The 11th Conference on Physics Teaching in Engineering Education PTEE 2022

May 11th to May 13th 2022

Tampere University of Applied Sciences (TAMK)

Tampere, Finland

PROCEEDINGS

Tampere University of Applied Sciences

SEFI European Society for Engineering Education

STEM CENTER TAMK
Physics Chemistry Mathematics Technology Pedagogy

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INTRODUCTION

A few words from the conference chair

Dear PTEE participants and members of the SEFI community.

PTEE 2022 was organized on-site after the pandemic restrictions, in Tampere, Finland, at the edge of Europe. Our small but enthusiast group of physics educators gathered to discuss teaching and learning and to learn from others. The feeling was contradictory. We were able to meet face to face after years. In turn, the sad news from the Ukraine had reached us some months earlier. The war that casts a shadow on the whole Europe continues.

In Tampere, we had two and a half days of interesting talks and enough time for social events that brought the participants together. We were happy to start the event with a sauna experience and offer some Finnish hospitality to our participants.

The event was also a milestone for the SIG of Physics. We elected a new chair, Arjan, who took the responsibility to steer us towards the upcoming challenges. We were also happy to announce the organizer of the next PTEE. The conference will be in Rosenheim, during May 2024.

Yours Sincerely,

Juho Tiili

Former Chair of the SIG

USING PRE-ASSIGNMENTS AS A BASIS OF GROUP DISCUSSIONS ON AN INTRODUCTORY PHYSICS COURSE

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The use of pre-assignments on a flipped introductory physics course in Tampere University was studied. The pre-assignments were conceptual exercises, worked through in small group discussions in the in-class phase. The data was collected by interviewing four students and two teachers of the course and analyzing the chosen pre-assignments. The results show that pre-assignments could be an effective tool if they are designed carefully. The key points to consider in the designing process are the topic and the content covered in the assignment, the structure of the assignment, and the form of the final answer.

Keywords: pre-assignment, flipped classroom, conceptual knowledge

INTRODUCTION

The research was conducted in Tampere University Hervanta campus on an introductory physics course (Laaja Fysiikka 3) with electromagnetism as the topic. The students of the course were engineering students with a major in physics, chemistry, or mathematics. This introductory course is one of the first physics courses for the Bachelor of Science in Technology degree which targets to Master of Science in Technology degree. This study is a part of Tampere University Flip&Learn project where the use of flipped classroom method is studied. The motivation for this study is to find out how conceptual pre-assignments and flipped classroom implementation could advance student conceptual knowledge. Advancing conceptual knowledge is important because it has been found that the problem-solving of experts and novices differs a lot, especially in the use of conceptual knowledge. [1][2]

The course was implemented using the flipped classroom approach. In the pre-class phase, the students watched recorded lecture videos and other short videos and used the course handout and the coursebook. After that, the students did the pre-assignments which were conceptual exercises about the topic of the week. The pre-assignments were worked through in the in-class phase where the students discussed the pre-assignments in small groups. The pre-assignments were published on the course Moodle site and the students should return them to the course Moodle site in free-text format before the group discussions. In addition to the pre-assignments, there were algebraic exercises at the course, and these were also discussed in the small groups. An example of a pre-assignment exercise is shown in figure 1.

Consider the principle of an electric motor. First, write the expression for the magnetic moment ($\bar{m}$) of a current loop and the expression for the torque ($\bar{\tau}$) on a magnetic moment in an external magnetic field.

a) How to avoid that the rotating loop does not stop as $\bar{m}||\bar{B}$?
b) How can the torque of the electric motor be increased?
c) How could one make the torque of the electric motor as steady as possible?

Fig. 1. An example of a pre-assignment used in the course.

In the in-class phase, the groups of 5 students met every week at the same time. There were two small groups and a teacher in one session. The meeting took two hours and in that time the students went through the algebraic exercises from the last week and the pre-assignments of the current week. In the beginning, the students discussed together. After that, they presented their answers to the other group and the teacher. The teacher asked further questions, helped the groups if needed, and underlined the most important things. The students should correct their answers by themselves in the meeting if needed, but they didn't need to return their answers after the meeting. The teacher used the pre-assignment answers of the students as a guideline when designing the group meeting. The student answers differed from each other quite a lot and that is the reason for the group discussions. The students could compare their answers and practice justifying their answers.

There were two pre-assignments every week in the course. Completing the pre-assignments at least four times out of six and attending at least four out of six group discussion sessions were mandatory to pass the course. The pre-assignments were graded pass/fail and the number of passed pre-assignments had a little impact on the total grade of the course. The pre-assignments differed from other readiness assurance testing [3] being the most significant part of the in-class phase. In addition, they made sure that students have studied the material given. The meaning of the pre-assignments was to add conceptual learning to the course exercises and allow the students to discuss their solutions with peers.

The questions we are answering in this study are:

1. How could the use of pre-assignments improve learning?
2. How should the pre-assignments be designed to improve learning and be suitable for the basis of group discussions?

METHODOLOGY

The study was conducted as design-based research [4] which consists of cycles where solutions to a specific problem are designed and tested. Only one cycle consisting of three parts was conducted in this study. The first part of the first cycle is a theoretical problem analysis where the researcher familiarizes himself with the former research and the theory of the topic. The second part is called empirical problem analysis where the data on the research topic is collected. After that in the third part, the interventions for the problem are designed. If the second cycle is applied, the interventions are tested, and more data is collected to improve the intervention.

Four students and two teachers of the course were interviewed for this study. The data was collected from the 2021 course implementation. Each interview took 60-120 minutes and was transcribed. In the end, there were 73 pages of transcriptions. The interviews were designed as semi-structured interviews where the same topics were discussed with every interviewee, but the order and the form of the questions could vary. There were no ready answer options, and the interviewees could talk about their observations that were not included in the questions. The questions were formulated using the theoretical problem analysis. The themes discussed were interaction in the groups, teamwork and working in the groups, roles in the groups, emotions, and attitudes toward working in groups, and the pre-assignments as a basis for group discussions. The relevant comments from the interviews were simplified. After that, the comments representing the same standpoint were brought together. This data was analyzed with theory-based content analysis techniques [5] where the analysis starts from the content but is conflated with the theory. The classification of the interview results is shown in figure 2 below.

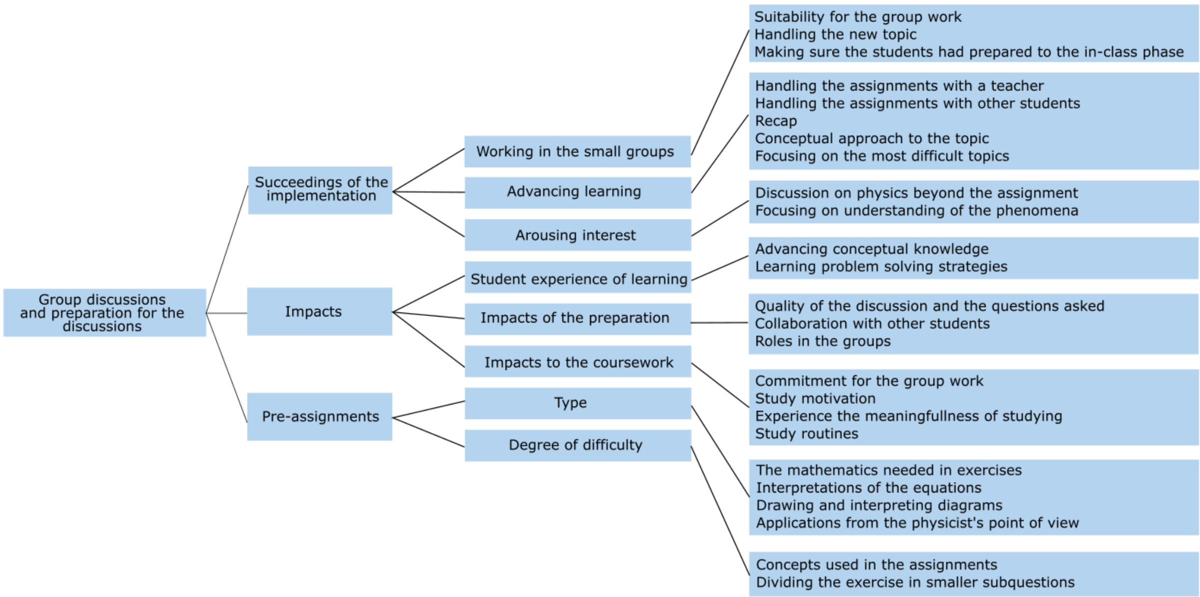

Fig.2. Classification of the interview results.

The pre-assignments analyzed in this study were chosen based on the interviews. Each pre-assignment represents a different kind of exercise. Four different types of exercises were

1. The mathematics needed in exercises
2. Interpretations of the equations
3. Drawing and interpreting diagrams
4. Applications from the physicist's point of view

According to the interviews, the best example of each category exercise was chosen from the pre-assignments of the course. The pre-assignments were analyzed using Greeno's Four Domains of Knowledge [6]. After that student answers for the chosen pre-assignments were analyzed. There were from 20 to 22 student answers available for each pre-assignment. The student answers were compared to the analysis conducted with Greeno's Four Domains of Knowledge.

RESULTS

The key elements of the pre-assignment design were divided into three categories: topic and content, structure and language, and the final answer. Under each category, there are instructions regarding the design of a pre-assignment.

1. **Topic and content**
   a. The pre-assignments use a conceptual approach to the topic.
   b. The pre-assignments cover the most important or the most difficult content of the course.
   c. The pre-assignments are based on the pre-study material.
   d. The pre-assignments combine different domains of knowledge.
   e. The concepts used in pre-assignments are familiar to the students from the pre-study material.

The interviews suggest that the conceptual approach of the pre-assignments is the most significant element of successful pre-assignments because conceptual pre-assignments and traditional algebraic exercises complement each other. The time in classroom discussion could help the students to learn the most if it deepens the conceptual understanding of the topic. The interviews also suggest that the discussion in small groups focuses on the topics and concepts covered in pre-assignments but not much beyond them. That is why the pre-assignments should focus on content that the teacher especially wants to be covered in in-class phase discussions.

From a readiness assurance testing point of view, the pre-assignments should be based on the pre-study material because they should also ensure that the students have studied the material given before attending the group discussion. The students pointed out in the interviews that it helped the discussion a lot that every attendee had studied the material and knew the concepts.

It was found from the pre-assignment analysis that the assignments could promote learning of translations between scientific knowledge domains introduced by Greeno [6]. A good example of that is an exercise where the students must analyze mathematical formulas, understand the abstract concepts beyond the formulas, connect the abstract concepts to the physical model they are having in the exercise, and consider the concrete solutions to the question asked. In addition, the research suggests that the students can handle complicated applications and understand them if the language used in the assignments is familiar. Technical language should be replaced with physics concepts and equations in the exercises.

2. **Structure and language**
   a. The pre-assignment is divided into several sections leading the student through the assignment.
   b. The pre-assignment should focus on asking "why" and "how".
   c. The pre-assignment could be ambiguous and have more than one correct answer.

The research shows that successful pre-assignments are divided into several sections to help students answer the question. The first part should test very basic knowledge, for example remembering or finding mathematical equations needed in the assignment. The second part could ask for example analyze the equation written: What do the symbols represent and visualize the different sides of the equation. Leading the students through the assignment in a way described here would help them answer questions they could not answer without this structure. It would also be easier to spot the point most difficult in the assignment when the assignment is divided into short sections. Bloom's taxonomy [7] could be a useful tool when forming a pre-assignment.

From the discussion point of view, the pre-assignments must be composed to ask "why" and "how" because it leads to a more profitable discussion. The students told in the interviews that they might have the correct answer for the assignment but noticed during the discussion that they haven't justified their answer comprehensively or they have understood the assignment differently than the others. Even though the students will be more engaged in a clear assignment they know how to answer [8], more ambiguous questions that could be understood differently could be more fruitful for the discussion in groups.

3. The final answer

a. The final answer to the pre-assignment must be easily comparable.

b. The pre-assignment should ask the students to justify their answers.

c. The final answer could use visual elements.

The answers for the pre-assignments should be compact enough to be easy to handle in the discussions. Another study [9] recommends the questions to be for example making decisions, sharing ideas, making comparisons, and making classifications. On the other hand, lists and long essays were not recommendable. When the answer is short enough and possibly visualized in some way, students notice easily, how their answer differs from the others. When stating the question, it is important to ask students to justify their answers. Otherwise, the pre-assignments could be done by guessing the answer and not going through the pre-study material.

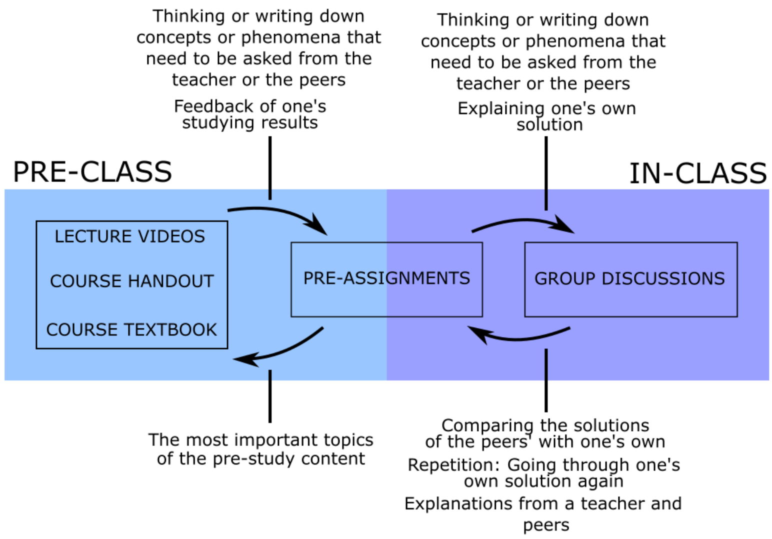

Fig. 3. Pre-assignment learning improvements in pre-class and in-class phases.

There are some of the learning improvements gained using pre-assignments shown in figure 2. The studying process in the pre-class phase could be a cyclical process where the students need to turn back to go through the material when doing the pre-assignments. When moving from the pre-study material to the pre-assignments the students get feedback on their learning and must think what concepts they did not understand when studying the pre-study material. If the first parts of the pre-assignments feel too difficult, the students have not studied the material carefully enough. In that way, the students are better aware of their competence. The students could notice the most important or the most difficult content of the material by doing the pre-assignments.

According to the interviews, the students find it helpful for their learning to discuss the pre-assignments in groups. They told it was helpful to see how the others had solved the problems and how they justify their answers. The discussions about the pre-assignments were helpful also because they forced the students to go through their answers again and possibly modify them. Because the students must show their solutions to the others they have to think about their reasoning. The students told in the interviews that they benefited from the peers' and the teacher's explanations.

CONCLUSIONS

In this study, we found out that the use of pre-assignments could improve learning in several ways. However, the pre-assignments should be designed carefully considering the content covered in the assignments, the structure of the assignment, the concepts used in the assignment, and the final answer asked. The designing process of the pre-assignments could be time-consuming but for successful use of the pre-assignments as a basis of the group discussion, the assignments should be carefully thought through. If the pre-assignments work well in the discussions, even more than two small groups could participate in the same discussion session. That would save teacher resources in the in-class phase. The pre-assignment model introduced in this study could also be useful in other engineering sciences.

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INNOVATING PHYSICS EXPERIMENTS FOR SCIENCE AND ENGINEERING COURSES: RESULTS FROM THE 'SMARTPHYSICS' PROJECT

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We present results from a pilot project involving two higher education institutions, one in Italy and one in the US, aimed at exploring the use of smartphones as data collection tools in introductory physics laboratory for science and engineering degree courses. We describe in particular an experiment consisting in the measurement of g using a pendulum and a proximity stopwatch, using data from a real class of students who performed the experiment in Fall 2021-22. Combining data from all the students, a reasonably accurate and precise value of g was obtained, confirming that smartphones can be easily and successfully used for introductory laboratory experiences in a university setting.

Keywords: ICT-enhanced learning, laboratory work, teaching innovations.

INTRODUCTION

Nowadays, smartphones are used for every daily activity, including teaching and studying. The benefits of using smartphones as learning tools has been pointed out recently: in fact, smartphones contain a lot of sensors that can be used for data collection, sharing, and even preliminary data analysis [1]. These sensors include, for instance, accelerometers, sound meters, gyroscopes, proximity sensors, barometers, magnetometers, and more.

Physics labs can take advantage of these smart tools to perform measurements in a quick and accessible way, at a laboratory as well as at home. Instructors can also use smartphones during lectures for quick experiments; in some cases, smartphones were even used as an alternative to traditional pencil-and-paper physics exercises [2].

During the current pandemic time, institutions have faced the problem of organizing remote laboratory sessions. Due to the possibility of performing measurements at home and easily share the results, smartphone-based laboratories have been one of the most effective solutions [3]. This experience has motivated physics faculty and administration to revise their curricula by incorporating new technologies such as smartphones-based experiments, and to explore their benefits even beyond the emergency time, for instance to overcome difficulties related to limited availability of laboratory equipment [4].

This change, however, does not occur automatically. Although these technologies are known in the physics education community, most physics instructors are not aware of, nor trained in using them [4]. The SmartPhysics project was developed by the University of Padua (UniPD) and the New York City College of Technology of the City University of New York (CUNY) with the aim of exploring the use of smartphones as a new tool to perform laboratory experiments in introductory physics courses for science and engineering programs, while creating innovative teaching materials that could be easily shared with colleagues.

METHODOLOGY

The project started in September 2021 with the goal of producing material to be used in general physics courses in the 2022 Spring term. To this end, the two units built a team composed of physics instructors, researchers in physics education, teaching assistants and students tutors to discuss, test, and document the use of smartphone-based experiments in the context of general physics courses of the two institutions, a large fraction of which involves students from the Engineering faculty.

Phyphox is the mobile application chosen for the project. This app was developed by researchers at Aachen University with the aim of making the smartphone's sensors easily accessible to the user [4, 5]. Phyphox is free, user-friendly, available for all mobile systems. It also offers the possibility to easily visualize, export and share the collected data. It also allows connecting a second device to operate the data acquisition remotely and visualize the collected data, a feature that is particularly useful when the smartphone itself is used as part of the setup. Phyphox is also linked to a community of people that collaborate to improve the experiments, and it is also possible to create and share your own experiments.

RESULTS

In table 1 we describe the experiments that have been tested during the project.

Table 1. Experiments tested in the project

Experiment	Short description	Sensor
Roll	The distance Δx rolled by a cylinder within Δt is computed from the velocity $v(t)$ of the cylinder. $v(t)$ is calculated from $\omega(t)$	Gyroscope
Pendulum (proximity stopwatch)	The phone records the motion of a pendulum swinging above it. The value of g is computed from the measured period T	Proximity stopwatch
Pendulum (accelerometer)	The smartphone itself acts as the pendulum. The value of g is computed from the pendulum's angular velocity employing $\omega^2 = g/L$	Gyroscope and Accelerometer
Doppler effect	The speed of sound is computed from the Doppler effect formula. We combined the Doppler experiment with the pendulum setup.	Frequency sensor
Speed of Sound	Two smartphones located at a known distance allow to measure the speed of sound as a signal that travels from one phone to the other.	Acoustic Stopwatch
Free Fall	The time interval Δt is measured using an exploding balloon that releases the mass and the noise of the impact with the floor.	Acoustic Stopwatch
Inelastic Collisions of a Bouncing Ball	A time series is generated by recording the time of each bounce and used to determine the highest points in the trajectory of the ball in between collisions, i.e. the potential energy, and therefore the energy lost at each bounce.	Acoustic Stopwatch

In the following we focus on one experiment, the measurement of g using a pendulum and a proximity stopwatch, for different reasons:

- the required sensor is available in all kinds of smartphones;
- it offers an interesting data analysis part;
- it allows obtaining a reasonably accurate and precise result;
- it has been already tested with students at UniPD in the Fall term.

Setup and data collection

Most phones contain a proximity sensor able to detect the presence of nearby objects without physical contact. Combining this device with a phone's stopwatch, it is possible to track the motion of a simple pendulum swinging above the sensor. This setup allows for an estimate of the pendulum's period T, that can then be used to compute the value of the gravitational acceleration g via the well-known formula

$$T = 2\pi\sqrt{\frac{L}{g}}$$

where L is the length of the pendulum, that is measured directly using a meter tape.

A light object is hung at the end of a string. Starting from a small angular displacement, the object is swung into motion approximately 5cm above the proximity sensor of a phone (typically located on the top frontal part). Before setting the object in motion, one enters the Proximity Stopwatch experiment under the Mechanics section in PhyPhox and presses ▶ (play) to initiate data collection. One may inspect the 'Raw data' panel to verify that data are being recorded correctly. The experiment can be run for e.g. 3 minutes, in order to collect data from a reasonable number of oscillations, whereafter one presses the pause button. The collected data can be exported in CSV or Excel format directly from the app interface.

Data analysis

The experiment was run in Padua in December 2021 with a class of about 70 first-year students. Figure 1 shows an example of a data spreadsheet. Column A displays stopwatch measurements (in seconds) corresponding to each activation/deactivation of the proximity sensor. Column B is labelled as 'Illuminance' and it contains activation/deactivation flags. An interpretation of column B is illustrated in the figure using the points A, B, C and D. When the pendulum swings over point A, a time measurement is recorded in column A along with a 0 in column B. When it swings over point B, on the other side of the proximity sensor, the sensor records a positive integer value (5 in our example). The pendulum continues to swing all the way to the right, reaches the turning point and then gets back to points C and D, which are labelled by 0 and 5 in column B, respectively. The pendulum proceeds to swing all the way to the left and it starts a new oscillation. The fifth line in the spreadsheet then corresponds to a new point A, and a full period corresponds to five rows in the data file. For example, from point A and back to A, the data excerpt in figure 1 gives a period of roughly T ~ 5.64s − 3.15s = 2.50s. Figure 2 shows a plot of how the raw data appear in the smartphone, and the points used to calculate one period, considering either the maxima (crests in the graphs) or minima (throughs) of the raw 'illuminance' data.

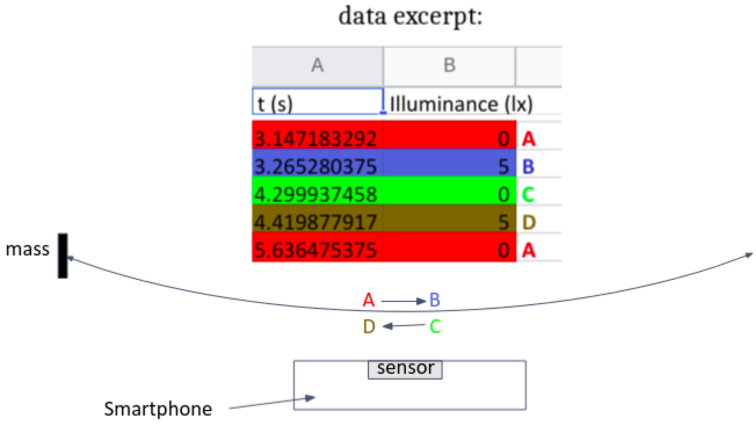

Fig.1. An excerpt of the raw data collected by the smartphone and their interpretation in relation to the motion of the pendulum.

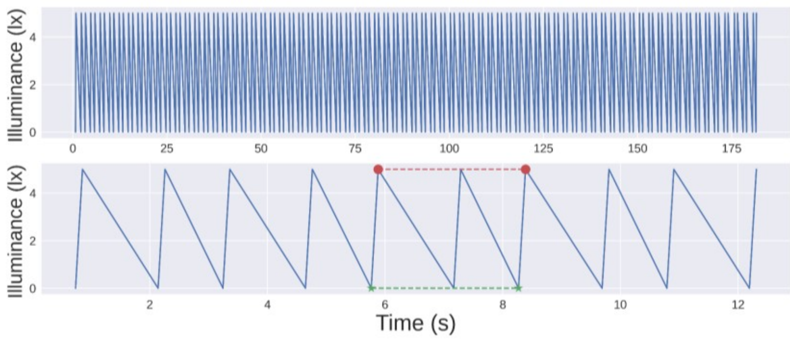

Fig.2. A sample measurement of the pendulum proximity sensor experiment. In the upper panel, the length registered by the proximity sensor is plotted against the time recorded in the sensor. In the lower panel, we show only a few oscillations of the upper panel for better visibility. The difference between the red dots or the green stars is used to compute the period.

Before estimating the period, we checked whether it remains constant over the whole measurement. We found that the period was slightly unstable in the first few points. We therefore did not use the first few oscillations in the analysis. With the data cleaned this way, we averaged the computed values over all the oscillations to estimate the period.

In figure 3 (left) we compare the results for all the students' experiments that produced valid and usable data. The students collectively provided 132 files, 19 of which were not in the requested format (excel) and were ignored. Eight files were corrupted due to the app not working properly on the specific smartphone model. Of the remaining 105 data sets, only 56 were accompanied by length data. We will restrict the following analysis to these ones.

We notice that for some points the period is doubled, measuring 5s instead of the expected ≈ 2.5s. Secondly, for some points the error is much larger than most of the other points. A possible explanation for the first phenomenon is that the proximity sensor was able to detect the swinging object only during the first half of the oscillation. Since this analysis assumes that the time measured is at each half oscillation, this results in doubling the measured value of the period. This may occur if the motion of the suspended object was slightly perturbed along a direction orthogonal to the plane of oscillation. As for the large errors, this could be the result of the sensor successfully detecting the mass twice per oscillation (as intended) only in some oscillations while failing to do so in others. Consequently, the measured period varies between 2.5s and 5.0s.

In order to obtain the best possible estimate of the period, we averaged over all the students' experiments, but we removed period values different by more than two standard deviations from the median of the whole sample, and points having an error larger than two standard deviations from the median of the errors on the period. The estimated periods before and after cleaning are shown in figure 3 on the right.

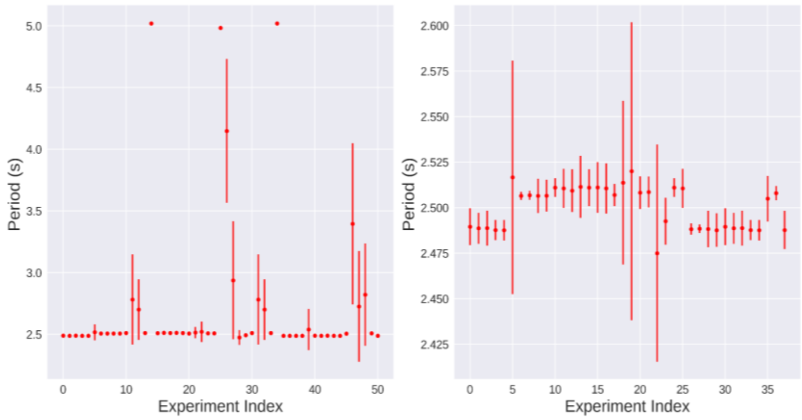

Fig.3. The periods estimated from students' experiments (labeled with an 'experiment index'), before (left) and after (right) data cleaning.

Finally, we used the above-mentioned equation to compute g and we calculated the uncertainty using error propagation:

$$\frac{\sigma_g}{g} = \sqrt{\left(\frac{\sigma_L}{L}\right)^2 + 4\left(\frac{\sigma_T}{T}\right)^2}$$

The results are shown in figure 5. The obtained estimate after cleaning the data is g = (9.84 ± 0.08) m/s^2. For comparison, the known value for Padua is 9,806450 m/s^2 (PTB-Physikalisch-Technische Bundesanstalt, Germany).

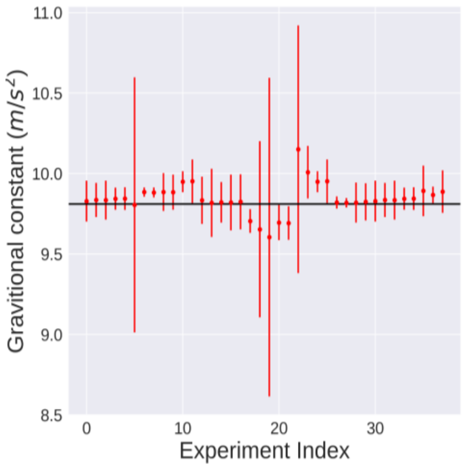

Fig.4. The individual estimated values of the gravitational constant for each experiment. The black line is the known value of g for Padua.

SUMMARY

The SmartPhysics project was developed by the University of Padua (UniPD) and the City University of New York (CUNY) with the aim of exploring the use of smartphones as a new tool to perform laboratory experiments in introductory physics courses for science and engineering programs. We have tested different experiences and we have described one of them (measurement of g using a pendulum and a proximity stopwatch) in detail. The data reported in the paper and used for the determination of g were taken by a class of students in the Fall term 2021-2022. Combining data from all the students and performing some data filtering, a reasonably accurate and precise value of g was obtained. The failure rate, defined as the inability to perform the measurement due to the device itself, was 8/132=6%. However, as the students worked in small groups, they were all able to get at least one valid and usable data set. These results confirm that smartphones can be easily and successfully used for introductory laboratory experiences even in university settings. The collaboration between the two institutions also allowed creating a link between teaching assistants from the two universities and, more in general, it provided a starting point and a best practice example for future collaborative projects aimed at improving physics courses. Finally, the project provided an opportunity for instructors' professional development based on a learning community approach.

ACKNOWLEDGEMENTS

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A COLLABORATIVE GROUP-LEARNING ENVIRONMENT FOR STUDENT ENGAGEMENT IN UNIVERSITY PHYSICS

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We have implemented a collaborative group-learning pedagogical approach in the introductory physics classes at George Washington University. This is a fully student-centered active-learning environment that minimizes formal lecture and maximizes "on-task time" for students in the classroom. The class meets for 5 hours each week, and laboratory activities are seamlessly integrated into the classroom time. We began deploying this pedagogy in 2008 and since 2013 all our introductory physics classes are offered in this collaborative mode. We have collected a variety of assessment data during the implementation period, and our results indicate higher student learning gains in the collaborative class compared to the conventional lecture/lab format.

Keywords: collaborative/active learning, student engagement, studio physics.

INTRODUCTION

Studies of science education have shown that students need to be actively engaged in the learning process for it to be effective. Passive lecturing ("teaching by telling") is known to be ineffective in developing students' skills in critical thinking [1]. One of the first collaborative group-learning environments ("studio physics") was developed by Wilson [2] in the mid-1990's to address this issue — students worked together in small groups and the instructor served more as a facilitator or "coach" rather than a lecturer. In the studio approach, laboratory activities are integrated into the classroom, such that class time is filled with a seamless progression of activities, ranging from group problem-solving exercises to lab experiments to short demonstrations to mini-lectures. By merging the collaborative approach with the integration of various pedagogical activities, a dynamic learning environment is created.

A practical limitation of the studio method is the small class size — it is difficult to staff multiple sections of a course with limited faculty resources. Beichner at North Carolina State University pioneered an extension of studio physics, called SCALE-UP (Student-Centered Active Learning Environment for Undergraduate Programs), which adapts the method for larger classes (up to 99 students) [3]. In this scheme, round tables accommodate 3 groups of 3 students (9 students per table) for all classroom activities. For this class size, one instructor and two Teaching Assistants are able to handle questions and promote useful discussions.

The SCALE-UP pedagogy has several basic characteristics: active learning, collaborative groups, integrated lecture/laboratory and technology assistance. In a SCALE-UP classroom, there is minimal lecturing in the conventional sense. The students are expected to prepare for class by reading the textbook in advance, and most of the class time is spent enriching the material by engaging the students in a variety of hands-on and "minds-on" activities. In that regard, the activities are built around three fundamental pillars: (1) *ponderables* are problems to think about, both numerical and conceptual, that students work on together in their groups with portable whiteboards, (2) *tangibles* are hands-on activities, ranging from short 5-minute demonstrations to more lengthy laboratory experiments, and (3) *computer simulations* that help students model physical behavior, usually done using the VPython language [4].

There are over 150 institutions around the world that have adopted the SCALE-UP pedagogy. While most of these schools are in the United States, at the present time there are at least a dozen institutions in other countries implementing this approach as well. The web site for SCALE-UP at North Carolina State University has a wealth of information about this collaborative approach and the results of this pedagogy at various institutions [5].

IMPLEMENTATION

We have implemented the SCALE-UP approach at George Washington University (GWU) for all our calculus-based and algebra-based introductory physics classes. We have redesigned two classrooms with 6 round tables, accommodating a total of 54 students in each room. Each group of 3 students has a portable whiteboard to facilitate their work together. The classroom walls have large whiteboards on which students can display their work and four large projection screens around the room for image projection. For a room of this size, one instructor and two Teaching Assistants can provide sufficient coverage for all students.

We instituted SCALE-UP in Spring 2008, and our implementation followed a "phased" approach in which we converted one course at a time. By Spring 2013, we had incorporated SCALE-UP into all our introductory calculus-based courses (taken by science/engineering students) and our algebra-based physics courses (taken by biology/pre-med students). We also extended SCALE-UP into our introductory astronomy course on a limited basis.

In our "usual" configuration, the class meets 3 times a week — 2 hours on Monday and Wednesday and 1 hour on Friday — with a weekly 20-minute quiz every Friday. Groups are carefully arranged by the instructor, where each triplet is composed of a balance of high, medium and low performing students. Students are reorganized into different groups at the mid-point of the semester — this helps keep the group interactions fresh and vigorous. In class, students work collaboratively on conceptual questions and numerical problems (*ponderables*) using their portable whiteboards, in addition to short hands-on activities and longer laboratory experiments (*tangibles*) using real-time data acquisition.

Homeworks are delivered via a web-based online system called *MasteringPhysics* [6] which is available through Pearson Higher Education, the publisher of the textbook that we use for the calculus-based course (*Physics for Scientists and Engineers: A Strategic Approach* by Knight [7]). We typically assign 16 problems per week, with an additional 2 problems being available for extra credit. These assignments generally take about 3-4 hours to complete. Since lecture is reduced to a minimum, class preparation is an important consideration for students. To gauge their understanding and to motivate their preparation for class, students have online pre-class "Warmups" to complete, also through the *MasteringPhysics* system. These consist mostly of about 10 multiple-choice conceptual questions related to the material to be covered in class on that day. The "Warmups" generally require about 30 minutes for completion and are presented to the students twice a week, before the Monday and Wednesday two-hour classes.

Tangibles are very beneficial, but it is challenging to devise short demonstration exercises that take only 10-15 minutes. An example of a simple tangible is to drop a meter stick between the fingers of a student to measure reaction time using free fall. The distance that the meter stick falls before the student catches it can be converted into a time interval by using free-fall kinematics, giving a rough estimate of the student's ability to react to the dropped meter stick.

Another tangible begins with a ponderable in which students calculate the angle at which a surface must be tilted for a metal block to overcome static friction and slide down the plane. This exercise yields the familiar result $\mu_s = tan\ \theta$. After the calculation, the students try the exercise themselves using their own whiteboards as the inclined plane. Each group member takes a turn slowly tilting the whiteboard until the metal block just begins to slide, then the other group members determine the tilted angle of the board. After all three group members have tried this, the measurements are averaged and an overall average value of μ_s is obtained. While the actual answer is unknown, the fact that 75% of the groups come up with a value within ±10% of $\mu_s \approx 0.35$ seems convincing that a consensus value has been reached.

Lab experiments also fall into the category of tangibles. For real-time data acquisition, we use probes and software from Vernier [8]. The SCALE-UP lab exercises are not so different from a conventional lecture/lab course, but the guidelines for conducting the experiments are "streamlined" to leave the exercise more open-ended and to allow students some flexibility. Some of the experiments conducted in our SCALE-UP class include the following:

- using video analysis to measure the acceleration of carts on an inclined plane
- using video analysis to analyze elastic and inelastic collisions of carts
- measuring moment of inertia of a uniform cylinder by wrapping it with a string attached to a mass and letting the mass fall, unwinding the string as it falls
- determining the density of air by floating helium balloons
- measuring the specific heat of an unknown metal sample

It is important for students to gauge their overall progress at regular intervals — for this purpose, we give a quiz every Friday at the beginning of our one-hour class. The quiz lasts 20 minutes and contains one conceptual and one numerical problem (possibly with multiple parts). The main idea is to simulate an exam-like environment so that the students can get a sense of how they are doing on a weekly basis, thus enabling them to take the necessary steps if they feel that they are struggling with the conceptual or the problem-solving aspects of the course.

RESULTS

We collected data over several semesters for the first-semester class (Phys 21) to assess the effectiveness of the SCALE-UP pedagogy at GWU. To monitor conceptual understanding, we acquired data on the Force Concept Inventory (FCI) [9] in all semesters. In two specific semesters of our initial SCALE-UP deployment (Spring 2008 and 2011), we had a large (concurrent) conventional lecture section take identical assessments for comparison purposes, including common in-class exams (*i.e.* consistent between the sections in the same year, but different between 2008 and 2011). The results of the in-class exams are shown below. All scores are based on a maximum exam score of 100 points and are rounded to the nearest integer.

Phys 21 (Spring 2008)	Exam #1	Exam #2	Final Exam
Standard Lecture **(Sec. 10 — N = 50)**	63	62	55
Bio-focused SCALE-UP **(Sec. 11 — N = 14)**	81	71	60
SCALE-UP **(Sec. 12 — N = 23)**	70	73	64

Phys 21 (Spring 2011)	Exam #1	Exam #2	Final Exam
Standard Lecture **(Sec. 10 — N = 120)**	68	62	68
Bio-focused SCALE-UP **(Sec. 11 — N = 19)**	77	76	82
SCALE-UP **(Sec. 12 — N = 29)**	77	72	72

Both of the SCALE-UP classes (Secs. 11 and 12) exceeded the exam performance of the conventional lecture section (Sec. 10) in all cases. Since the bio-focused class in Sec. 11 (aimed primarily at biomedical engineers and biophysics majors) had additional biological content in the course and in their exams, a more direct comparison can be made between Secs. 10 and 12. It is noteworthy that the SCALE-UP section had an exam average approximately 7-11 points higher than the corresponding lecture section in most cases.

It should be mentioned that, to the best of our knowledge, students did not "self-select" the SCALE-UP section specifically over the conventional lecture section. That is, the former did not have "better" students than the latter, based on enrollment data. A review of the overall university academic grade averages for the SCALE-UP students indicated the same range of academic performance as compared to the conventional lecture students.

The Force Concept Inventory (FCI) [9] diagnostic instrument was given to the Phys 21 classes in each semester to gauge conceptual understanding. The composite FCI results for seven semesters are shown in Fig. 1 below.

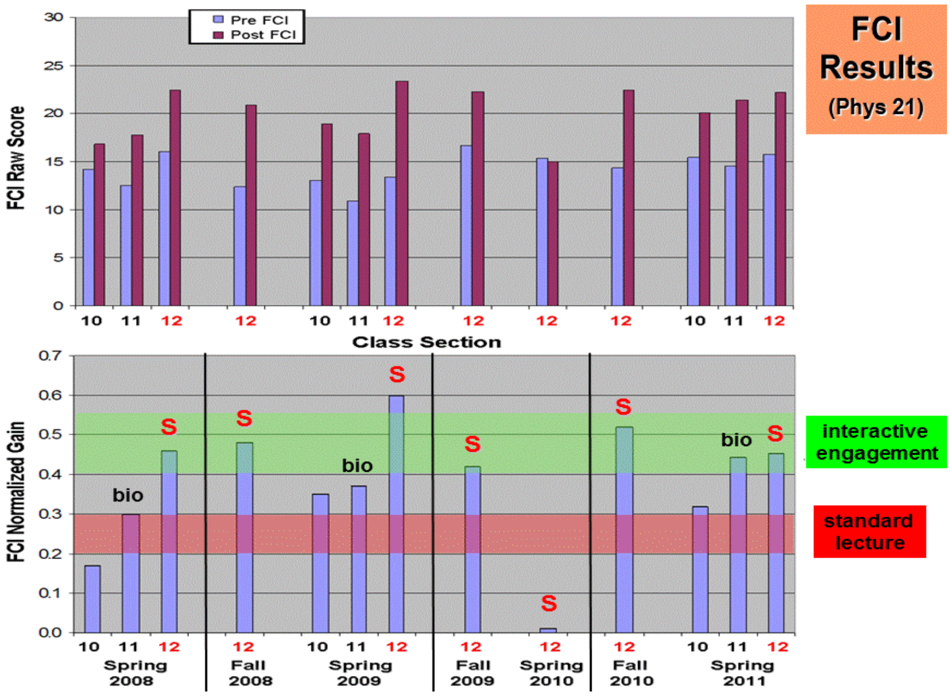

Fig.1. FCI results for seven semesters of Phys 21. The top panel shows pre/post test scores; the bottom panel shows normalized gains. The SCALE-UP sections are indicated by a red "S"; the bio-focused sections are indicated by "bio".

The top panel shows the pre- and post-test scores, where the maximum score is 30. The bottom panel shows the normalized gain $\langle g \rangle$ defined by Hake [10], such that $\langle g \rangle = \frac{post-pre}{30-pre}$. Also shown is Hake's estimate of a range indicative of interactive engagement classes (the green band, for $\langle g \rangle$ = 0.40-0.55) as compared to conventional lecture classes (the red band, for $\langle g \rangle$ = 0.20-0.30). It is evident that the SCALE-UP classes (marked with a red "S") have performed very well, although the bio-focused SCALE-UP classes (marked by "bio") seemed to require a few semesters before reaching the interactive engagement level. In each semester, all the SCALE-UP classes are showing gains well into the interactive engagement domain (green band), with the exception of Spring 2010 when the delivery of the FCI post-test was not allocated sufficient time for completion.

We also have data for assessments related to the second-semester course (Phys 22). In this case, we used the Conceptual Survey of Electricity and Magnetism (CSEM) developed by Maloney *et al.* [11] as our standardized assessment. Our results are compared to those of other institutions in Fig. 2 below — our data have been added to the plot from Ref. [11] as the filled green circles. The pre/post-test scores are plotted on the x and y axes, and lines corresponding to various values of the normalized gain $\langle g \rangle$ are shown. Note that the four GWU semesters shown are fairly consistent with each other (this includes three different instructors) and that the gain values of 37–44% are among the highest values compared to other institutions.

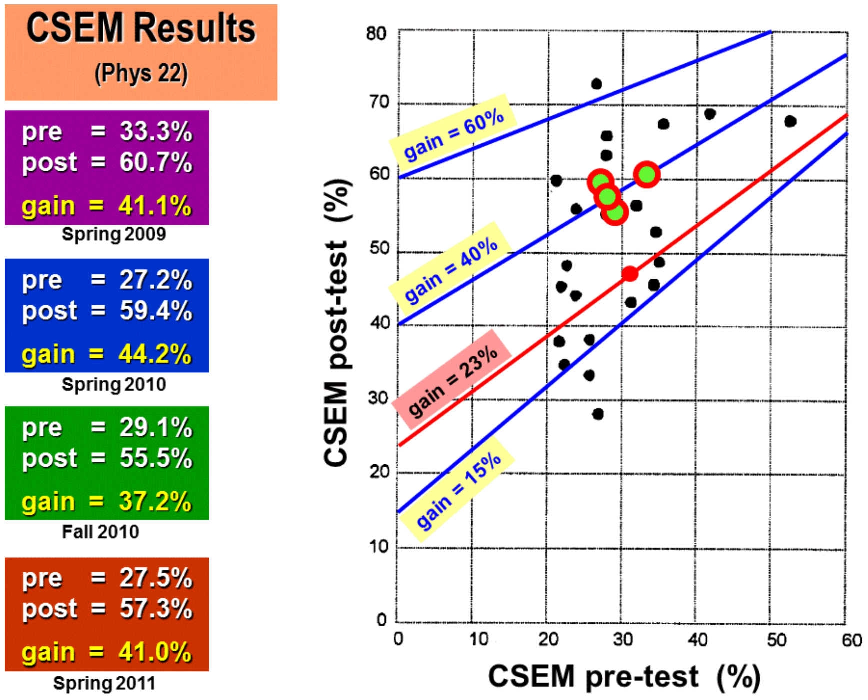

Fig.2. CSEM results for Phys 22, compared to results from other institutions [11]. The specific pre/post test scores (with corresponding normalized gains) are shown on the left, and these results are plotted as the four green data points. Several different values of the normalized gain are shown as lines of constant slope.

PERSPECTIVE

As a closing note, it is worthwhile to share some "impressions" from our experience in teaching the introductory physics classes utilizing the SCALE-UP pedagogy. Admittedly, the following comments are anecdotal, but at some level, the observations and intuition of the instructor have some validity in judging the effectiveness of an educational experience.

- SCALE-UP really motivates the students and "squeezes" the best out of them
- students work harder throughout the semester, but for greater rewards
- the student working groups develop into cohesive units that function well
- the classroom atmosphere is much more dynamic in the collaborative mode
- instructors get to know the students better (and students know each other better)

In the end, here is one last comment about the approach — it is considerably more satisfying to be a "coach" rather than a lecturer, and the SCALE-UP pedagogy definitely affords that opportunity. Ultimately, this is much better for the instructor to promote active learning and to be able to assess student progress in real time, and certainly it is more beneficial for the students.

SUMMARY

We have now been using the SCALE-UP collaborative group-learning pedagogy at GWU for 14 years in all our introductory physics classes, both calculus-based and algebra-based. From the data that we have collected, we have evidence that students are performing better in the SCALE-UP class than in a conventional lecture class. Student engagement is high in the SCALE-UP environment, and it seems that students gain a greater facility with the physics material in this collaborative mode compared to less interactive approaches.

Educational trends favoring more interactive engagement techniques have been gaining momentum in colleges and universities in the United States over the past two decades. This sentiment concerning the shortcomings of the conventional lecture style of science education has been echoed by various authors in short and incisive articles in a more mainstream forum, namely *Science* magazine [12-13].

With our experience in SCALE-UP for our physics classes, we are working to disseminate the advantages of this approach to other STEM faculty members on our campus, and at other institutions that are interested. It is clear that such collaborative techniques are transferable to other STEM disciplines, and we will continue to promote SCALE-UP as much as possible.

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MINOR MEDICAL TECHNOLOGY FOR ENGINEERING AND PHYSICS STUDENTS

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In this article we present our new minor course on Medical Technology. The minor was first given in 2019. This 10-week-minor is intended for Engineering students and has a total study load of 15 ECTS. The minor consists of a combination of theory, practical work and a group assignment by a company, hospital or applied research group. The course layout will be described and we will share our experiences from the last three years.

Keywords: medical technology, project-based learning, course development

INTRODUCTION

In 2016 the curriculum of the 4-year bachelor in Applied Physics at the Hague University of Applied Sciences (THUAS) has been changed. In 2018-2019 the new 3rd year programme came into being with a highly desired flexibility for students. During this year, students have to follow an internship at a company or research institute for one semester. During the other semester, minor programmes (2x15 or 1 x30 ECTS) can be followed. In this paper we describe one of the minors developed by the Applied Physics department, namely *Medical Technology*. The other minor developed by our department is *Microsystems: processes and devices*. Our motivation for developing a minor in the field of medical technology is twofold. First, we observed that several students have an interest in working in a field in which physics and engineering have a direct effect on people's health. A minor Medical Technology can fulfil this interest. Secondly, practice-oriented research for universities of applied sciences has become more important in the Netherlands in the last decades. As most universities of applied sciences, THUAS chose to focus on health technology. The development of this minor naturally leads to a connection between students and researchers searching for students to work on practice-oriented problems. In this way students can develop their investigative ability and networking capabilities [1]. To stimulate a multidisciplinary approach to problems in the field of medical technology, the minor that can be followed by engineering students of most of our bachelor programmes, like electrical and mechanical engineering or mechatronics. The 10-week minor has a total study load of 15 ECTS and is taught in the Dutch language. Several other minors on health and technology are given at different universities of applied sciences in our country, see for example [2] for an overview of all Dutch minors open for students from other institutions. These minors tend to focus more on (product) design, the minor we will present here pays more attention to practice-oriented research.

GENERAL LAYOUT OF THE MINOR

The minor consists of three parts, as shown in Figure 1. The major part of the minor is dedicated to project-based learning. A group of 3 or 4 students is given a 10-week assignment from a research group or company, supported by weekly coaching and training on research skills. This project has a study load of 7 ECTS.

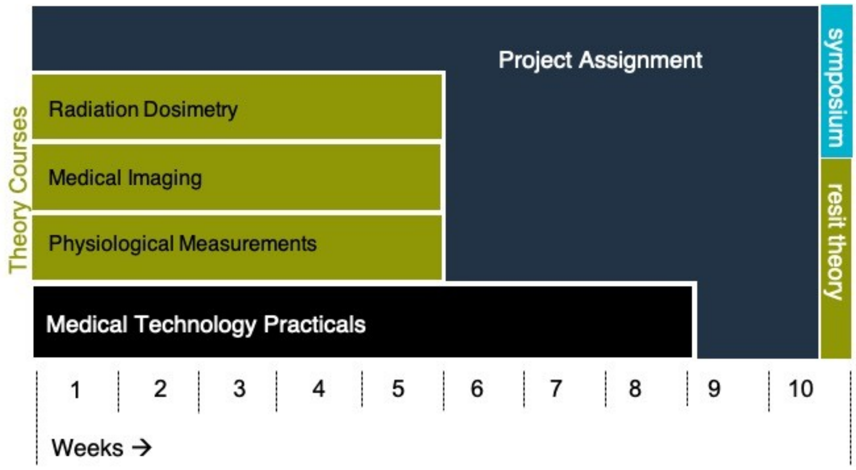

Fig.1. Educational structure of the minor.

The second part is formed by three theory courses, each with a study load of 2 ECTS: Radiation Dosimetry, Medical Imaging and Physiological Measurements. These courses are taught in the first five weeks of the minor to provide the students with knowledge that can be used at the project work later. Finally, the students' measurements skills can be trained in lab sessions in which several techniques are available. This lab sessions are scheduled 2 hours a week and have a study load of 2 ECTS. Each of the parts of the minor will be further explained in the next paragraphs.

THEORY COURSES

Three theory modules are given in the first five weeks of the minor, each with a study load of 2 ECTS and 4 lecture hours per week.

1. **Radiation Dosimetry** focuses on the physics of ionizing radiation and techniques to measure radiation. Furthermore, students learn to make simple dosimetry calculations and know the health hazards when working with ionizing radiation. Also, attention is paid to applications in medicine.

2. **Physiological Measurements** gives an introduction to the operation of cells, biopotentials, human anatomy and physiology and connects this with measurement techniques. Not only well-established techniques like ECG (electrocardiogram) and blood pressure are discussed but also more recent developments in this field like biomedical microelectromechanical systems (bio-MEMS), lab-on-a-chip, organ-on-a-chip and wearables.

3. The **Medical Imaging** course describes four imaging techniques:

- Ultrasound,
- Magnetic Resonance Imaging (MRI),
- X-ray and Computed Tomography (CT),
- Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT)

The physics behind each imaging modality is explained, as well as the techniques to generate the medical image. Students learn which technique is used when and which factors and artefacts can influence the image quality. They also learn to perform simple calculations.

For the Medical Imaging and Physiological Measurements modules the book Biomedical Engineering: Bridging Medicine and Technology from Saltzman [3] is used. The Dutch book Praktische Stralingshygiëne [4] is used for the dosimetry course.

In the first year of this minor, an overall multiple choice examination was given in the fifth week of the minor with a resit in week 10. The theory lecturers have successfully implemented active learning methods like group discussions, presentations etc. during the lecture hours. The first year, we did not grade the students' performances on these activities. In later years we made a shift to more continuous grading of assignments and even a replacement of the multiple choice examination.

DEVELOPMENT OF MEASURENT SKILLS

During the project, the students have 8 lab sessions of two hours in which they perform 4 experiments in total. We have 9 experiments available, from which students are allowed to make a selection, depending on their bachelor degree programme. Figure 2 shows the available experiments, they are also listed in table 1. Most of the experiments are purchased from manufacturers of educational scientific equipment, some are based on earlier work form others [5][6] and adapted with own equipment to meet our learning objectives.

Table 1. Experiments, for photographs see Figure 2.

Number	Experiment	Manufacturer
1	Nuclear Magnetic Resonance	Leybold Didactic
2	X-ray Tomography	Leybold Didactic
3	Skin Spectroscopy	Avantes, Ocean Insight
4	Blood Pressure	-
5	Electrocardiography, electromyography	Leybold Didactic
6	Beta radiation	Leybold Didactic
7	Ultrasound with eye dummy	PHYWE
8	Ultrasound with heart dummy	PHYWE
9	Ultrasonic Doppler Effect	PHYWE

As the emphasis is on the development of measurement and not on reporting skills, we use fill-in forms for the students. Students typically learn to handle larger data sets than encountered in first and second year physics labs. Furthermore, data interpretation can be more challenging. The total study load for this part is 2 ECTS.

Fig.2. Available experiments for the development of measurement skills, for manufacturers see Table 1.

PROJECT WORK

The project work in this minor is typically performed in groups of 3 to 4 students. The teams are, as much as possible, composed of students from different major programmes. Each group is given an assignment provided by either a hospital or other healthcare institution, by a company active in the medical technology or by the practice-oriented research groups of THUAS. The assignments are diverse and range from literature study and computer simulations to data interpretation, developing measurement setups and performing measurements. To give an impression, several images are depicted in Figure 3.

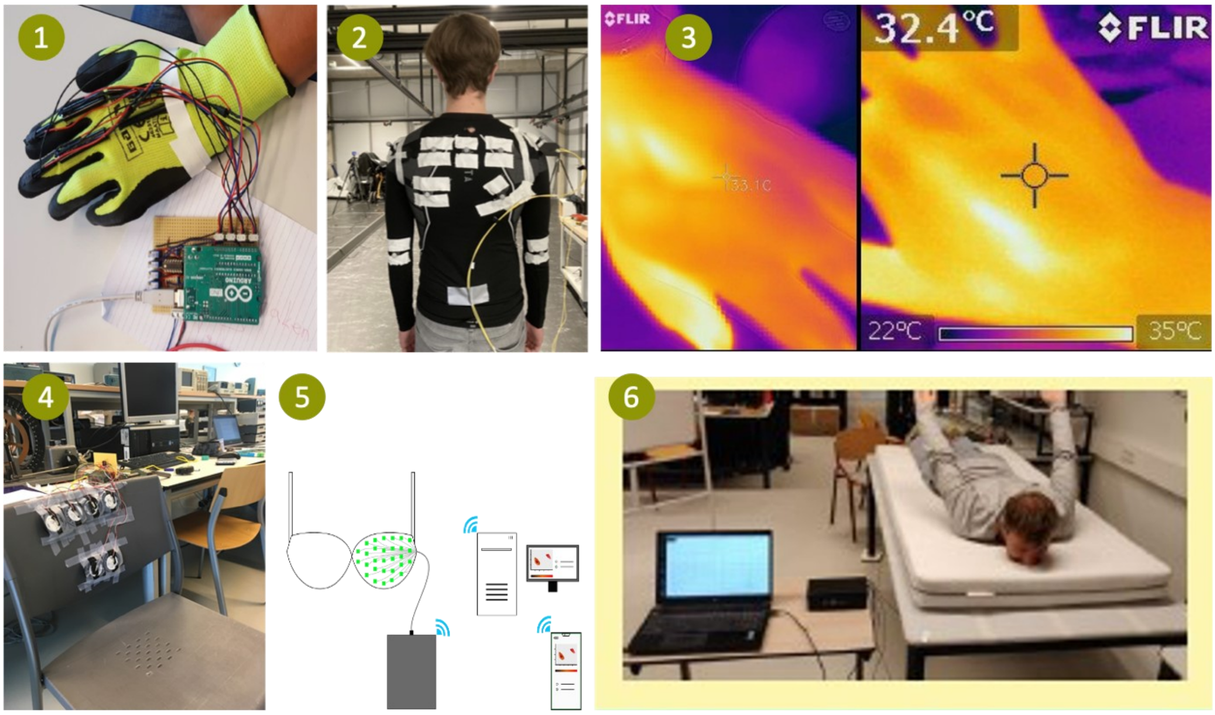

Fig.3. Impressions of the (results of the) project work.

1. Development of a plastic fiber optic based sensor to detect finger bending for the company SenseGlove, 2. comparison of Fiber Bragg Grating shape sensor with 3D movement registration system at THUAS, 3. advice for the use FLIR One smartphone Thermal Imaging Camera in skin care practice together with skin therapy department of THUAS, 4. development of a setup to monitor seating position for patients with spinal cord injury for Rijndam Revalidation, 5. design of a setup to monitor radiation dose with scintillating fibers with VanderHoek Photonics and Franciscus Vlietland Hospital, 6. setup to stimulate and monitor movement after surgery for the Medical Delta Living Lab Better in Better out.

Each team of students has a weekly contact hour with the lecturer. During these hours the progress of the project is discussed. Next to these hours, there are several discussions with the client, i.e. the provider of the assignment.

We have a collaboration with the Erasmus Medical Centre in Rotterdam. During the 10 weeks, several medical physicists from the Erasmus Medical Centre give guest lectures on actual trends in imaging technology, hyperthermia, radiotherapy and Raman spectroscopy. Furthermore, a visit to the radiotherapy department is organized.

After 10 weeks of work, the students hand in a report. We organize a symposium where the students present their results to all minor students, clients, researchers and lecturers. We also invite first year students to join this symposium. The symposium consists of short presentations and demonstrations with a poster session, see Figure 4. The grade for the project not only depends on the report and presentation, but also on the quality of the work as seen by the company and the effort and professional skills of the individual student.

Fig.4. Symposium

EXPERIENCES AND FUTURE WORK

Each year, typically 30 to 40 students participate in this minor, most of them are in

their 3rd or 4th year. From these students, 75% follows the Applied Physics programme, the other 25% are mechanical engineers, mechatronics students and applied math students. The students have a strong interest in medical applications of engineering and many of them are intending to do internships at healthcare institutions or companies. We noticed that the students without a physics background had to work harder for the theory and the practical work, but in the end they succeeded in all parts of the minor. Their contribution to the project work is very valuable as they have learned to approach problems in other ways than physics students.

From student evaluations, we learned that the minor is highly appreciated by most of

the students. They learned to really listen to the needs of the commissioning companies and to provide them with solid advice. The providers of the assignments were happy with the results of the students. Although 10 weeks is short for development and research, steps were taken to tackle several problems and new insights were gained. This led to follow-up research in many cases.

We have spread the study load over 10 weeks. However, we observed that students

had to do resits for other courses during the regular examination weeks in our institute (week 8,9 and 10). This reduced the effort put in the project. Furthermore, students had to get acquainted with the active learning techniques employed in the theory courses. There were complaints in the first year the minor was given, however these complaints were significantly reduced by setting clear expectations.

The covid-19 pandemic threw a spanner in the works last two years. In 2020, we were forced to give online lectures and had to reformulate the project assignments to literature studies and calculations at home.

In the future, we will extend our lab sessions with a low-cost electroencephalogram

(EEG) headset and an educational Optical Coherence Tomography (OCT)-scanner.

Acknowlegdements

We gratefully thank Erwin de Vlugt, leader of the research group Technology for Health at THUAS for fruitful discussions and our colleagues René Vellekoop, Hedde van Hoorn and Bart Kieviet for the development of the practical work and courses on Physiological Measurements and Radiation Dosimetry.

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TOWARDS A THERMAL CONCEPTUAL ASSESSMENT FOR FIRST-YEAR ENGINEERING STUDENTS – TCA-1Y

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We report from an ongoing process to develop a thermal conceptual assessment that covers the essential concepts of first-year thermodynamics to be administered to engineering students. The goal is to develop a measurement instrument in order to investigate students' pre-knowledge as well as the influence of teaching and learning settings. The assessment builds on known misconceptions and concept questions described in the literature. The original items have been modified significantly in the current version 3 of the test in order to create single-choice questions with four distracters each that address frequent misconceptions from student answers in a systematic way. The working process to create these distracters is described exemplarily.

Keywords: Thermodynamics, SoTL, test development

INTRODUCTION

In order to characterize students' pre-knowledge and to determine their learning gains suitable measurement instruments are necessary. Within the scope of the scholarship of teaching and learning (SoTL) [1] such standard measurement tools are essential for the comparison of different teaching and learning settings. Often, concept inventories, which have been developed for various subjects in physics or related engineering fields, are used for this purpose [2]. Concept inventories are multiple choice questionnaires in which the correct answer is mixed up with known student misconceptions as "distracters" [3]. By analyzing students' selection of the distracters one can conclude that there is a misconception and what it could be.

One of the most commonly used concept inventory is the force concept inventory FCI [4] which is a worldwide applied and accepted tool to probe students' conceptual understanding in mechanics [5]. We have been using the FCI in a standardized manner for first-year engineering students at an University of Applied Sciences on a regular base since almost a decade. It serves us to monitor students pre-knowledge when entering our physics courses ("pre-test"), to adjust course contents towards students' needs and to determine their learning gains depending on teaching formats after the course ("post-test") [6]. In order to extend this approach to further topics in physics, we were looking for a similar instrument, first of all in thermodynamics.

From the established concept inventories presented in the literature, we could not find a test that fits all our needs. They are either intended for schools (e.g. Introductory Thermal Concept Evaluation, TCE [7]), the range of addressed concepts is too limited for our purposes (Heat and Energy Concept Inventory, HECI [3]), their level is significantly beyond the learning goals of our first-year courses (Thermal and Transport Concept Inventory TTCI [9]), or the questions are a combination of multiple-choice and open reasoning format [10].

GOAL

Our goal is to set up a feasible assessment that addresses the fundamental thermal concepts relevant to engineering students from different programs at Universities of Applied Sciences in their first year (TCA-1Y). It is to mention that the aim of these programs is to prepare students for engineering careers in industry or subsequent studies towards a master's degree. The focus is on applying science to industrial research and development, not on academical research.

Further requirements on the test are, that it is possible to use it as a pre-test (at least partly) and as post-test. Moreover, the necessary time to administer the test should be in an acceptable range and its items should be single choice with five answers each in order to ease the analysis.

FRAMEWORK

Since far more than twenty years researchers in science, technology, engineering, and mathematics education report that students often have their own ideas about the underlying mechanisms in physical or technical situations. Their ideas can be erroneous or incomplete, and are often called "misconceptions". In this work we take a perspective towards learning similar to that described by Heron [11]. We try to determine "student difficulties […] that must be addressed in instruction" for students to gain a functional understanding of the subject matter, that is (as defined by McDermott) "the ability to interpret and use knowledge in situations different from those in which it was initially acquired" [12].

Our aim here is not to conduct detailed research on student misconceptions, but we want to build on previous research and take into account known insights on the subject matter in order to adapt, combine and further develop them, towards a practical assessment that suits our needs.

TEST DEVELOPMENT PROCEDURE

According to [2] it is recommended that an ideal concept inventory should address one concept per item and should have several items per concept. An assessment that fulfills these requirements can either address only few concepts or takes a lot of time to administer, which reduces the acceptance of faculty to deploy it. As on the one hand we intended to cover the fundamental concepts of the whole thermodynamic part in the physics course and on the other hand we limited the necessary time to carry out the assessment to a maximum of 30 min, we had to make a compromise.

For that reason we decided to follow a more pragmatic strategy and reduce for each concept the number of items to two or more (except of content "principles of heat engines" with only one item). We justify our approach with the fact, that our starting point builds on previous approved test items. Additionally we worked on strategies to improve and optimize each item in a way, that we could gain maximum insight into students' thinking even with a lower number of items per concept. Being aware that this could reduce the informative value on single misconceptions, we took into account this trade-off in favor of obtaining an overview on students' overall fundamental thermodynamic concepts in the first year.

In a first step we determined the content and the underlying concepts that should be addressed by the assessment. Four longtime experienced lecturers of first-year physics courses for engineers agreed on the following content: 1. Physical perception, 2. Definition of temperature and heat, 3. Thermal equilibrium and steady state, 4. Heat capacity, 5. Phase transition, 6. Emission, reflection and absorption of thermal radiation, 7. Ideal Gas, 8. Principles of heat engines.

In a second step we searched for known misconceptions and approved questions to this content in literature. After a detailed inspection we selected 19 possibly suitable items from literature, translated them into German, but left the structure and content mostly unchanged. It is to mention that already the translation can have an impact on the meaning of the respective item and it has to be examined carefully. We started a first run of version 1 with a pilot group of 47 and 39 engineering students as pre- and post-test respectively in the winter term 2018/19.

In the subsequent analysis it turned out, that the first version of the assessment had several drawbacks: questions were partly too easy, some questions were not precise or unambiguous, or one would need pre-knowledge to understand them. Others were multi-step questions with either a second multiple-choice answer or asking for reasoning. Those questions are difficult to analyze. In fact we had to modify all except two of the initially selected items in order to meet our requirements in form and content.

In version 2 of the assessment 6 questions were completely replaced. The new questions either stem from literature or by experiences from lecturers with student difficulties in informal context and exam answers. Moreover we aimed to obtain a systematic base for the development of single choice questions with 5 items each, that contain distracters with the most common misconceptions.

In order to do so, we additionally asked in 10 out of the 19 items the students to give reasoning for their answers in free-response format. In 4 other questions of the 19 we pose two-step questions with the second step containing the reasoning for the preceding answer. Other multiple choice questions had more or less than 5 answers. There we tested, which items are chosen most frequently by the students.

Version 2 was administered to another pilot group of 130 engineering students as pre-test and 110 engineering students as post-test in the summer term 2019.

From an in-depth analysis of student answers and reasoning of version 2, we could newly build most of the 19 items (details see below). They now comprise the new version 3, that is the current working version of the assessment - the thermal concept assessment, first year: – TCA-1Y. It contains only single-choice questions with five answers each. The items often have sketches of the underlying physical situation in order offer different representations (words and pictures) of the same situation. Moreover the test starts with more simple questions and address slightly advanced questions in the rear part. The order was chosen in that way, because we consider to use item 1 to 10 as pre-test, and item 1 to 19 as post-test for future investigations. This is a difference to the administration of the FCI, which can be used as pre- and post-test as a whole. The reason for this is, that the students' pre-knowledge in thermodynamics is often less pronounced than in mechanics.

Version 3 of the test was administered as pre-test with 33 students in the winter semester 2019/ 20 and as post-test from winter semester 2019/20 to 2021/22 to 52 students.

ITEM DEVELOPMENT IN DETAIL

The modifications of the items in version 3 of the assessment with respect to formulation, level, context, or answers are often quite substantial. The distracters of 10 questions have been constructed from student reasoning, by carefully identifying, analyzing and counting the prevailing misconception in the free-responses. The distracters of 4 two-step questions have been developed by determining the most dominating combinations of wrong answers and reasoning.

When choosing and adapting the formulation of the distracters directly from students' free-responses we were careful that they contain correct physical expressions and technical terms. For example we don't write: "in wool more heat can be conserved" but: "in wool more thermal energy can be conserved". Even though a wrong answer, we don't want to mess students up with wrong usage of state or process variables. We wanted to avoid that students, who take part in the assessment get used to wrong concepts due to the assessment itself. Moreover we intended to elicit intuitive misconceptions in contrast to other misunderstandings.

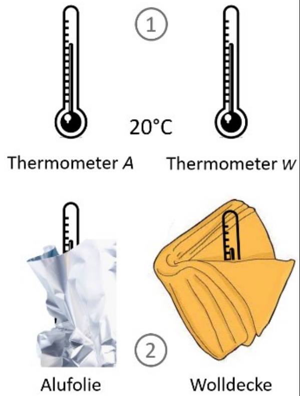
EXAMPLE FOR ITEM DEVELOPMENT

The steps of the development of an item is shown exemplarily with item 5 of the TCA-1Y addressing thermal equilibrium. In different studies it has been shown that students have difficulties in applying the concept that all bodies and materials have the same temperature in thermal equilibrium. Several misconceptions that go along with it are reported in [8]: the temperature of different objects is different even though they have been placed in the same environment, wool warms things up, or metal attracts, hold or store heat and cold. Items addressing this concept can be found in several concept tests like TCE, TTCI and HECI.

Table 1: Item 5: original item from [7], version 2, and version 3

Original:	**Version 2, Item 5 (Translation from German):**
Four students were discussing things they did as kids. The following conversation was heard: Ami: "I used to wrap my dolls in blankets but could never understand why they didn't warm up." *a. Nick replied: "It's because the blankets you used were probably poor insulators."* *b. Lyn replied: "It's because the blankets you used were probably poor conductors."* *c. Jay replied: "It's because the dolls were made of materials which did not hold heat well.* *d. Kev replied: "It's because the dolls were made of material which took a long time to warm up."* *e. Joy replied: "You're all wrong."* *Who do you agree with?*	*Two identical thermometer in the same room show 20°C at room temperature. One thermometer is wrapped in a shining aluminum foil, the other in a woolen blanket. How does the temperature reading changes on both thermometers?* *A. The thermometer in the aluminum foil shows a lower reading than the thermometer that is insulated with a blanket.* *B. The thermometer insulated with the blanket shows a lower reading than the thermometer that is in the aluminum foil.* *C. Both thermometer continue to show the same reading.* *The answer to the preceding question is correct….* *a. Because the woolen blanket is a significantly better thermal insulator than the aluminum foil.*

<table>
<tr><td></td><td>b. Because the shining aluminum foil reflects incoming radiation more effectively than the woolen blanket.
c. Because the shining aluminum foil emits radiation more effectively than the woolen blanket.
d. Because the system is in thermal equilibrium.</td></tr>
<tr><td colspan="2">Version 3, Item 5 (Translation from German): Two identical thermometers in the same room show the same temperature reading at 20°C. Now, thermometer A is wrapped in a shining aluminum foil, thermometer W in a woolen blanket. How do the temperature readings change relatively to each other of the thermometer A that is insulated with aluminum foil compared to thermometer W that is insulated with wool?



a. A shows a lower temperature than W, because the shining aluminum foil reflects the radiation more effectively than the woolen blanket.
b. A shows a higher temperature than W, because the shining aluminum foil A reflects the radiation more effectively than the woolen blanket.
c. A shows a lower temperature than W, because in the material wool more thermal energy can be stored than in the aluminum foil.
d. A shows a higher temperature than W, because the woolen blanket is a much better thermal insulator than the aluminum foil
e. A and W continue to show the same temperature, because the system is in thermal equilibrium.</td></tr>
</table>

We chose item 26 from TCE [7] to address this concept (original see Table 1). After translating the text into German, we changed it into a more scientific setting by replacing the doll with a thermometer. We did so because the test is to be used with engineering students. In order to have a clear reference frame we shifted the problem towards a setting that compares two situations – wool and aluminum foil. As being a good thermal insulator involves being a poor thermal conductor, we only chose "insulator" and we additionally offered reasoning that addresses thermal radiation.

Table 2: Students' result of item 5, version 2 + 3

Version 2: Combination of answers and reasoning for post-test, item 5, summer 2019 of 100 first-year engineering students. Answers A, B, C are given in rows, combined with the reasoning in columns. Percentage of students choosing the corresponding combination. The correct combination C+d is highlighted green. Highlighted in red is the physically illogical combination of answer and reason. The three most frequent wrong combinations (highlighted blue) have been selected for distracter construction.

100 students				
	a	b	c	d
A	4%	21%	2%	0%
B	10%	4%	6%	0%
C	0%	0%	0%	53%

Version 3: Single choice post-test results from winter terms 2019/20 to 2021/22 from a total of 52 engineering students. Percentage of students choosing the corresponding answer. The same blue tone in the results of version 2 and 3 address the same answer and reasoning combination. Answer e is correct.

52 students				
a	b	c	d	e
23%	4%	4%	8%	52%

Additionally we formulated it as a two-step question in order to separate answer and reasoning. The students' combined answers with reasoning for version 2 are presented in Table 2. Approximately half of the students selected the correct answer with correct reasoning. After determining the three most prevailing wrong answer patterns we constructed three distracters for a new version 3 of item 5. The known misconception that wool stores thermal energy was added as a further distracter. The physically wrong reasoning (highlighted red in Table 2) was skipped. The new version 3 of item 5 can be found in Table 1, the percentage of students choosing the corresponding answer Table 2. The results in Table 2 show that the prevailing misconceptions in version 2 are also selected in version 3.

In order to refine the results and to analyze the new version 3 of the assessment in more detail with respect to validity, difficulty and discrimination more student data have to be gathered, which can hopefully be done as soon as the pandemic allows face-to-face lecture again.

SUMMARY AND CONCLUSIONS

We report our procedure to set up a conceptual thermal assessment for first year engineering students. Known misconceptions and existing concept inventories were taken as a starting point. Special tests were designed in order to obtain the prevailing reasoning students give in the context of wrong answers. The present version 3 of the TCA-1Y covers eight concepts with 19 items. We plan to use version 3 as pre – test and post – test in order to understand students pre-knowledge and study the influence of teaching methods on learning gains.

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MODELING SPATIAL AND TEMPORAL FAST FOURIER TRANSFORM OF EXPERIMENTALLY SUPERIMPOSED MECHANICAL WAVES

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We present the results of an introductory physics laboratory designed to help students understand the connection between Fast Fourier Transform analysis and complex mechanical wave forms. The exercise helps students obtain a conceptual physical connection between a complicated mathematical analysis and real two-dimensional complex waves generated by commonly available lab equipment. Specifically, the input variables controlled by the students compare favorably with the outputs from Fourier transform analysis. Output uncertainties provides insight into data collection.

Keywords: Wave Superposition, Fourier Transform.

INTRODUCTION

The superposition of waves is an essential concept for understanding a variety of wave phenomena in physics and engineering that use digital signal processing. Complex waves are "unscrambled" through the discrete Fourier transform (DFT) process yielding the complex wave's frequency or wave number, and corresponding amplitudes. The history of the Fourier transform precedes Fourier and can be traced back to Carl Friedrich Gauss' interpolation of asteroid orbits [1]. The advent of the Fast Fourier Transform (FFT) [2] has been universally adopted across science disciplines for digital signal processing of basic and applied complex wave analysis. The FFT was an important improvement because it reduced the number of transform operations of N data points from the order of N^2 to order of N*log(N) calculations, with enormous savings in computational time [2].

Even before considering the level of mathematical sophistication required of students to understand how Fourier transforms work there is a more fundamental question: What is "wave superposition" in general? Superimposed waves are easily simulated by graphing programs [3]. However, these simulations do not provide much insight for students about real wave superposition, for example as observed on stringed instruments. Below we describe a final project [4] that has evolved into an undergraduate lab in which student explore a mechanical analog of complex waves consisting of two different frequencies and wavelengths. The complex waves can be observed in real time and analyzed with the use of a strobe light. The data is recorded using slow motion cell phone video capture. Lastly FFT analysis of the videos provide details and limitations of both temporal (frequency) and strobe image spatial (wave number) information. The frequency and wavelengths of these mechanical waves are controlled by the students making the FFT analysis output more transparent.

The common way of exploring complex wave forms, such as a high frequency wave superimposed on a carrier wave, is through computer generated wave simulations. These can be easily created, and animated, using interactive mathematics software such as

GeoGebra [5]. Figure 1 is a sample code and output for the condition of two waves with an amplitude and frequency each differing by a factor of 5:

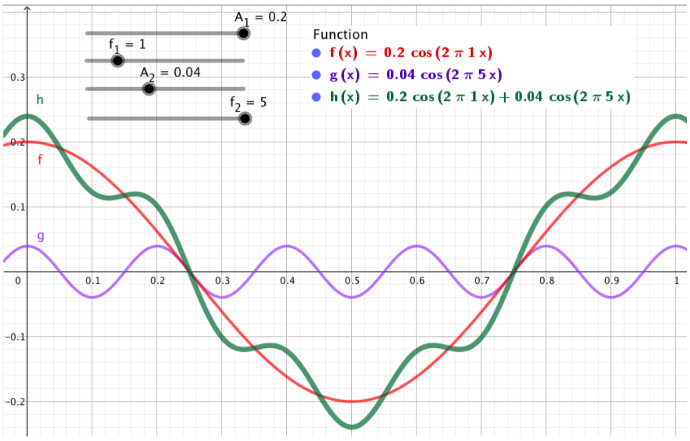

Fig.1. Example of Superimposed waves. Frequency and amplitude coefficients are the input.

This simulation takes only minutes to generate, and the exaggerated scales make the distinction between the two wave forms easy to see. The FFT amplitude and frequency or wave numbers are built into the sliders. However, this simulation provides little in the way of physical "feel" for how complex mechanical waves behave or look like "in real life". For example, how would these waves realistically present themselves on a stringed instrument? To answer that question, and attempt to recreate the simulated complex wave form, we constructed the following lab activity.

METHODOLOGY

A lab version of the simulation in Fig. 1 connects two wave generators at opposite ends to a string 0.76 m apart, each generator capable of controlling their own amplitude and frequency (Fig. 2a). The 1.5 g/m string was placed under a modest tension of 0.50 N and allowed to freely slip through a hole in one of the wave generator oscillator arms.

$$v = \lambda f = \sqrt{\frac{F_T}{\rho_L}}$$

These math models above are developed by the students as follows. The first explores how wavelength on the string changes with frequency, with the constant being wave speed. Students are then split into two groups with one group exploring the dependence on tension and the other examining the dependence on linear density. Given the conditions described above the students discover the wave speed is about 18 m/s.

In the next part of the lab the students use the above models as a foundation for understanding what a Fourier transform means in both space and time. The strobe light frequency was matched to the slow-motion cell phone video setting (240 Hz) and was used to illuminate the string's oscillations at maximum amplitudes, individually and the complex wave form (Fig. 2b), for purposes of still and video photography recording. The still shots below have amplitudes 1.8 cm for the carrier wave and 1.0 cm for the high frequency component with frequencies of 24 Hz and 120 Hz respectively. These frequencies are taken with the wavelength data and providing students with an important confirmation of the 18 m/s wave speed determined in the first part of the lab.

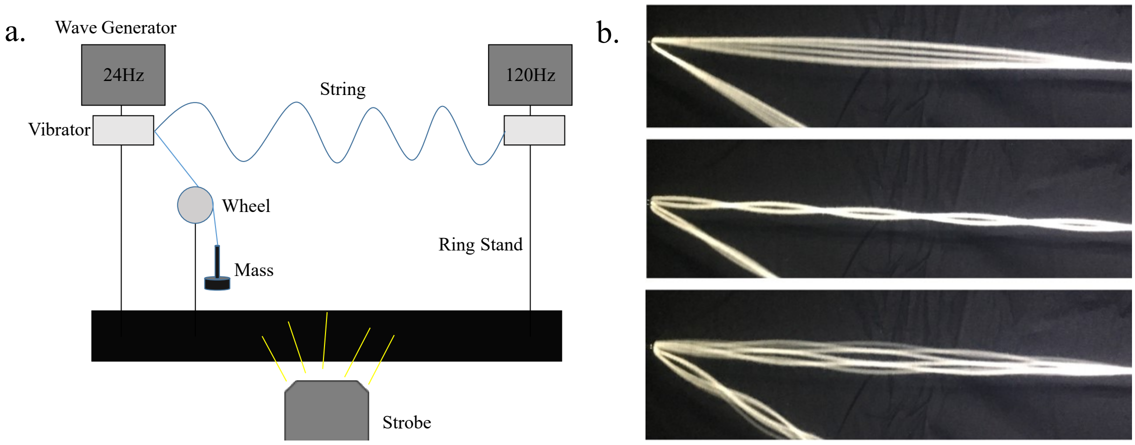

Fig. 2a. Experimental set up and examples of carrier and high frequency waves. Fig. 2b. For the clarity of presentation only half of a wavelength (0.38m) of the carrier wave is shown, along with the same overall length of the high frequency and complex waves.

Data collection and analysis of this experiment can be performed in a typical two to three-hour physics lab period. The students find that the video provides insightful visuals. The temporal and spatial data were analyzed using Vernier Video Analysis [6] software. Video analysis software often include FFT analysis functions with outputs (e.g., frequency and wave number spectra) that students compare to their inputs. Students quickly learn that LOTS of data is required to obtain FFT results having error smaller than the Fourier coefficients. On the experimental side care must be taken to adjust the frequencies of the two generators to avoid "beat frequencies" that make video recording difficult.

RESULTS AND DISCUSSION

Clearly, Fig. 2b bears little resemblance to Fig. 1. The Fig. 2b strobe image was intentionally matched to the 240Hz slow motion capability of the cell phone camera. This in turn places limits on the driving frequencies and maximum amplitudes, which shrink dramatically as frequency increases. Additionally, Fig. 2b includes features such as damping and/or higher harmonics not built into the simple simulation. The live example complements the simulation and provide a launch pad for a rich discussion on the complexities of mechanical wave behavior. The advantage of the real images is that students can analyze these oscillations for both spatial (wave number) and temporal (frequency) features. These can be compared inversely with the spacing between the ends of the strings to extract wavelengths or with student control of the frequency generator. The spatial Fourier transform of these two-dimensional waves helps students appreciate the "wavenumber", commonly associated with infrared spectra in chemistry:

$$\frac{k}{2\pi} = \bar{k} = \frac{1}{\lambda}$$

The FFT analysis of the individual waveforms are consistent (that is the inverse of) the measured wavelengths from video snapshots of 0.76±0.01 m and 0.15±0.01 m (Fig. 3).

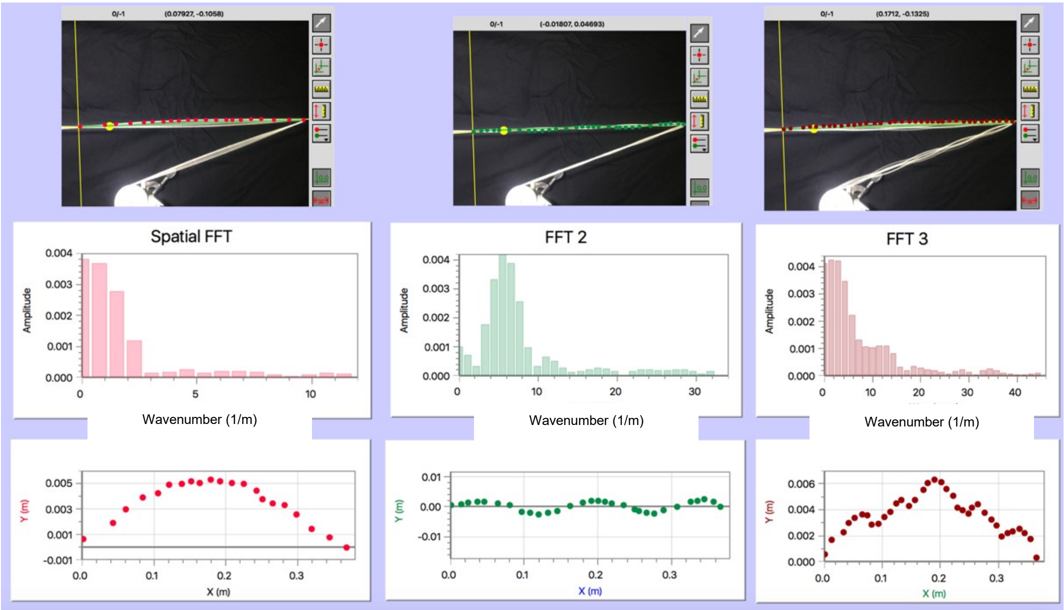

Fig.3. Three video analysis stacks: long carrier wave on left, shorter wavelength in the middle, and combined waves at right. Top row: single strobe image with data points taken at ≈2 cm intervals. Bottom row: magnified x-y data points. Middle row: spatial FFT based on the data from each stack. The wavenumbers from the FFT are 0.7+0.7 m^{-1} for the left stack, and 5.5±1.0 m^{-1} for the middle stack, and the third stack has peaks at 2±1 m^{-1} and 12±1 m^{-1}, double that of the single wavelengths. We suspect this reflects overtones created when tuning the two oscillators. Note large error bars, a consequence of insufficient data point collection.

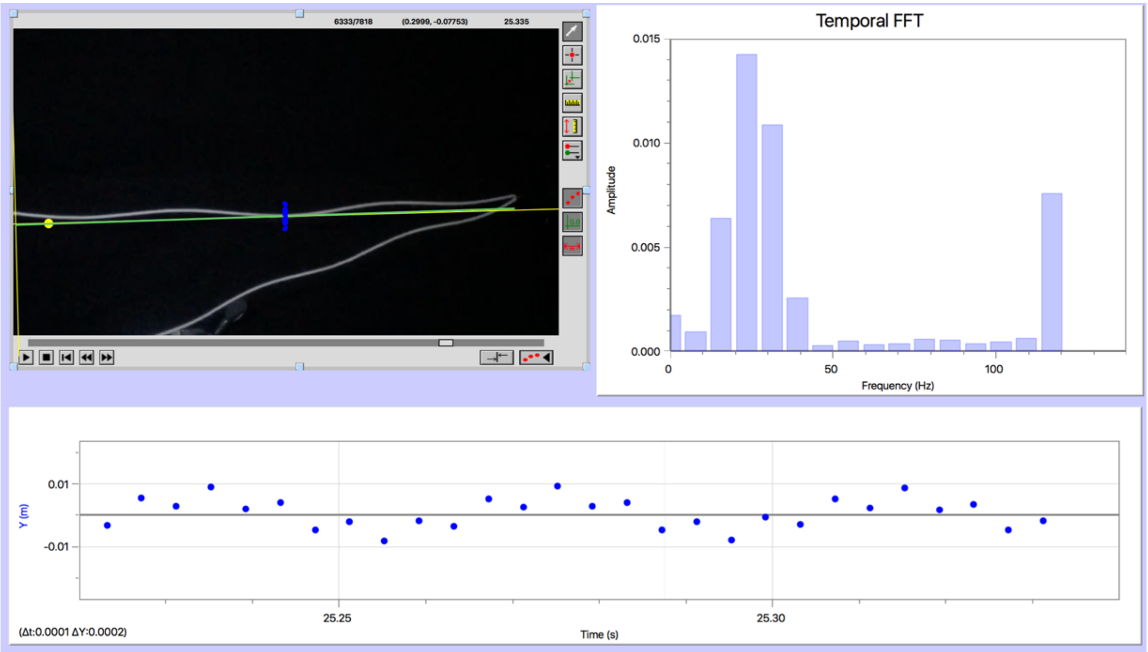

Fig.4. Results from temporal FFT analysis of the complex wave. Frequency peaks are found at 23±8 Hz and 118±8 Hz, in good agreement with the wave generator frequencies in use.

The Fourier transform of the wave in the time domain is expected to provide the two frequencies used in this experiment, 24.0±0.1 Hz carrier wave and 120.0±0.1 Hz high frequency wave.

$$\frac{\omega}{2\pi} = \bar{\omega} = f = \frac{1}{T}$$

In both cases the poor experimental resolution of the FFTs can be traced back to limited number of data points acquired by students. This is an important point for class discussion – the resolution achieved very much depends on the quality and number of data points collected.

Student learning outcomes: The University of New England introductory physics courses serve primarily life science majors (~ 95%). We employ a combination of modeling physics instruction [7] and introductory physics for the life sciences (IPLS) [8]. The IPLS emphasis results in a course heavily invested in the understanding of fluids and waves as a tool to investigate biological and chemical systems. This helps to understand our second semester learning outcomes described below:

1. Construct and use four main models (graphs, diagrams or simulations, math equations, and words) to predict, record, describe, quantitatively analyze, and explain the properties of fluids and waves.
2. Demonstrate safety and proficiency in data collection using computer interfaces, software, and laboratory hardware.
3. Demonstrate a functional understanding of the scientific methods to make informed decisions based on scientific information.
4. Demonstrate scientific literacy and the ability to communicate science-based information.

The FFT investigation develop above fully addressed these general learning outcomes. Specific outcomes from students are summarized in the bullet points below from their observations of the live activity and the manual analysis.

- Surprise about the difference between the simulation and "in real life" superimposed wave demonstration.
- Appreciation of automated analysis after completing the time-consuming manual data collection and analysis of a period of wavelength in space or oscillation in time.
- Chemistry students claimed a better understanding of wave number.
- All students agreed the connection between wavelength/period and Fourier peaks of frequency/wave number were now more transparent.
- Better understanding of the error surrounding number of manual data point entries.
- The students liked that the advanced lab connected to the initial model development of the wave equation, and that the ratios in the previous bullet point matched the 18 m/s they uncovered while developing the simple wave equation.

SUMMARY

A realistic example of a complex mechanical wave can be easily created using two opposing, independent frequency-controlled wave generators attached to the same string under tension. Still motion and video capture of the complex waves were analyzed to provide FFT outcomes consistent with the physically observed features, lending transparency to the FFT process. Data collection and analysis of this experiment can be performed in a two to three-hour physics lab period. The materials needed are present in most physics classrooms and video can be collected with cell phones capable of slow-motion video capture. Insightful visuals can be produced to help students better understand complex mechanical wave form structure. The data was analyzed using video analysis software. Taking the FFT of data collected from video analysis yielded an accurate amplitude versus wave number or frequency plot. Overall, this experiment is a simple and inexpensive way to demonstrate the superposition of complex waves and compare the results of FFT to the inputs controlled by the students. Anecdotal evidence from student feedback indicated that physically viewing the superposition of waves and analyzing collected data provided a more conceptually meaningful experience than computer simulations alone.

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INTEGRATION OF THE PHYSICS LAB IN THE CURRICULUM SEQUENCE 'ENGINEERING EXPERIENCES'

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The classical physics lab, focusing on cognitive learning and the development of some professional competencies among first-year engineering students, has disappeared and is included in an innovative new course, part of a curriculum sequence called 'Engineering Experiences'. The reasons behind this reform are explained and the perceptions of the students after the first year of implementation are described. We can conclude that the immersion of the physics lab into an integrated learning environment has not harmed physics, on the contrary.

Keywords: physics lab, professional competencies, integrated learning environment.

INTRODUCTION

Laboratory and practical work are characteristic features of a Bachelor's programme in any engineering discipline [1]. The benefits are clear: develop competencies that will enable graduates to operate professionally as an engineer; deepen the understanding through relating theory to practice and motivate students by immersing them in authentic assignments.

The physics lab, mostly situated in the first year of the Bachelor's programme, contributes definitely to these objectives [2]. However, the methodology and specific learning outcomes have evolved over the span of the last century [3]. During the first half of the 20th century the focus of the physics lab was on vivifying conceptual and analytical knowledge of the most important facts of physics and carrying out precise measurements in order to reduce error. This more fundamental view evolved into a more societal oriented view mid-20th century to keep in touch with industry and the rapidly changing technologies. At the end of the 20th century this resulted in additional learning outcomes in the physics lab such as teamwork and lifelong learning [3]. Nowadays, physics labs serve a broad set of learning goals and they are organized in many different ways according to institutional culture, student population and the objectives pursued. The possible approaches are among others:

- Project- and problem-based design [4-5];

- Model-based design [6];
- Learning environment for several competencies [2];
- Single experiments (learning objects), relating the phenomenon to real life and introducing boundary conditions [7];

However, the learning outcomes envisaged by these different visions are rather similar [3]:

- Constructing knowledge;
- Modeling;
- Designing experiments;
- Developing technical and practical laboratory skills;
- Analyzing and visualizing data;
- Communicating physics.

Professional competencies are inherently part of these learning outcomes. It should be emphasized that we use 'professional competencies' instead of 'soft skills' since the latter has negative connotations [8]. The inclusion of professional competencies in the physics lab is a great step forward. It allows to decrease the gap between physics education and the way professional engineers rely on physics in their engineering practice. Following this reasoning, we have constructed a completely new curriculum sequence in 2019-2020 in the reformed Bachelor's programme in the Faculty of Engineering Technology at KU Leuven: 'Engineering Experiences'. In this curriculum sequence students are challenged to use, integrate, and apply all the competencies acquired in other courses, both technical and non-technical, in order to tackle authentic assignments. These assignments are carried out individually or in teams and become increasingly complex and realistic, requiring more and more independence while progressing through the Bachelor's programme. This gives students an insight into possible future professional practices and supports them to find out where their interests and strengths lie. This curriculum sequence counts a significant number of ECTS credits, i.e. 24 ECTS credits spread over the entire Bachelor's programme. The required space in the curriculum was created thanks to the integration of labs and projects from different disciplines.

In this paper we report on the first step in this curriculum sequence at Campus De Nayer: the physics lab (and others) immersed in the course 'Engineering Experiences 1'. We focus in the first paragraph on the content and the goals of this new approach and in the second paragraph on the consequences for the physics lab. Afterwards the experiences of the students are discussed and we finish this paper with a conclusion.

NEW APPROACH: ENGINEERING EXPERIENCES

The first year of the Bachelor's programme includes 'Engineering Experience 1'. During this 9 ECTS credits-course, we introduce the students to the integrated approach and the way engineers work: coordinate multiple competencies to accomplish a goal [9]. This course runs during the whole academic year and starts in the first semester with what we call 'the integrated lab' (2 ECTS credits). During the second semester we proceed and challenge them with 'the project' (3 ECTS credits). These two assignments are accompanied by two courses: ‘spatial insight and CAD’ (3 ECTS credits) in the first semester and ‘seminars professional competencies’ (1 ECTS credit) during the whole academic year.

In ‘**spatial insight and CAD’**, students are familiarised with the spatial thinking process and the foundations of the technical drawing language. The aim is to gain insight into a technical drawing so that, regardless of their further education, a drawing can be read and understood easily. The knowledge and skills gained with this course during the first semester are applied directly into ‘the project’ where they have to design and draw a technical construction.

The ‘**seminars professional competencies’** aim at teaching very specific learning outcomes. In the first semester, students are first introduced with the Basic CFrame. This framework includes the basic communication principles that facilitates to communicate effectively to different audiences. The Basic CFrame is the foundation in any other communication course in the Bachelor’s programme. Other first semester seminars are: information literacy, scientific writing, critical reflection and ‘health, safety and environment’. In the second semester, the focus is on presentation skills, project management and team dynamics. These seminars are limited to only 1 ECTS credit because the training of these competencies on the one hand and the feedback and evaluation by peers and the teaching staff on the other, is done during the ‘integrated lab’ and ‘the project’. The integrated approach is strongly supported by research: engineer’s technical work is inseparably intertwined with professional competencies [9]. By consequence, the professional competencies cannot be taught in isolation from the technical context in which they will be used. Nonetheless, these seminars are on purpose explicitly included as ‘seminars’ in ‘Engineering Experiences 1’, since it is proven that this explicit attention is essential for learning [10]. Because the training and assessment are organized during ‘the integrated lab’ and ‘the project’, the teaching staff of these seminars is also part of the multidisciplinary team that supports and challenges the students during ‘the integrated lab’ and ‘the project’.

During the first semester, students carry out well-defined hands-on assignments in ‘**the integrated lab’**. These assignments are closed, authentic tasks with a specific predefined outcome, designed according to the traditional cookbook laboratory approach:

- Measure the properties of mechanical vibrations via sensors;
- Program a car to drive as efficiently as possible in order to pass several traffic lights;
- Optimize heat loss through the facades of an on campus-building;
- Build a galvanic, electrolysis and fuel cell.

We call these tasks ‘integrated’ because various disciplines and competencies come together like in the real world.

The ‘**project**’ runs during the second semester. At that moment students already have some more disciplinary knowledge and laboratory-experience. Teams of four students are challenged by open assignments linked with Sustainable Development Goal 12 ‘Responsible Consumption and Production’ [11]. ‘The greenhouse of the future’ is defined as our central theme, and students can choose to approach the challenge from four different disciplinary perspectives:

- Civil engineering: design a greenhouse structure on top of an existing building;
- Chemical engineering: recycle the water of a greenhouse with the help of algae cultivation;
- Electromechanical engineering: build an adjustable hatch for a greenhouse;
- Electronical engineering and ICT: control environmental factors in a greenhouse.

The project approach has different advantages. First, by addressing the domains of the various majors, the project helps students to refine their choice of the major which they have to make after the first Bachelor's year. Second, these team-based projects are considered to be a valuable approach to develop a broad set of professional competencies, such as project management or team dynamics [10]. Third, first-year students experience for the first time the feeling of 'operating like a real engineer'. This motivates the students and improves their retention [12].

CONSEQUENCES FOR THE PHYSICS LAB

The 'old' physics labs that have disappeared in order to create space in the curriculum for this integrated approach, had the following goals:

- deepen the understanding of the theoretical concepts (such as heat flux);
- measure and process physical quantities in a correct and precise way;
- provide opportunities to work together;
- write a report;
- motivate students and stimulate their interest in the subject.

All these goals are still present in the actual course 'Engineering Experiences 1'. The concepts (and sometimes also the material) of the 'old' physics labs are explicitly part of 'the integrated lab'. Due to this integration it is even more clear for the engineering students that they need concepts from physics to solve 'engineering' problems. Previously, the physics labs focused on more conceptual themes such as 'measure the thermal conductivity', whereas now it is part of a more authentic setting to 'optimize heat loss through the facades of an on campus-building".

In the project assignments, the link with physics is less explicit. But students now get the chance to train their professional competencies more intensively and under supervision of coaches. Although the same competencies were also a goal of the 'old' physics lab, students now also learn that these professional competencies are not linked to one course only, but are essential to solve engineering tasks in general. The chances of transfer over courses in a semester, year or whole curriculum are increased, in line with the idea of lifelong learning.

STUDENTS' EXPERIENCES

The reformed Bachelor's programme in the Faculty of Engineering Technology at KU Leuven was implemented for the first time in 2020-2021. At the end of that academic year, we consulted the students and asked for their experiences on how they perceived some of the key elements. We collected data anonymously during the physics college.

At the end of the first semester, we collected the perceptions of 44 students (response rate 50%) concerning some characteristics of 'the integrated lab' via a five-point Likert scale (completely dissatisfied, less satisfied, neutral, satisfied, very satisfied) using polleverywhere. The lowest rated key element is the feedback obtained by the students during the integrated lab (Figure 1a). There was also a need for more clarity on the objectives. The students were neutral about the broad set of proposed professional competencies and they were satisfied about the content of the integrated lab, the challenging nature of the assignments, the infrastructure in the lab and the support by the staff. And finally, we were pleased that the students were (very) satisfied with the integrated character of this new activity – the highest rated key element (Figure 1b).

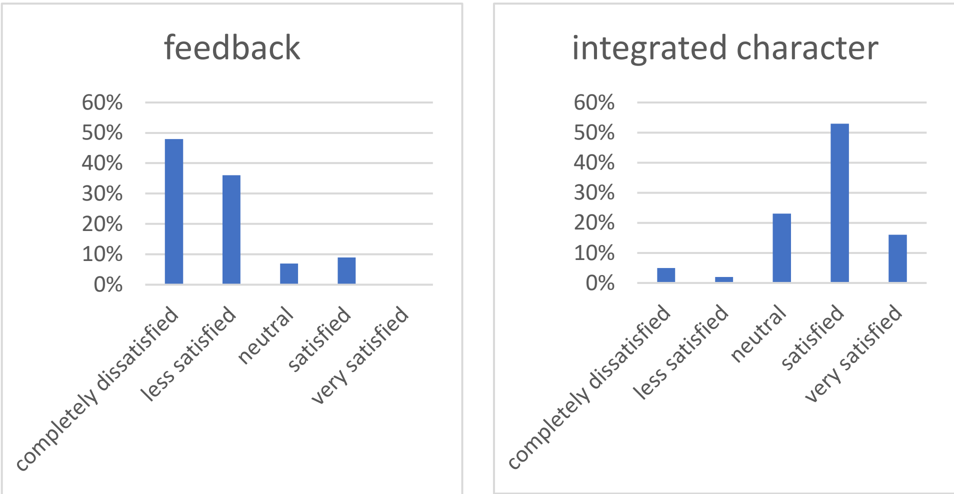

Fig.1. Lowest and highest rated key element of the integrated lab according to the students.

'The project' was evaluated at the end of the second semester by 51 students (response rate 58%) using open questions, which was made possible through Qualtrics. We asked about their views on the greatest strengths and weaknesses and obtained the following top three for the strengths: (1) independence, (2) good support by the staff and an ex aequo for (3) 'learned a lot' and 'was fun'. The most frequently mentioned weaknesses were: (1) processing new knowledge independently, (2) little support by the staff and (3) lack of clarity. The contradictions that we read here are probably a result of the fact that this population is very diverse since all of them are first-year students. Some of them like the independence, others need more support.

Also, at the end of the second semester we gauged students' views on the 'seminars professional competencies'. They appreciated very much (1) the implementation in practice, (2) the large amount of feedback and (3) the coaching. Improvements were possible for (1) the communication of the deadlines, (2) the organization of the digital learning environment and (3) the amount of reflection exercises.

CONCLUSION

Two of the three most important advantages of integrated programmes according to the literature [13] are confirmed by the students surveyed in the context of this specific course: it provides motivation to learn, and meaningful learning is easier to achieve. We believe that this integrated course also succeeded in realizing the third advantage, in casu a better management of introducing the professional competencies to students. For example, we can now guarantee a systematic approach to 'writing skills', whereas before students had to write a lot of reports without any introduction into communication or any systematic feedback while moving from one lab to another.

This academic year 2021-2022, we have made some adjustments based on the feedback of the students. We reorganized the digital learning environment in order to create a supportive learning community for the students and we introduced the first steps of a feedback ecosystem [14]. We did not change the integrated character of 'Engineering Experiences 1'. On the contrary, we strengthened it by stimulating students in the project to collaborate beyond the borders of their specific theme.

Thanks to the collaboration of experts in professional competencies and experts from sciences and various technological fields, we have exchanged a lot of information and learned from each other. The disappearance of the 'old' physics lab had some emotional impact on the teaching staff, but it turns out to be a smart move. The usefulness and attractiveness of physics as a subject and course is strengthened. Sciences, and physics among them, serve as the basis for engineering endeavors.

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ONLINE TEACHING PHYSICS BY VIDEO-ANALYSIS METHOD

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Teaching physics during the Covid-19 pandemic and subsequent anti-epidemiological measures that did not allow full-time teaching became challenging for both students and teachers. The inability to perform real experiments was complicated by the building of new knowledge in students and the development of their abstract thinking. Video-analysis is a possible substitute for experiments - analysis of real physical events recorded in the form of videos using the Tracker program. The following article describes an e-learning course for physics students at home and finally offers an evaluation of the students themselves.

Keywords: STEM education, video-analysis, program Tracker.

INTRODUCTION

As mentioned in previous works, students' understanding of physical processes is not always correct [1]. Other authors have also confirmed that the basic skills of primary school students in physics (but also in mathematics) have declined dramatically in recent decades [2]. Physics is often considered a complex subject. The basic laws are expressed in the language of mathematics. Teachers are constantly working to make students better understand and understand the various phenomena and basic laws. One of the creative methods of teaching physics that makes science more interesting for students is video-analysis (VAS method) using the Tracker program [3]. Group projects based on digital video analysis provide an educational, motivational and cost-effective alternative to the traditional activities associated with an introductory physics course [4].

The traditional teaching of Newtonian mechanics in the first years of university studies only slightly eliminates the misconceptions of students acquired during high school studies, the so-called misconceptions. It has also been shown that traditional lectures help to acquire only basic knowledge without a deeper understanding and problem-solving ability; students do not demonstrate a conceptual understanding of the subject, which should result from a sufficient number of solved quantitative tasks and from logically clear lectures [5].

This led us to create an interactive USB key with a set of videos, with which we explained the laws of physics in lectures and carried out video measurements in seminars [6].

Problems can be considered as problem-solving tasks with a well-defined problem and according to Bloom's taxonomy of cognitive goals, which require a solution at a higher level - mostly at the level of application, analysis and synthesis. Many video analysis-based tasks are suitable for demonstrating simple mathematical analysis, the use of integrals and derivatives in physics. The use of tasks based on video analysis in physics can significantly affect differences in knowledge when students solve traditional tasks from a printed textbook [3].

E-LEARNING COURSE VIDEO-ANALYSIS AND MODELING OF REAL EVENTS

The supporting electronic material on the USB key [6] contains more than 100 videos and images suitable for physical analysis. The theoretical basis is described in the university textbook [7]. The e-learning course for students is organized as follows (Fig. 1):

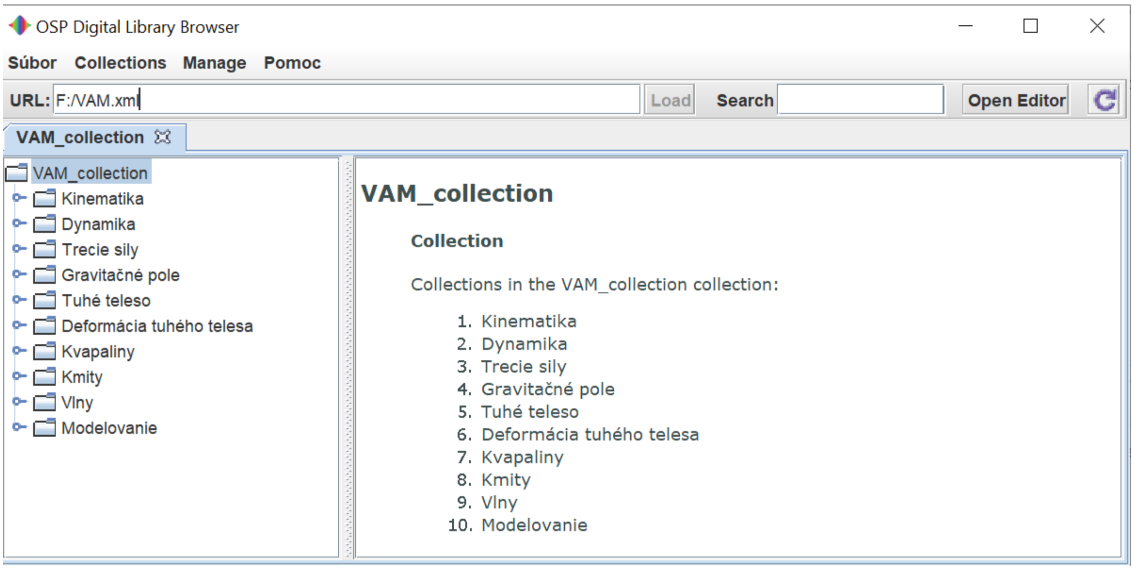

Fig.1. The library window of individual topics in the Tracker program - kinematics, dynamics, friction forces, gravitational field, rigid body, deformation of a solid, fluids, oscillations, waves, modeling.

Following the clicking of the given topic, other subtopics will appear with the assignments of specific tasks (Fig. 2).

Tracker is free, open source, it can also be installed on a USB key and run directly from a USB key. Working with this program is intuitive, the program contains help in several languages, instructions for working with the program can also be found in [6]. Students can work with this program by inserting a video from the database into a USB key into the program, performing a subsequent calibration and capturing the position of a moving object (either automatically after marking the moving object or manually). Or it is possible to use a file from USB where the calibration and the scanned position have already been performed (Tracker allows you to save the scanned position of the mass point and then return to the already calibrated and scanned data (Fig. 2).)

The task of students is to describe the event from a physical point of view - to make a mathematical analysis of the acquired dependencies (the program offers 24 predefined time dependencies, it is also possible to define other dependencies and investigate not only time dependencies, as the program also allows you to change predefined physical quantity).)

Subsequent analysis should describe the movement in the direction of the x, y axis, determine the initial velocity in the direction of the x, y axis. From the analysis of velocity in the given directions we can determine the instantaneous and average acceleration (examples from mass point kinematics).

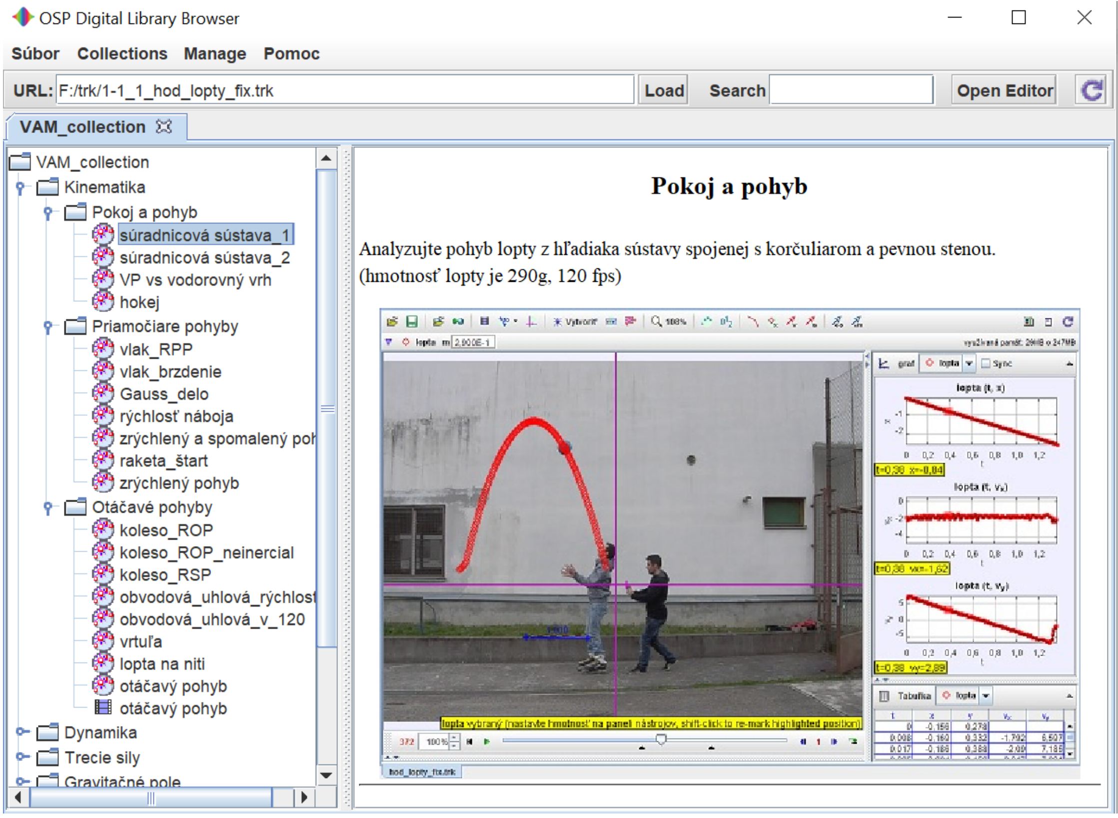

Fig.2. The library with the topic Kinematics and enter an example – analysis of motion.

Fig.3. Ball throw analysis in the y-axis direction using the Data Tool.

Figure 3 shows the analysis of the y-axis event using regression curves. The task of students is to describe the meaning of the obtained parameters A, B (average acceleration in the direction of the y-axis - gravitational acceleration g, initial velocity of the moving body in the direction of the y-axis) and also determine the value of instantaneous acceleration at any time (for example at time $t = 0.4\ s$, the ball speed was $v_y = 2.6\ m/s$ and the instantaneous acceleration $a_y = 9.93\ m/s^2$, (Fig. 3)). During the semester, 10 thematic units are prepared for students, which follow up on the lectured topics, the last topic is modeling of real events, where it is necessary to use analytical (equations for position x, y) or dynamic model (equations for forces F_x, F_y) and compare the result with the real situation.

TRADITIONAL TEACHING VERSUS VIDEO-ANALYSIS

As has been confirmed and presented [3], many video analysis-based problems are suitable for demonstrating simple mathematical analysis, the use of integrals and derivatives in physics. The use of tasks based on video analysis in physics significantly improves the understanding of basic laws and the acquisition of knowledge compared to students who have solved traditional tasks from a printed textbook. Video analysis and simulation (VAS method) of problem tasks using the interactive program Tracker is one of the methods that significantly helps to shape conceptual thinking and at the same time eliminate misconceptions, develop students' manual skills and intellectual abilities and increase students' knowledge [8-11]. These results were determined and confirmed using pre and post FCI (Force Concept Inventory) tests [12].

Due to the situation and measures related to Covid-19, the previous academic year could not be realized in person, both semesters, in which we implement the subjects Introduction to Physics in the winter semester and Physics 1 in the summer semester were realized remotely, using MS Teams. Some of the tasks in the form of video analyzes were used during the semesters as motivational, demonstrative and explanatory (especially in eliminating misconceptions).

After the exam, students had the opportunity to comment on the course of the semester, from their answers we select:

• thanks to the analyzes in the Tracker program, I understood many things, it was more lively, I liked the applied physics,

• I liked the lectures, many things were from everyday life, I got a different perspective, it was an experiential form,

• I know more than I knew the progress compared to what kind of physics I had,

• it was more interesting than theory, an interactive form of explanation, I liked physics, it was a connection between theory and practice,

• visual demonstrations helped me, I understood a lot, it was good because I had little physics in high school,

• I had a difficult start in physics, but this form helped me - not only the interpretation but also the video, it was clearer,

• an interesting way of learning, it has revived online education, my physics has improved,

• it was lively, interactive, many engaged in discussions and were forced to think, I liked the connection to the practice - I learn when I see something,

• finally it was proper physics from practical life,

• I don't have to do physics, but I liked it with you, not only theory but also practice,

• I slept in some online lectures, but not in yours, I didn't succeed,

• videos opened my eyes, I liked going to classes,

• it was understandable, I expected it to be harder ...

SUMMARY

Watching videos of real events and their subsequent video analysis has a positive effect on the growth of knowledge and improved understanding of Newtonian mechanics. As the students themselves said, video analysis with Tracker makes it easier for students to learn physics, and students can set their own pace of work and learn while analyzing videos. With the help of an interactive way of teaching physics, it is possible to eliminate students' misconceptions, reduce the departure of first-year students and also improve the level of understanding and knowledge of students in introductory general physics courses. Based on analyzes from FCI tests, the e-learning course Video Analysis and Modeling of Real Events helped students eliminate misconceptions and improved their understanding of the basic principles of physics and the functioning of the laws of this world.

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