exercise was described in more detail by Saunders et al. [11]. The interview exercise in week 6 is aimed in getting information from witnesses by students who are provided with basic interviewing techniques. This exercise aims to expose students to the fact that in addition to technical knowledge and attention in an investigation, often a human touch is also needed for aspects of an investigation. Using a real-life accident case, a dynamic PBL exercise involving staff and students role playing the different witnesses to the accident is carried out, focusing on the soft skills necessary to deal with people in high-stress, traumatic, and even hysterical states. After 7 weeks the students will have gained understanding of each phase of an investigation separately and have a basic understanding of the forensic engineering steps. In the final week, for example, a lecture is devoted to formulating conclusions and making recommendations. This is an important step as the outcomes of an investigation can result in future improvements hereby enhancing aviation safety.

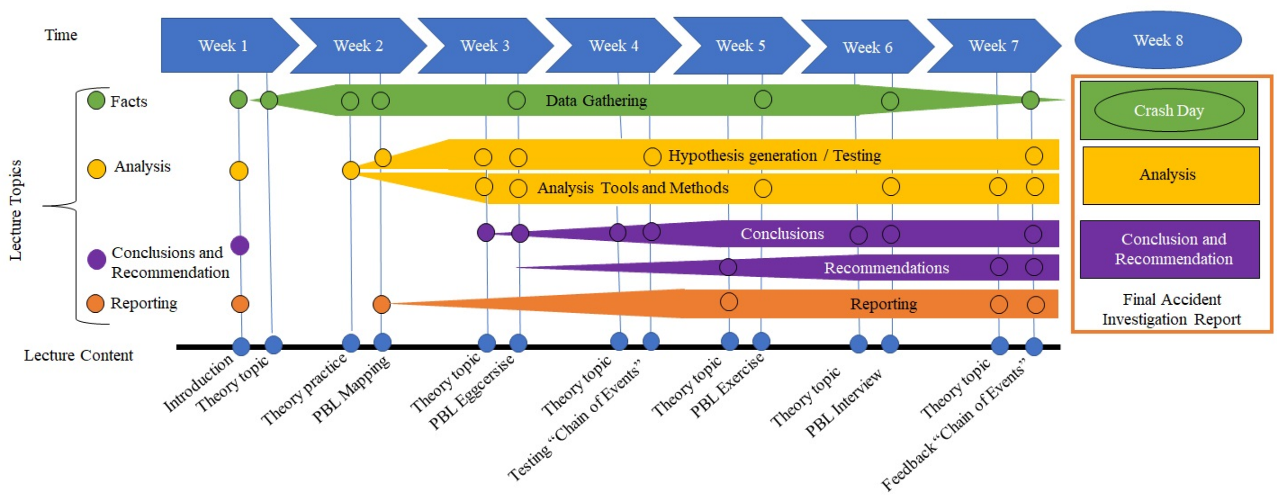

Fig. 2 The Forensic Engineering PBL based course setup with learning activities week 1 through week 7 and the final exam in week 8 (field part; "Crash Day" and report part: accident investigation report).

C. Assessment

The final group-based exam on "Crash Day" consists of 5–7 students, who have been working together during the lectures, carrying out a simulated accident investigation (field part) and writing a final accident report (report part) on this accident. Three lecturers assesses each group during the field part of the exam using a predefined set of observation and grading criteria. The group receives a field grade which is 50% of the final student grade. After the field part of the exam, students have four weeks to write a final accident report following Annex 13 format. With regards to report grading, it is not necessary that students obtain the conceived accident cause. It is recognized that in setting up a simulated accident scene, extraneous details or misleading clues could be overlooked by the instructors and misinterpreted by students. Thus, the primary goal of the report is to have students develop scenarios (hypotheses) based on the evidence they have gathered during the field exam. For grading the final reports an assessment rubric was created which takes into account specific facts gathered by the investigation teams, rather than all of the facts known (and placed) by the instructors. The formulation of hypotheses and their analysis is part of the assessment rubrics. The adherence to the reporting standards listed in Annex 13 [7] as well as the the way the report text is written is part of the assessment rubrics. The final report counts for 50% towards the final grade.

IV. The "Chain of Events" Exercise

As the Forensic Engineering course progresses and students are becoming more familiar with the basic steps of a forensic engineering investigation each lecture , it is apparent that a mismatch between the above described PBL activities and the final assessment is present. Each forensic investigation step was dealt with in a separate (topical) lecture and PBL activity; however, the final exam requires the ability to synthesize each of these steps into a single accident investigation exercise. In the course students did not get the opportunity go through all the investigation steps themselves as a whole. With the exam being at the Bloom level of creation and evaluation a course misalignment was present. In order to bridge the learning level gap a multi-week team challenge was introduced entitled "Chain of Events". The aim of the " Chain of Events" exercise was to increase Bloom's hierarchical learning level for students to experience each investigation step themselves as a whole. The "Chain of Events" exercise is done as homework separate from the lectures but runs parallel to the topical material taught during the lectures.

The "Chain of Events" exercise is based on a bicycle chain failure. With approximately 84% of the Dutch population owning at least one or more bicycles and around 25% going to work by bicycle The Netherlands is recognized as a huge cycling country[12]. With a combined staff and student population of around 25,000 a lot of cycling is done around the Delft University campus. Furthermore, the bicycles driven by a student are typically old and the overall structural state, due to financial constraints on maintenance, is poor, which results in potential chain failures every day. This makes this a relevant, understandable, real-life topic students can relate to. Over a period of 4-5 weeks each forensic engineering student team is required to perform their own investigation into a specific chain failure and report on it. The main exercise tasks are to reverse engineer the bicycle chain failure and report on it. The "Chain of Events" exercise allows each student team to go through the main phases of an investigation themselves while obtaining a deeper learning and understanding of the course material. In the sections below the different phases of the exercise are described and in Fig. 3 an overview is given on how the exercise is timed over the 7 weeks Forensic Engineering educational lecturing period.

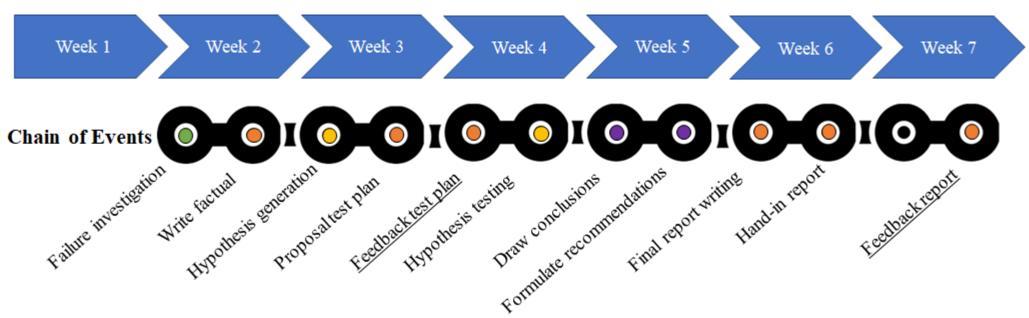

Fig. 3 Linking the "Chain of Events" exercise with The Forensic Engineering PBL based course setup with learning activities and concurrent lecture activities..

A. Data Gathering

Over a four-month period this author together with other Aerospace Engineering staffs could collect eight failed bicycle chains spread across the Delft University campus. The eight different chains exhibited a variety of failures and wear. This was the starting point for the "Chain of Events" student exercise. Each student group received their own chain for the exercise, an example chain is shown in Fig. 4. Their first task was to observe and document any factual information about the nature of the failure, including visual observations of failure locations and relevant measurements of structural details. In the first week each group has to examine the chain and report on the failure as shown in Table 1. Given the fact that the chain was found without any witnesses present, students can only rely on engineering investigation techniques. The students are allowed to examine the chain by any means they choose. The only boundary condition given to students is that, just like in a real investigation, the chain of evidence should be kept intact. This means that only non-destructive testing (NDT) and observations can be performed by the students. As each team contains at least one student from the Aerospace Structures and Materials Track, NDT knowledge is present in each team. Following the data collection phase a factual report needs to handed in by the students which ends the data gathering phase. The report is reviewed by instructors to provide feedback to each group.

Fig. 4 Example failed bicycle chain.

B. Hypothesis generation and testing

During the data gathering phase, the students are asked to think about possible scenarios and establish a hypothesis that can be tested. The exercise is further enhanced by providing the students with 3 similar bicycle chains for laboratory testing. Also, a tensile test machine in the Aerospace Structures and Materials Laboratory is made available to conduct the tests during the lecture. This allows each student group to test the hypothesis they deem the most likely. The ultimate goal for students is to reproduce the exact chain failure with the example chains. Before students can test their hypothesis, the students are required to submit a test plan for the laboratory test. This requires the students to think in detail (create) about the hypothesis, and the test set up and what to test for and how to verify their hypothesis. The laboratory technical staff review each test plan on feasibility and safety prior to testing. Only when the technical staff in the laboratory signs off on the test, can the students execute the test plan with the aid of the technical staff. The students should follow the submitted test plan and note down the results. As the availability of the test machine is limited, preparation and student participation is essential to stay on schedule. Also the feasibility of the test forces students to think, prepare and better conceptualize what needs to be accomplished. An example of a bicycle chain in a test machine is given in Fig. 5.

C. Analyses and conclusion reporting

After the (hypothesis) testing the students are required to evaluate the test results and come up with a conclusion with respect to their original hypothesis and possible recommendations. Experience with student aviation incident reports from previous years showed that in reporting, using specific and accurate wording can be an issue for our students, most of whom are non-native English speakers. As such the reports from the "Chain of Events" exercise are reviewed and elaborate feedback is given to student team. This is in part to prepare them for the final exam for which a similar but more extensive report is required.

V. The learning outcomes

This exercise was first run in the 2016/17 academic year and for a second time in the 2017/18 academic year. The first time it was run, the "Chain of Events" exercise was not evaluated separately and in its second year it was decided to take a closer look at its effects. We looked at the outcomes from a instructor point-of-view,from the student's point-of-view with the aid of two surveys and finally, a benchmark is attempted by comparing the self-assessed learning outcomes of

Fig. 5 Example bicycle chain in test machine.

Table 1 Overview of student activity during the "Chain of Events" exercise.

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Failure investigation		Start	End				
Hypothesis formulation		Start	End				
Test plan		Start	End	Feedback			
Hypothesis testing				Start- End			
Conclusion				Start	End		
Recommendations					Start	End	
Reporting					Start	End	Feedback

students of the year 2017/18 with the outcomes reported by the students who took the course in 2013/14, as previously published by Saunders et al. [1].

A. Instructor observations

Both instructors involved in teaching the Forensic Engineering course observed a large diversity in student group's ability to tackle the "Chain of Events" in the first year. Some initially did not take the exercise too serious and the quality of their work showed it. Other groups found it hard to get to grips with testing and some groups went through the exercise as intended. From this experience the instructors emphasized in the second year why students were given the exercise in order to avoid the reported underestimating of the exercise. Despite these observations it was was however noted that for both years the "Chain of Events" was done the students were more prepared and were more methodical in their data gathering and hypothesis forming during "Crash Day" compared to previous years. It was also found that students were better in asking the right questions, which were more factual, on which information was or was not available. As opposed to questions in previous years on how to proceed further. As such it was felt by the instructors that the students appeared to have a better grasp of expectations and needed less support to complete their investigation. Furthermore, some students groups impressed the instructors by going above and beyond what the exercise entailed by coming up with innovative test solutions and analyses of the evidence. This showed the students ability to increase Bloom's learning level by the "Chain of Events" exercise.

B. Reported learning outcomes

In order to quantify the learning outcomes for the class 2017/18 from a student point-of-view, students were asked to take part in the course survey by filling in two questionnaires. One at the start of the course and one directly after the "Crash Day" exam. A total of 20 students participated in the course of which 19 gave permission for their data to be used (response rate: 95%). As the survey was to be used for an academic publication permission was obtained and granted from the TU Delft's Human Research Ethic Committee beforehand as required by Delft University of Technology standards.

The outcomes of the survey showed that students were in general overwhelmingly positive when asked about the organization of the course as can be seen in figure 6.

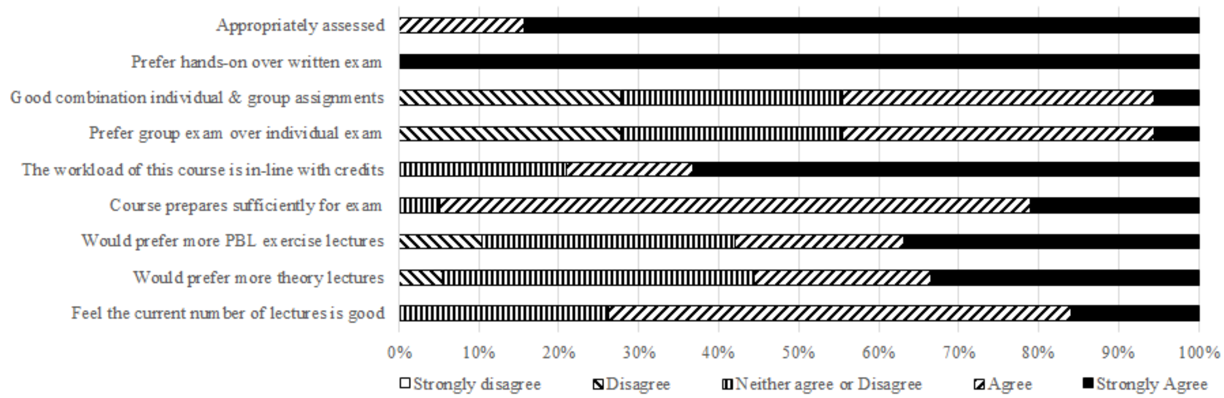

Fig. 6 Student opinion on the overall course organization

The students were also asked how much each of the 4 core exercises contributed to their level of preparedness for the exam. As can be seen from figure 7 all 4 exercises were seen as contributing somewhat to greatly to the students level of preparedness for the exam. The "Chain of Events" was the only exercise for which none of the students said it did not contribute.

Finally, the students were asked to rank the theoretical lectures, and the four exercises (Field Mapping, Eggcercise, Incident Interview and "Chain of Events" exercise) in order of contribution towards reaching their learning objectives. A score was calculated for each of these activity by assigning a value to each rank (First ranked - 5 points, second ranked - 4 points etc.). The results can be seen in Table 2. The "Chain of Events", together with the Field Mapping and Incident Interview Exercise are deemed most valuable by the students in aiding them in meeting the learning objectives.

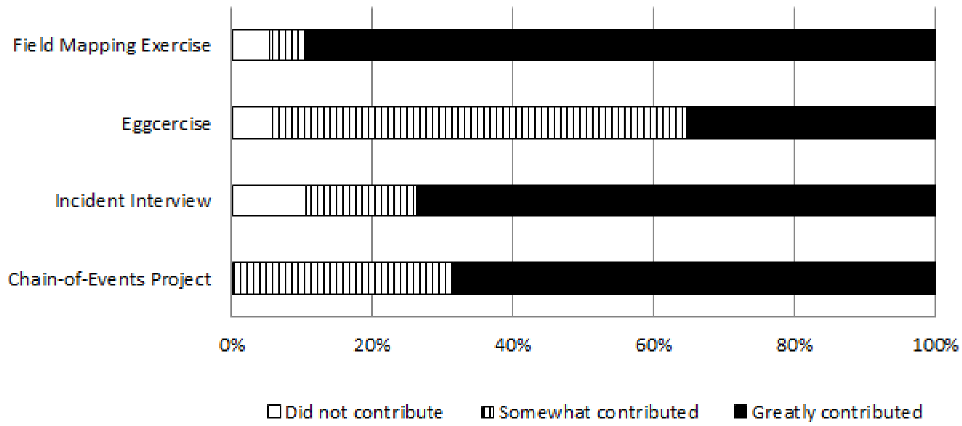

Fig. 7 Student opinion on the course exercises contribution to prepare them for the exam

Table 2 Most contributing course activity to students meeting learning objectives.

	Score
Theory Lectures	54
Field Mapping	58
Eggcercise	41
Incident Interview	58
"Chain of Events"	58

C. Benchmarking

This course in its current format is now in its fifth year running. In the first year running research was also carried out in this course and reported in [1]. Several questions in 2013/14 on the survey were repeated in the 2017/18. Which gave an opportunity to compare. One the identical questions asked to students was to rate themselves in their forensic engineering skills level before and after the course. In Table 3 the average scores for each of the years surveyed are listed. For each year a Wilcoxon signed Rank test was carried out to see if there was a significant increase in their growth in Skill level. This was found to be the case for each course run, both with a large effect size. Next we compared the increases in reported skill level by the students from each cohort. The reported average growth in skill level for 2013/14 was higher(ave=2.74, $S.D.$ = 1.259) than that for the 2017/18 cohort(ave=2.000, $S.D.$ = 1.732), however the standard deviation is rather large for both samples indicating a large spread in reported growth. A Mann-Whitney test was performed, with U=140 and p>0.01, which means that there is no difference between the two cohorts.

Table 3 Comparison of self-reported growth in skill-level in Forensic Engineering between the class in 2013/14 and the class in 2017/18.

	2013/14 Before	2013/14 After	2017/18 Before	2017/18 After
Average Grade	5.3	8	5.7	7.6
n	29	28	17	19
$S.D.$	1.236	0.693	1.714	0.663
z		-4.577		-3.567
p		<0.01		<0.01
r		0.86		0.87

VI. Conclusion

There is a real need for students to not only retain factual knowledge but more importantly use and apply the knowledge to initiate their own investigation in the world of Forensic Engineering. Although the course in its conception was actively teaching students on how to investigate, there was not sufficient opportunity for students to practice in creating and initiating their own investigation prior to their final assessment. As a result the instructors work load was quite high in the lead up and aftermath of the final exam "Crash Day" in answering student's questions. It was found that by introducing the "Chain of Events" exercise, students were able to practice and become more prepared for the final exam. As the "Chain of Events" gave students the opportunity to perform a similar investigation and deliver a similar report with feedback on their work prior to the final assessment. Staff observed a reduction in workload in terms of answering questions and an increase in students preparedness for the exam.

This was also collaborated by a survey filled in by the students themselves. Students overwhelmingly report that the "Chain of events" contributes to their level of preparedness for the exam. They also report that the exercise is one of the major contributors to them meeting the learning objectives of the course.

The comparison of Forensic Engineering skills level before and after the course was also looked at. The data of the 2017/18 student group was compared to that of the first student group doing the course in 2013/14. A significant increase in skill level growth was found with no significant differences between the self-reported scores. This shows the structure of the lectures are aligned and the learning objectives are met.

The Forensic Engineering course is being redeveloped and tweaked each year to incorporate new challenges and to better prepare students for the exam. As a result of this effort the "Chain of Events" was developed to bridge an identified learning gap and to realign the course objectives. Now it has been validated to be useful the "Chain of Events" exercise will be stay in the course outline. As the survey also has showed that 4 core exercises contributed to the students level of preparedness for the exam these exercises will also be included in next year Forensic Engineering class.

VII. Acknowledgments

The authors would like to thank the Delft Aerospace Structures and Materials Laboratory staff of Delft University of Technology for their invaluable assistance, cooperation and advice in making the "Chain of Events" exercise happen. Also all the colleagues who sourced bicycle chains and all the students who have taken the course, without whose open and honest feedback this paper could not have been written.

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