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Student's perception about mechanical stress and what is most important for learning during a practical task using digital interactive lab description

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Abstract
This study investigated student's knowledge and understanding of mechanical stress including strain, and the relation between mechanical stress and strain, using material created by the authors of this text. It also investigated what the students perceived helpful for learning. The material was a complete laboratory setup and was intended to be simple and visual, including a digital part. During the studies in a Swedish upper secondary school, students enrolled in the technology programme took a general introductory course in solid mechanics. The students' participation in our study was composed of four classes. The study was implemented by answering a questionnaire prior to laboratory and a similar one after the laboratory, 85 out of 107 students answered both questionnaires. A thematic analysis was applied on the material, resulting in six thematic groups based on the students' previous knowledge and how much they have learned from the laboratory. To find correlations between the thematic groups, classes, and what the students perceived important for learning, a One-way Analysis of Variance (ANOVA) with multiple comparison post hoc test was performed. A significant difference between the class and the thematic groups was found ($p<0.05$). Another significant difference was found between the teacher and the class the students were in ($p<0.001$). This study showed that the teacher was important for the students' perception of solid mechanics during this laboratory and that the interactive lab description played less roll. The teacher's importance depended on what class the students were in.

Keywords
Technology, solid mechanics, practical task, interactive links, learning, teacher

Introduction
A didactical model may be used to explain and reason about the different teaching approaches that a teacher may conduct. The teaching approach depends on the context that is to be taught (Wickman et al., 2018). This is also discussed by Hattie (2003). The didactical model should not only be used when planning and conducting a single learning activity, but also in its evaluation (Jank & Meyer, 2003). The didactical model used in the laboratory was to keep equipment simple to use and visual in nature. (Hattaja et al., 2019). Follow the development of Quality 5.0 and their excellence model (SIQ, 2022) the success of an organisation requires motivated teachers and the relation between the student and teacher is important.

Technical solutions are often a compromise of many properties; as an example between choice of manufacturing method, chosen material, weight and solid mechanics calculations. Teaching technology in upper secondary school in Sweden is an activity of great complexity and the important role the teacher has for student learning is well established. The interest for the importance of the teacher during student learning has also been interest over a long time (eg. Darling-Hammond, 1996). The teacher´s role may concern, for example, relational aspects where a good teacher-student relationship is fundamental for student´s learning. Students describe, when describing a good teacher, a teacher that shares the responsibility of learning together with them and that the teacher know them not only as a learner. The teacher's knowledge of the taught subject is described as less important than both passion for teaching or the subject itself. A good teacher cares about the students' self-esteem and their confidence (Hirsch, 2021). Furthermore, the teacher's attitude towards the subject is also of importance as previous studies have shown that teachers are usually reluctant to teach subjects, they have little or no confidence in (Holroyd and Harlen, 1996). This of course will have an impact on teaching of the students, especially in a course with a broad course plan. For junior students, textbooks and class notes are important for learning, but in higher grades digital interactive learning becomes more important for supporting the learning process. Digital interactive learning is, for example, interaction between the teacher and student through chat groups (Hirsh and Sergolsson, 2021).

Experimental work plays an important role in learning science due to the visual effect of the experiment. It helps to first learn the method of the scientific experiment before performing a practical task on the subject. Secondly it helps the students understanding of the connections between known concepts and gaining learnings of known scientific knowledge. Experiments are often seen as a tool for students to learn new concepts and should be seen as a means of communication and less as a discovery (Millar, 2004) The interactions between teacher and students are very important for learning during an experimental task. This includes how the teacher acts and what is communicated (Hogstrom, 2010). The visual attention from teacher has a direct impact on the students learning (Haataja et al., 2019). During the technical design process the students usually create a model by a practical work through experimentation in a lab with lab equipment or simulate a computer model. The technology course is mandatory in Sweden and is studied in all ten years of compulsory school. It has a broad curriculum where students are introduced to both the engineering aspect as well as to the importance of technology in daily life. The course also highlights, among other things, different historical technical advancements as well as the importance of stable constructions (Skolverket, 2019a). In Table 1 it can be seen what the students learn about construction over the school years.

Table 1. Number of students in each thematic group.

School year	Technology education
Compulsory school 1-3 and pre-school class	Start with materials and construction (Skolverket, 2019a).
Compulsory school year 4-6	Start with stable construction and continue with reinforcements and trusses (Skolverket, 2019a).
Compulsory school 7-9	In the last three years they talk about tensile and compression strength, elasticity and hardness. In year 9 the grade criteria for the students includes that they should be able to: carry out technical development and construction work (Skolverket, 2019a).
Upper secondary school	In the final year of the compulsory school, students apply for an upper secondary school programme and about 8.4% of all students choose a program with a technology specialisation (Skolverket, 2023b)
University	Engineering education or similar

In the programs in upper secondary school all students are introduced to the subject of technology through a compulsory introductory course. This course has many perspectives including ethical aspects on technology, technical properties of materials including calculations, and the technical design process. (Skolverket, 2022).

The technical programme includes graduation goals, covering obligatory and optional courses (Skolverket, 2023a). Each course has a course plan with central content and criteria that the students must achieve. Solid mechanics calculation and designing are prominent in the technology course plan. In the introductory course at the technical programme, and even though its role may have lessened, it is still widely used when teaching solid mechanics calculations. Materials is one other important aspect and still play a significant role in the technology course criteria.

Technical calculations are also included in the course criteria (Skolverket, 2022) in the new course plan valid from June 2025. Designing is specifically mentioned as; concepts of designing, theories for designing, and models for designing. Calculations related to designing are mentioned in the central criteria for the course plan (Skolverket, 2024). Simulations have also been used to help students in their learning and was shown to be helpful in learning theoretical concepts in a more accessible manner (Carbonell, 2016).

Many studies have investigated how digital aids can help students perform practical tasks (Barrow & Rouse, 2009; Karlsudd, 2014; Usulu & Usulu, 2021). An international study (Inquimbert, 2019) reported that well adapted digital tools decrease the stress level students feel during practical tasks. Blended learning, a hybrid between digital and on place experiments, can be implemented to increase collaboration between laboratories, reduce costs, and to share knowledge and experiences (Nau, 2022). Previous studies (Saleh, 2009) have shown that visual aids during or before lab time can help the students to properly prepare for the lab. Visual aids also help the teacher to explain and work as a supplement for the practical work. (Skolverket, 2021) express importance of digital tools that can be implemented to ease learning by students. Digital tools increase motivation and engagement of students if it supports collaboration. Studies from (Skolverket, 2022) show digital aids bring value to learning if they are instructive and to support communication between students and between student and teacher.

This study focuses on the students initial learning of stress calculations via one lab experiment. Thus, an interactive digital material was designed specifically for a lab experiment involving visual effect of mechanical strain and stress calculations based on measured results. The students performed the practical experiment by measuring elongation of a rubber band using different weights and calculated stress and strain. During the practical task students used an interactive material which described the lab with an interactive formula sheet. Additionally, earlier research (Forsell, 2019a) showed that the attitude the teachers have when approaching solid mechanics and construction as a learning activity was important for the students learning. In the study some challenges regarding teaching solid mechanics were identified. The present study focuses on one of these challenges, namely the learning of new terms and concepts like mechanical stress and strain. The study was designed to evaluate the impact of digital support on students learning also considering the role of the teacher. The interactive material was used during the lab experiment. The students are asked about their knowledge and asked to rate the importance of different factors for learning.

Aim

The aim of this study was to evaluate student learning while using and following a digital lab description designed by the authors. The study was designed with the intention to view the digital support the student received through the lab description in the learning of mechanical stress and strain. The material included a practical task and the students had, among other things, a description with digital links and a formula book, also with digital links. Further the aim was to identify, while performing the task, what the student thought was most important for their learning of mechanical stress and strain. More specifically we will address the following research questions:

- What did the students know about mechanical stress before the experiment and how did their knowledge change after?
- What in the material do students perceive as helpful for their learning about mechanical stress?
- Is there any difference in what the students perceive helpful depending on their knowledge before and after or what class they belonged to?.

Method

Participants

The participants consisted of 107 students in total, recruited from four different classes of one school. The school chosen school was a big school close to Sweden's biggest city. The average merit value for the technical programme in Sweden was 260.5 (Skolverket, 2023c) and the median at the school was 289 and the lowest 255 (Nacka,2023). This means this school had students with slightly higher grade than average. All classes were part of the technical program after upper secondary school selection. The selected classes criteria had high degree of interest in learning technology as subject. The students were at the second year of three years of upper secondary education. Students read the last term of the technical basic course. The students went to four different classes and all classes had different teachers. None of the participants had any previous knowledge of solid mechanics in their course before. Although, as told before, all the students should have read about stable construction and materials in compulsory school. All students were informed about the study and its purpose, including that it was voluntary to participate. The students filled in a form where they accepted participation. The students received a form to answer before and after the practical task and 85 students answered both forms. All the questions on the forms were answered. The ethical advice and rules for the Swedish research council where followed (Vetenskapsrådet, 2017).

Experiment

An interactive lab description of a tensile test was designed and implemented. The test was performed in three different ways. The lab description and formula sheet, both had interactive links to aid the students to understand words and new concepts. The links had explanations, pictures and/or videos that explained the terminology. See example in figure 1.


Uppgiften

Uppgiften som handlar om hållfasthetslära går ut på att rita en dragprovkurva som visar relationen mellan spänning och töjning, detta är grundläggande inom hållfasthetsläran, samt kunna tolka resultatet (ku på en dragprovkurva. lag (wikipedia) sträckgräns (wikipedia), brottgräns (w asticitet samt säkerhetsfaktor.
Ett exempel på dragprovkurva.

1. Starta med att rita upp din figur hur du skall sätta upp din provutrustning så att du mäter det som skall mätas. Vad är det som du skall mäta?
2. Börja med att dra med händerna i gummibandet och beskriv vad du ser. Du skall skriva ned vad du tror, vilka materialegenskaper som skall vara uppfyllda för gummibandet som du kommer att göra prov på.
3. Sätt samman din mätutrustning och gör minst fem olika mätningar med olika vikter där du för varje vikt mäter gummibandets förlängning.
4. Genomför ett antal beräkningar med hjälp av dina mätningar och rita graf där du beskriver relationen mellan spänning och töjning. Grafen du ritat är en spänning-töjningskurva. Du behöver veta vad mekanisk spänning och töjning är, det går även att titta i formelsamlingen.

Fig 1. Exempel på spänning töjningskurva

Figure 1. Example of explanation from interactive lab description.

Before and after the interactive lab task the students received two questionnaires with identical questions about solid mechanics to answer. The questions to the students shortly described the terms so the students could recall them from earlier studies in grade school. The questions were asked in Swedish but are here translated. The questions posed were the following:

- Mechanical stress occurs in a material when you try to pull out the material so that it becomes longer. Mechanical stress is defined as a force acting on a surface that is orthogonal to the force. What do you know about mechanical stress?
- Strain occurs when pulling a material. Strain is how much you extend a material relative its original length. There is a relation between strain and elongation. What do you know about this relation?
- Stress and strain relate to each other. When you draw a graph (curve, as a mathematical function with appearance f(x)= x) that describes the relationship between mechanical stress and elongation, you get a certain appearance that is unique for the material being studied. What do you know about the graph? What does it describe?

The questions were open and were to be answered with free text. In the questionnaire, after the experiment, the students were also asked to rate the importance of different learning aids, previous knowledge, or digital links for their own learning. The rating covered; their own preparation (how they prepared for before the laboratory experiment), the lab description, the interactive links, the interactive formula book, the course book (all the classes had the same course book), the teacher, and the execution of the lab (the performance of the experiment itself). The students were asked to rate everything on a six graded scale, where six was considered the most important thing and one the least important one. Each of the learning aids were rated independently, hence everything could be rated the same importance.

Thematic analysis

As an initial step, a thematic analysis (Braun and Clark e, 2006) was applied where six different groups (here after called thematic groups) were identified. Each group within the thematic groups was defined based upon the student's answers from the questionnaires, combining answers both before and after. Depending on how the students expressed their understanding of the term mechanical stress including understanding of strain and the relation between stress and strain. All answers were analyzed, and comparison made between, before and after, the experiment. The answers to the three questions (see above) in the questionnaires were analyzed together. Since the questions were constructed to build on each other. If the student knew something about strain and not stress it was seen as the student knew some about strain or stress. All answers from students were put in the identified thematic groups. The number of students in each thematic group is shown in table 2.

The thematic analysis was performed as follows. First, authors became familiarized with the data. Followed by identifying significant statements, phrases, and sentences commonly used in the different answers. Themes in responses were identified where statements from students answers similar meaning were grouped to form themes.

Patterns in the answers were scrutinized and certain phrases found, helping in producing themes. Six thematic groups were created, which were then summarized and described The creation of each thematic group was done by looking at the student answers before and after the experiment. The 87 that answered, out of 107 students were put into these six groups that was determined through the thematic analysis. Each group had different perceptions of mechanical stress before and/or after the performed experiment. We did not order the themes in any order since we wanted to be open of the different result and perceptions of mechanical stress before and after the experiment. The thematic groups that were found during the thematical analyses was later used for a statistical analysis.

Table 2. Number of students in each thematic group

Groups	Number of students
Group 1	40
Group 2	7
Group 3	10
Group 4	2
Group 5	14
Group 6	12

Statistical analysis

A One-way ANOVA with multiple comparison post hoc test was used for the statistical analysis. The groups that came out with the thematic analysis were analysed against the rating the student provided on learning aids. In this analysis we assume the observations are normal distributed and the variances of the thematic groups are the same. The observations are independent of each other. This kind of analysis identifies different mean values between different groups that are analyzed. The (Ostertagova et al., 2013) analysis was used to find associations and relations between the different thematic groups generated in the thematic analysis regarding their perception of mechanical stress. It was also used to identified differences in the four different classes. More specifically the mean and standard deviation for the students' ratings were calculated. The statistically significant relations between classes and the thematic groups were also investigated. All the students went to four different classes in one school. The classes were investigated against the thematic groups generated from the thematic analysis. The classes were also investigated against the rating of learning aids that the students made before and after the practical experiment.

Result

In table 3 the results from the thematic analysis are described; student answers are used for exemplifying the thematic groups descriptions. In three of the four classes, most students were found in thematic group 1. Most of the students (thematic group one) learned less than desired even though the provided material, more specifically the digital links, was reported to have been of some help; the digital links were not the most important thing compared to teacher, lab description, formula book and the execution itself. It seems like the “normal way” of describing the lab was more important than the digital links. Table 3 shows different examples of answers from the different thematic groups. In figure 2 it can be seen the progress for each group where it can be seen that group 1 and 3 increased their knowledge most of all thematic groups.

Table 3. Groups of students with different perception of mechanical stress.

Thematic group	Example of an answer before the task	Example of an answer after the performed task
Group 1 Before the task: Students know nothing, or very little, about mechanical stress, strain, or about the relationship between the two. They expressed this by writing things that were wrong or by not writing anything at all. After the task: Students express some understanding of the concept mechanical stress but no or very little understanding of what how affects material or the relationship to strain. They could also have expressed some understanding of the relationship but nothing about the concept of strain.	“No idea, no clue, do not know”. “Hardly anything. This relationship can be described with a formula: Graph shows when our material is stretched too much and can break”	“It's the power divided by the area in mm^2.” “Nothing, doesn't understand what I should have realized with the graph”
Group 2 Before: Same as group 1 After: Express some understanding of mechanical stress, strain and the relationship between them.	“Nothing, nothing special”	“It depends on epsilon and the stress.” “It is the mechanical stress. Elasticity”.
Group 3 Before: Express some understanding of the concept mechanical stress. After: Express some understanding of strain and the relationship between strain and mechanical stress. The student also expresses an understanding of the concept mechanical stress.	“Looked a little at it. I know F/A = some stress. Beyond that I do not know more.” “I know there is a relation between them. I do not know how you use it or what equation I should use.” “I know that the graph probably gets a bigger y value the more stress you have and enough stress result in that the material will break.” “It depends a lot on different material.”	“I know now that F/A = stress. Thus, when you pull a material, the stress will increase depending on how big area you have.” “I know now that strain is depending on the elongation and the original length of the material you had.” “I know that the graph descries the correlation between stress and strain.”
Group 4 Before: Express an understanding of the concepts	“A force on object that you pull.” “A Rubber band.” “But I do not know more	“An object is stretched when a certain stress occurs on the object. The more stress, the

mechanical stress and strain and the relation between them. After: They do not express any difference in understanding before the task as compared to after the task.	about this." "Do not know anything but my guess is that there is a relation between the length of the material and the force you pull with. There is also a relationship with what material it is. Rubber can stretch more than stone." " Have absolutely no idea."	more strain." "It describes the relationship between the strain and stress."
<u>Group 5</u> Before: Express no understanding of the concepts stress and strain or the relation between them After: Express no understanding on the concepts stress and strain or the relationship between them.	"Nothing". "The stress increases when you stretch something. "High stress means that the object you are pulling stretches a lot." "Proportional increase in the graph."	"Mechanical stress in a material occurs when you try to pull out the material so that it becomes longer." "Stress is a force that is applied on a surface that is perpendicular to the force." "Proportional relation. It should be equally constant."
<u>Group 6</u> Before: Express some understanding of the concept mechanical stress After: No difference in understanding after the task than before.	"Mechanical stress in a material occurs when you pull a material, so it gets longer."	"You calculate stress by F/A = the force divided by the area."

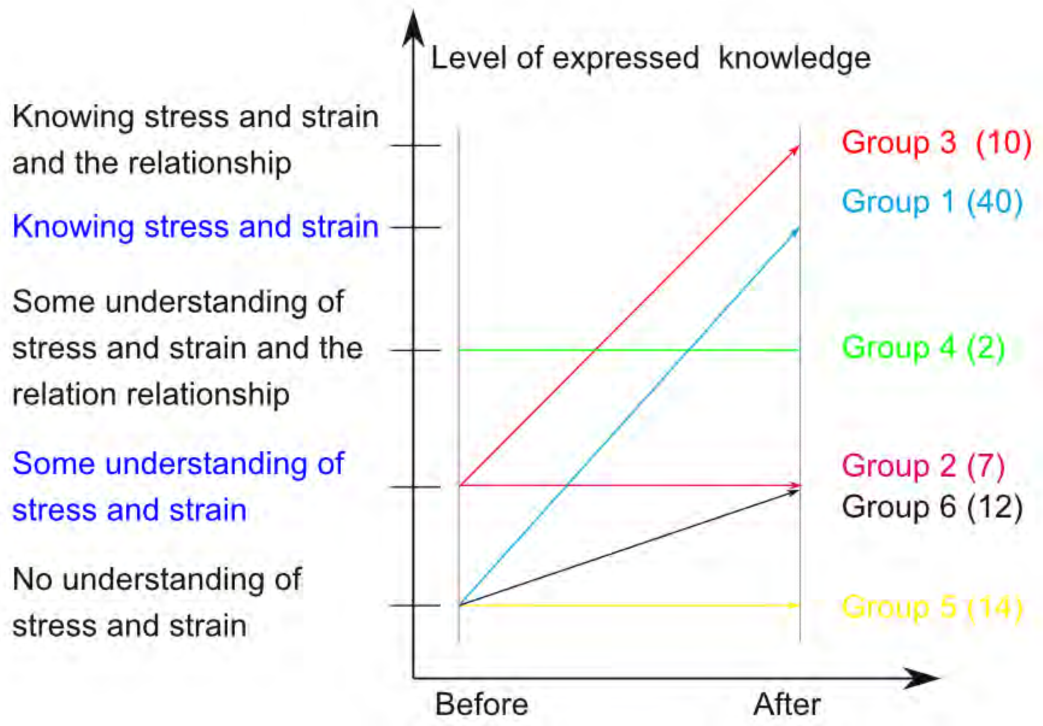

Figure 2. Groups of students with different knowledge on mechanical stress. Figure describes the understanding of mechanical stress before and after the practical task. The number in () are the number of students in the group.

The numbers in parenthesis are the number of students belonging to respective thematic group. Group 5 and 2 didn't change their understanding at all compared before and after the experiment. In table 4 it can clearly be seen how the students in different classes were divided in the different groups. The product of the class that went to a certain group can be seen in parenthesis, if there exist more than 10 students in the group. Most of the students went to group 1 and in class three more than 60% are placed in group 1. Execution of the lab was most important for the perception. However, there were significant differences between groups of students with different perceptions and different classes they belonged to ($p<0.05$). It seems that (table 4) shows that most of the students went to group 1 except in class 4.

Table 4. Number of students in the four classes divided in the different thematic groups. The % of the class that went to a certain group can be seen in brackets if more than 10 students in the group.

				Groups				Total
		1	2	3	4	5	6	
Classes	1	11 (39,3%)	4	5	0	6	2	28
	2	11 (61,1%)	2	2	0	2	1	18
	3	16 (64%)	1	0	0	3	5	25
	4	2	0	3	2	3	4	14
Total		40 (61,3%)	7	10 (11,8%)	2	14 (16,5%)	12 (14,1%)	85

Table 5 presents the results from the importance of different aids during the laboratory. If we look at table 6, the digital links are less important for group three than for the other groups. This difference was significant for group 1, 5 and 6. Group 3 is one of the groups that learned most but so did group 1 too. For the class versus what teacher there was also a significant difference ($p<0.01$). In class 2 the teacher seems less important and in class 1 most important of the four different classes (table 7c). In table 7b, it can be seen that the course book is more important in class 1 than in class 2 (a significant difference). This is the class that through the teacher was the least important of the classes. If we look at the digital links versus the classes (can be seen in table 7a), it can be seen a significant difference between class 3 and the other classes. Class three seems to think that the links are a little more important than the others (this difference was significant).

Table 5. The importance of different aids during the lab for the different thematic groups, expressed as mean values of a rating 1-6 where 6 was most important.

Groups	Own preparation	Description of lab	Interactive links	Formula book	Course book	The teacher	Execution of the lab
All the students	2.86	4.32	2.72	4.18	2.45	4.50	4.98
Mean Std	1.41	1.68	1.80	1.68	1.74	1.73	1.33

Table 6. The Groups they are in versus importance of group versus: a) own preparation b) description of the lab c) formula book d) course book, e) teacher f) execution of the lab g) interactive links. Rated 1-6 where 6 was the most important.

A)

OWN PREPARATION	Mean	Std.
1	2.78	1.510
2	3.43	1.618
3	2.90	1.370
4	4.00	2.828
5	3.00	1.961
6	2.42	1.311

B)

DESCRIPTION OF LAB	Mean	Std.
1	4.30	1.506
2	3.86	.900
3	4.30	.949
4	3.50	2.121
5	4.64	1.447
6	4.42	1.621

C)

FORMULA BOOK	Mean	Std.
1	4.28	1.853
2	4.14	1.345
3	3.50	1.841
4	3.50	.707
5	4.71	1.326
6	3.92	1.564

D)

COURSE BOOK	Mean	Std.
1	2.15	1.657
2	2.57	2.370
3	2.40	1.647
4	2.00	.000
5	3.29	1.858
6	2.50	1.624

E)

THE TEACHER	Mean	Std.
1	4.63	1.462
2	4.00	1.633
3	5.10	1.449
4	3.00	.000
5	4.86	1.834
6	4.50	1.732

F)

EXECUTION OF THE LAB	Mean	Std.
1	5.30	.939
2	4.29	1.380
3	4.80	1.398
4	4.50	2.121
5	4.57	1.785
6	5.00	1.595

G)

INTERACTIVE LINKS	Mean	Std.
1	2.70	1.728
2	2.57	2.370
3	1.40	.699
4	2.00	1.414
5	3.57	1.950
6	3.08	1.782

Table 7. The importance of a) class versus interactive links b) class versus book c) class versus teacher. Rated 1-6 where 6 was the most important.

a)

Class versus interactive links	**Mean**	**Std.**
1	2.50	1.95
2	2.22	1.31
3	3.52	2.00
4	2.36	1.22

b)

Class versus book	**Mean**	**Std.**
1	2.93	2.28
2	1.83	1.10
3	2.08	1.35
4	2.93	2.32

c)

Class versus teacher	**Mean**	**Std.**
1	5.71	0.54
2	3.17	1.30
3	4.24	1.69
4	4.93	1.39

Discussion and Conclusion

We could see from the result that approximately half of the students had some knowledge about mechanical stress prior to the laboratory (probably from compulsory school). Three of the groups raised their knowledge but three remained on the same level after the laboratory as before. The present study found a correlation between the importance of the teacher and which class the student belonged to when learning something new.; also, between the group and class. It is interesting that in all classes most students were put in group 1 according to the thematic analysis except class 4. One explanation could be that the answering rate was low in that class.

If we look at the student´s own preparation, group four had the highest value. Maybe the preparation led to their higher understanding before the task. The course book has low values for all the groups and maybe not so important for the students for this specific experiment. If we look at the importance of the teacher, the result imply that the teacher was very important for the outcome of the laboratory and depending on which specific teacher the student had, the teacher was more or less important. Could it be that a committed teacher gets students who prepare to a greater extent and then use the experimental material to a greater extent, but that they still see that the teacher is the "catalyst" to make it happen? The group with the highest importance was a group that changed understanding significantly and the one with the lowest stayed on the value they were at before the laboratory. One limitation is the difference in students that choose to join the study. So, the variation could have played in. The importance of the teacher has been of interest for a long time (Darling-Hammond, 1996). Teacher role is a complex task and the relationships with the students. That the course book was not most important in class 2 when the teacher was less important. For class 1 though the course book was more significant and important than in class 2. Earlier studies have seen course books and notes as important for learning (Hirsh and Sergolsson, 2021). We could not see that the course book was so important for the outcome of this learning experiment. Maybe if we asked for a longer period the course book would have been more important for learning. This was an isolated learning experiment and maybe that's one reason for the other things rated higher.

Preparation, according to earlier research, is important for learning (Saleh, 2009). We did not have a digital preparation for the students. Maybe that is why the students rated their own preparation as low. A digital preparation might have helped the learning and change the importance of the students rating of their own preparation. It might also change the importance of the digital concept for the students. During a practical task time is limited and preparation might give the students more time to look at digital links etc… If the preparation were digital, it may perhaps help the learning; this would be interesting to further investigate in later studies.

Earlier studies have also seen that it could be the teacher's communication including facilitating support and instructions during the lab practical task, is important for the learning (Hogstrom, 2010). Since we only could observe what happen during one lesson the teacher's importance might of course be influenced of earlier lessons with the students. This since the students knew the teacher and the class.

We found that the digital links was most important for class three. Most of class 3 went into group 1 which had an increase in understanding.

The students in the school had high grades in comparison to Sweden in average and that of course influences the student knowledge before the experiment. Our belief is that some of the schools will have even lower starting knowledge than this school. We think that maybe the three groups that have no or little knowledge before the laboratory are more representative of average Swedish students. 107 students were asked to answer the questions where only 87 answered all questions.

The biggest drop in participants came from the ones that made the choice to only answer the first survey. For the students that felt they did not learn anything we do not know, so this is a limitation in our study. Since students were asked to answer the questions twice, they may choose to answer similar as first time and did not think further. One limitation is also that teachers different way of teaching influenced the result of the study. The teachers also help students in the classroom and there by intervene with the result of the practical task. Maybe less help from teachers would have made the digital links been used more.

Thus, we think the importance of the teachers dominated in our study and other significant differences might not have been not seen. Maybe with less help from the teachers we could have investigated how much help the digital aids gave to understand the concepts stress and strain. It might also be that the teachers facilitated the use of the digital aids and the students rated this as teachers' importance (Collison and Cook, 2013). The importance of using the digital links and exactly how it is used thus needs to be further investigated.

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References

Barrow, L., Markman, L., Rouse, C. E. (2009). Technology's edge: The educational benefits of computer-aided instruction. American Economic Journal: Economic Policy, 1, 1, 52–7.

Carbonell, V., Romero, C., Martínez, E., & Flórez, M. (2013). Interactive simulations as teaching tools for engineering mechanics courses. European Journal of Physics, 34(4), 991–1004. https://doi.org/10.1088/0143-0807/34/4/991

Collinson, V. & Cook, T. (2013). Organizational Learning: Leading Innovations. International Journal of Educational Leadership and Management, 1(1), 69-98. doi: 10.447/ijelm.2013.03

Virginia, B., Victoria, C. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3:2, 77-10.

Darling-Hammond, L. (1996). The quiet revolution: Rethinking teacher development. Educational Leadership, 56(6), 4–10.

Finlayson, C. S., Fu, M. R., Squires, A., Applebaum, A., Van Cleave, J., O'Cearbhaill, R., Derosa, A. P. (2019). The Experience of being aware of disease status in women with recurrent ovarian cancer: A phenomenological study. Journal of Palliative Medicine, 22(4), 377-384.

Forsell, C., Engström, S., Norström, P. (2021a). Teachers' attitudes to teaching introductory solid mechanics in upper secondary school. Techneserien - Forskning i slöjdpedagogik och slöjdvetenskap, 28(2), 448–454.

Forsell, C., Engström, S., Norström, P. (2021b). Teachers' attitudes to teaching introductory solid mechanics and the challenges the teachers see the student face, in upper secondary school. Manuscript, to be submitted.

Hamza, K., Lundegård, I. (2018). Didaktik och didaktiska modeller för undervisning i naturvetenskapliga ämnen. NorDiNa, 14(3).

Hattaja, E. Moreno-Esteva, E G. Salonen, V. Laine, A. Toivanen, M. Hannula, M. (2019). Teacher´s visual attention when scaffolding collaborative mathematical problem solving. Teaching and Teacher Education, 86.

Hattie, J. (2003). Teachers make a difference: What is the research evidence? Paper presented at the building teacher quality: What does the research tell us, ACER research conference, Melbourne, Australia

Hirsh, Å. & Mikael Segolsson, M. (2021) "Had there been a Monica in each subject, I would have liked going to school every day": a study of students' perceptions of what characterizes excellent teachers and their teaching actions, Education Inquiry, 12:1, 35-53, DOI: 10.1080/20004508.2020.1740423

Hogstrom, P., Ottander, C., & Benckert, S. (2010). Lab work and learning in secondary school chemistry : the importance of teacher and student interaction. Research in Science Education (Australasian Science Education Research Association), 40(4), 505–523. https://doi.org/10.1007/s11165-009-9131-3

Holroyd, C., Harlen, W. (1996). Primary teachers' confidence about teaching science and technology. Research Papers in Education, 11(3), 323–335.

Inquimbert, C., Tramini, P., Romieu, O., Giraudeau, N. (2019). Pedagogical evaluation of digital technology to enhance dental student learning. European Journal of Dentistry, 13(1), 053–057.

Institutet för kvalitetsutveckling (SIQ)

Karlsudd, P. (2014). Tablets as learning support in special schools. Problems of education in the 21st Century, 59(59), 49–58

Millar, R. (2004, June 3). The role of practical work in the teaching and learning of science. Paper presented at the “High School Science Laboratories: Role and Vision” Meeting, Board on Science Education, National Academy of Sciences. Wa.

Nacka kommun (2024). Antagningsstatistik för gymnasieprogram på Nacka gymnasium Slutlig antagning 2023. Nacka kommun

Nau, J., Henke, K., Streitferdt, D. (2022). New Ways for Distributed Remote Web Experiments. In: Auer, M.E., Pester, A., May, D. (eds) Learning with Technologies and Technologies in Learning. Lecture Notes in Networks and Systems, vol 456. Springer, Cham. https://doi-org.focus.lib.kth.se/10.1007/978-3-031-04286-7_13

Ostertagova, E., Ostertag, O. (2013). Methodology and application of One-way ANOVA. American Journal of Mechanical Engineering, 1. 256-261.

Saleh, T. A. Visualization resources: to better utilize lab-time and to enhance teaching introductory chemistry laboratory. J. Comput. Chem., Jpn. 2009, 8 (2), 93– 96, DOI: 10.2477/jccj.H2026

Skolöverstyrelsen. (1970). Teknologi. I Läroplan för gymnasieskolan Lgy 70: Supplement 3-årig E, H, N och S linje samt 4-årig T linje (pp. 90–96). Stockholm, Sweden: Skolöverstyrelsen.

Skolverket. (2019a). Läroplan för grundskolan, förskoleklassen och fritidshemmet 2011, reviderad 2019. Stockholm, Sweden: Skolverket.

Skolverket. (2021). Digitala lärarresurser kan främja engagemang och motivation, 2021. Stockholm, Sweden: Skolverket.

Skolverket. (2022). Ämnesplan i Teknik för gymnasieskolan, 2011, reviderad 2022. Stockholm, Sweden: Skolverket.

Skolverket. (2023a) Teknikprogrammet, gymnasieprogrammen. Stockholm, Sweden: Skolverket.

Skolverket. (2023b). Elever på program redovisade efter typ av huvudman och kön. [Students on programmes reported by type of principal and gender], läsåret 2022/23 Report from the Swedish National Agency for Education, Stockholm: Skolverket

Skolverket. (2023c). Sökande från årskurs 9 läsåret 2022/23 till gymnasieskolan läsåret 2022/23 per program. [Applicants from year 9 in the academic year 2021/22 to upper secondary school in the academic year 2022/23 per programme, läsåret 2022/23 Report from the Swedish National Agency for Education, Stockholm: Skolverket

Skolverket. (2024). Ämnesplan i Teknik för gymnasieskolan, gällande från juni 2025. Stockholm, Sweden: Skolverket.

SIQ, 2022. SIQ Management model. https://en.siq.se/vara-tjanster/siq-managementmodell/

Uslu, A., Uslu, N. A. (2021). Improving primary school students’ creative writing and social-emotional learning skills through collaborative digital storytelling. Acta Educationis Generalis, 11(2), 1–18.

Vetenskapsrådet [The Swedish Research Council]. (2017). Good Research Practice. Stockholm: Vetenskapsrådet.