Technische Hochschule
Brandenburg
University of
Applied Sciences
Fachbereich
Technik

The Role of Hand-Calc Skills for First Year Students of Engineering

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  - Math challenges
- Math software: chances and pitfalls
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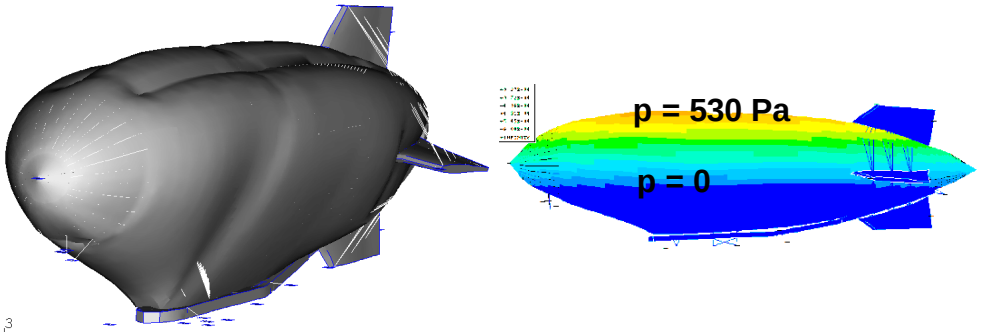
Introduction



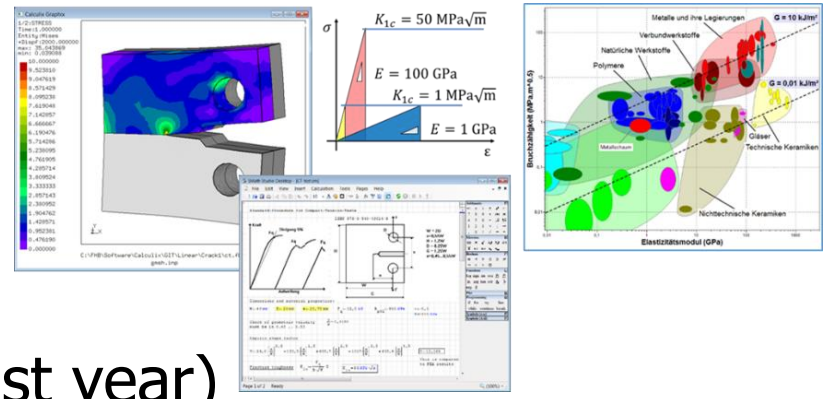
Education:

- Mechanical Engineering in Moscow, Freiberg (Sa.) and Berlin
- Research and teaching assistant at the Institute of Mechanics at the TU Berlin

Professional experience:

- Structural analysis at CargoLifter
- Metal forming simulation at INPRO Berlin
- Non-destructive testing and process monitoring

Introduction



Teaching at THB:

- Engineering Mechanics (1st year)
- Materials science (2nd year and master)
- Finite element analysis (3rd year and master)
- Product development (2nd year)

Research at THB:

- Mechanics of materials and structures
- Free math software
    - Documentation, tutorials, examples
    - Development of extensions

Engineering

…is designing, making and operating of complex technical systems.

What engineers need to know

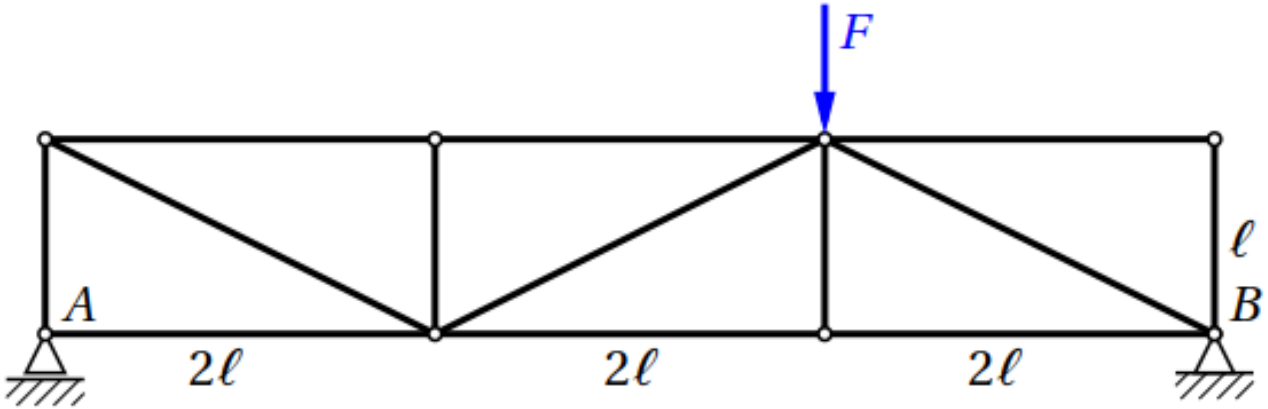
- Properties of the elements
- Ways how to modify these properties
- Possible interactions between elements
- Tools to predict the system properties
- Customers and their requirements
- Social and environmental impact of engineering

Engineering Mechanics: A Typical Task

Will the system carry the applied load?

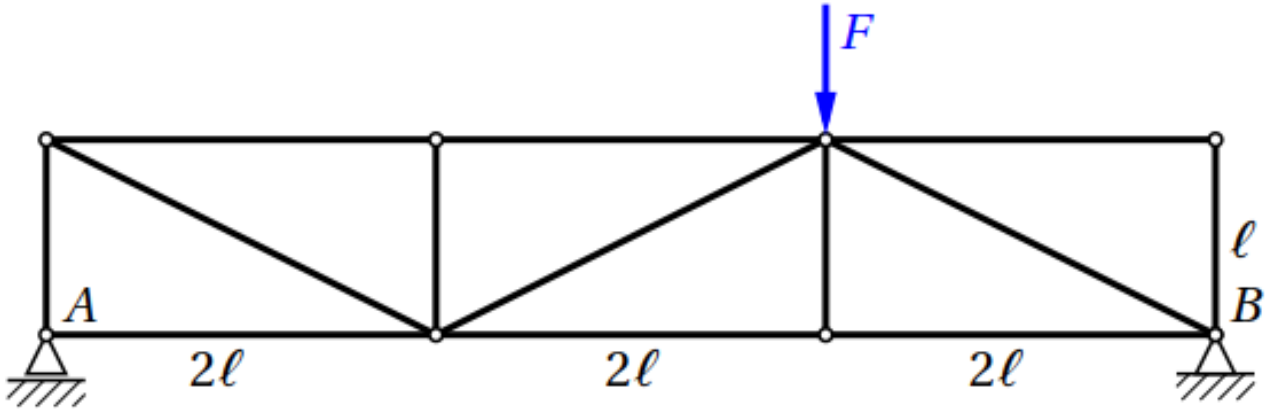
Does it break?

Will there be excessive deformations?



Engineering Mechanics: A Typical Task

Determine the load in the individual members.



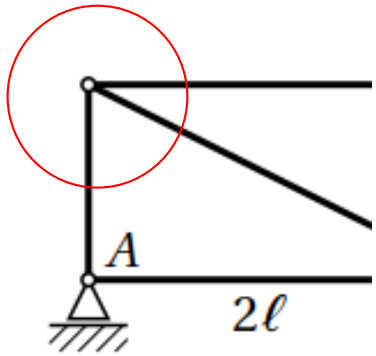
Possible solution:

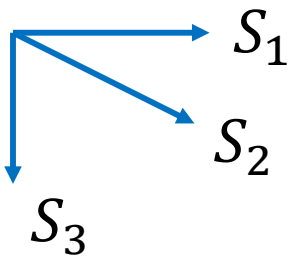
Establish the equillibrium conditions at each node and solve the resulting system.

Modelling

Free body diagram.

This actually introduces the target quantities:

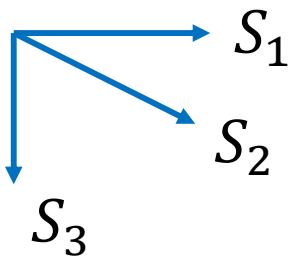




Modelling

Nodal equillibrium.

Sum up the forces in horizontal and vertical directions:

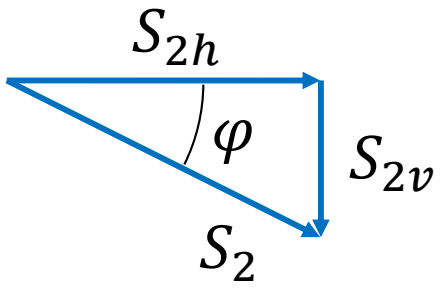


$\rightarrow \Sigma F = S_1 + S_2$ times what?

$\downarrow \Sigma F = S_3 + S_2$ times what?

Geometry

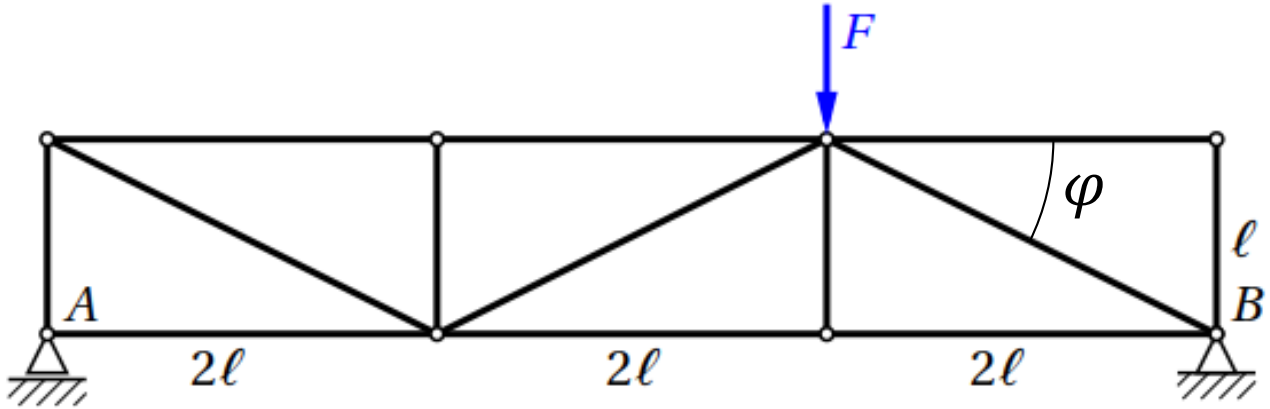
Trigonometry.



$$\tan\varphi = \frac{\ell}{2\ell}$$

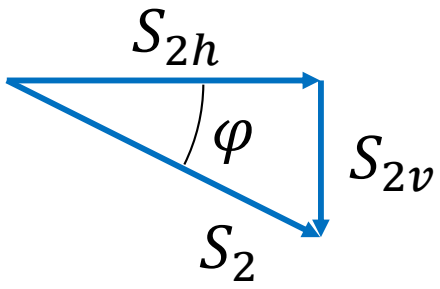
$$\sin\varphi = \frac{S_{2v}}{S_2}$$

$$\cos\varphi = \frac{S_{2h}}{S_2}$$



Geometry

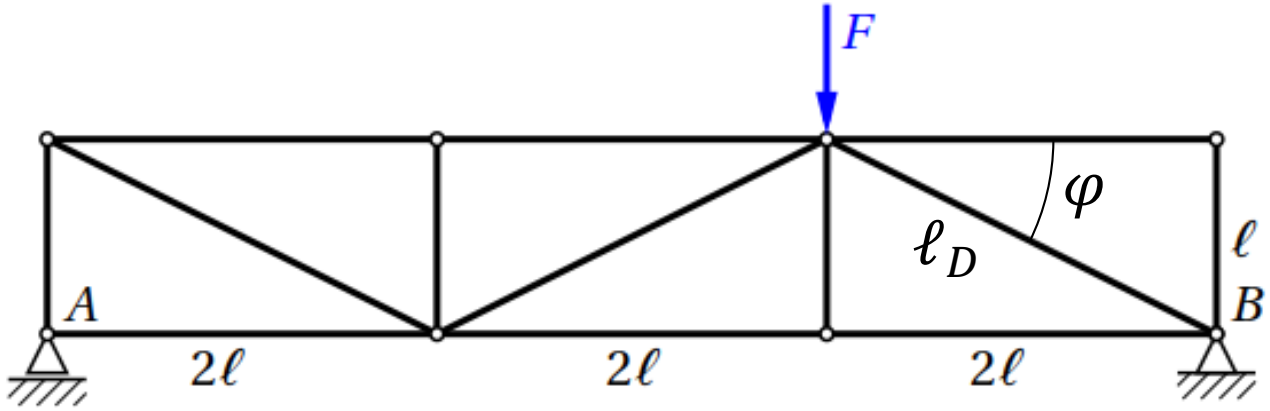
Proportions.



$$\frac{S_{2v}}{S_2} = \frac{\ell}{\ell_D}$$

$$\frac{S_{2h}}{S_2} = \frac{2\ell}{\ell_D}$$

$$\ell_D = \sqrt{\ell^2 + (2\ell)^2}$$



Challenges

- Apply trigonometric functions and Pythagorean theorem
- Establish proportions for similar triangles
- Transforming and solving of equations
- Multiply and divide fractions
- Handling of percentages

Should be no problem for first year‘s, should it?
If it was, what could we do?

Math Software

Motivation:

- **Reliable** documentation and performance of calculations
- **Avoid mistakes** due to lack of concentration
- **More fun** to debug, streamline and modify an automatic document instead of tedious repeated hand calc.

Math Software

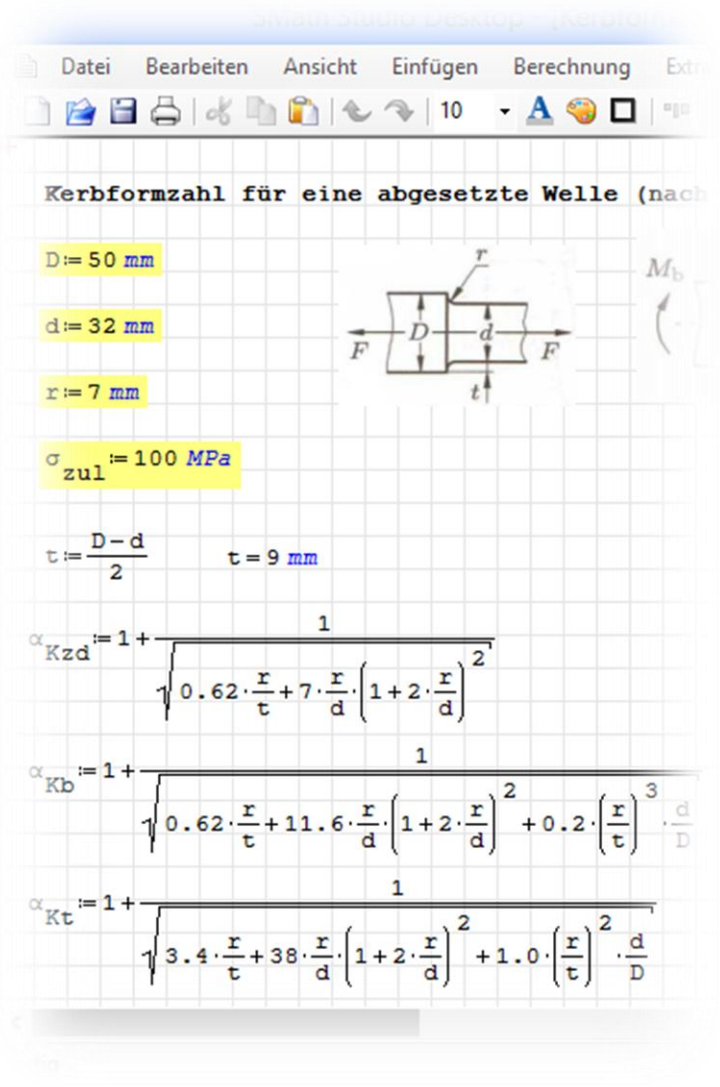
Expected challenges when I joined THB:

- Students are used to CAS tools from school – how to handle that: **ban or integrate**?
- Can math software compensate for low hand calc skills and allow focussing on the mechancis stuff?
- How to promote efficient use of software for documenting and performing of technical calculations?

Math Software

Adopted Strategy:

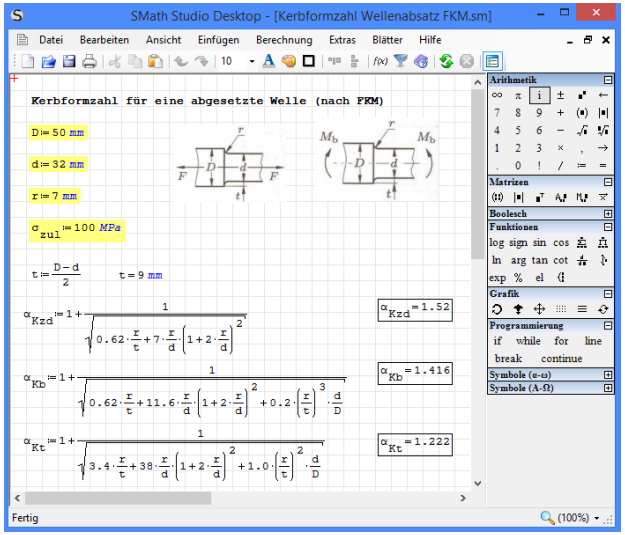
- Selection of SMath Studio
- Investigate the efficient use in Engineering Mechanics
- Identify shortcomings
- Contributions to extend documentation and functionality



Hand Calc Replacement Software

SMath Studio:

- Human-readable document format (sheet)
- Features match the needs of engineers (e.g. unit handling)
- Poor documentation (handbooks, tutorials)
- Weak symbolic (CAS) and plotting functions

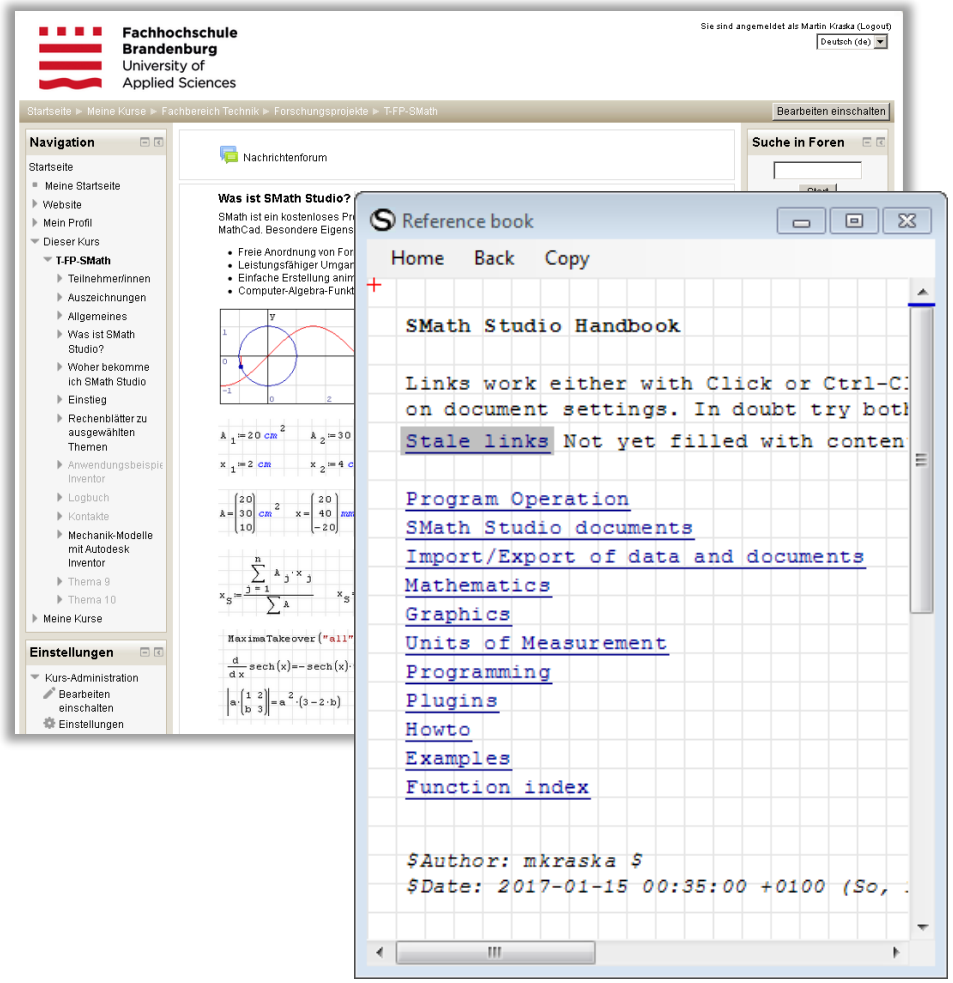


Create teaching material (Moodle course)

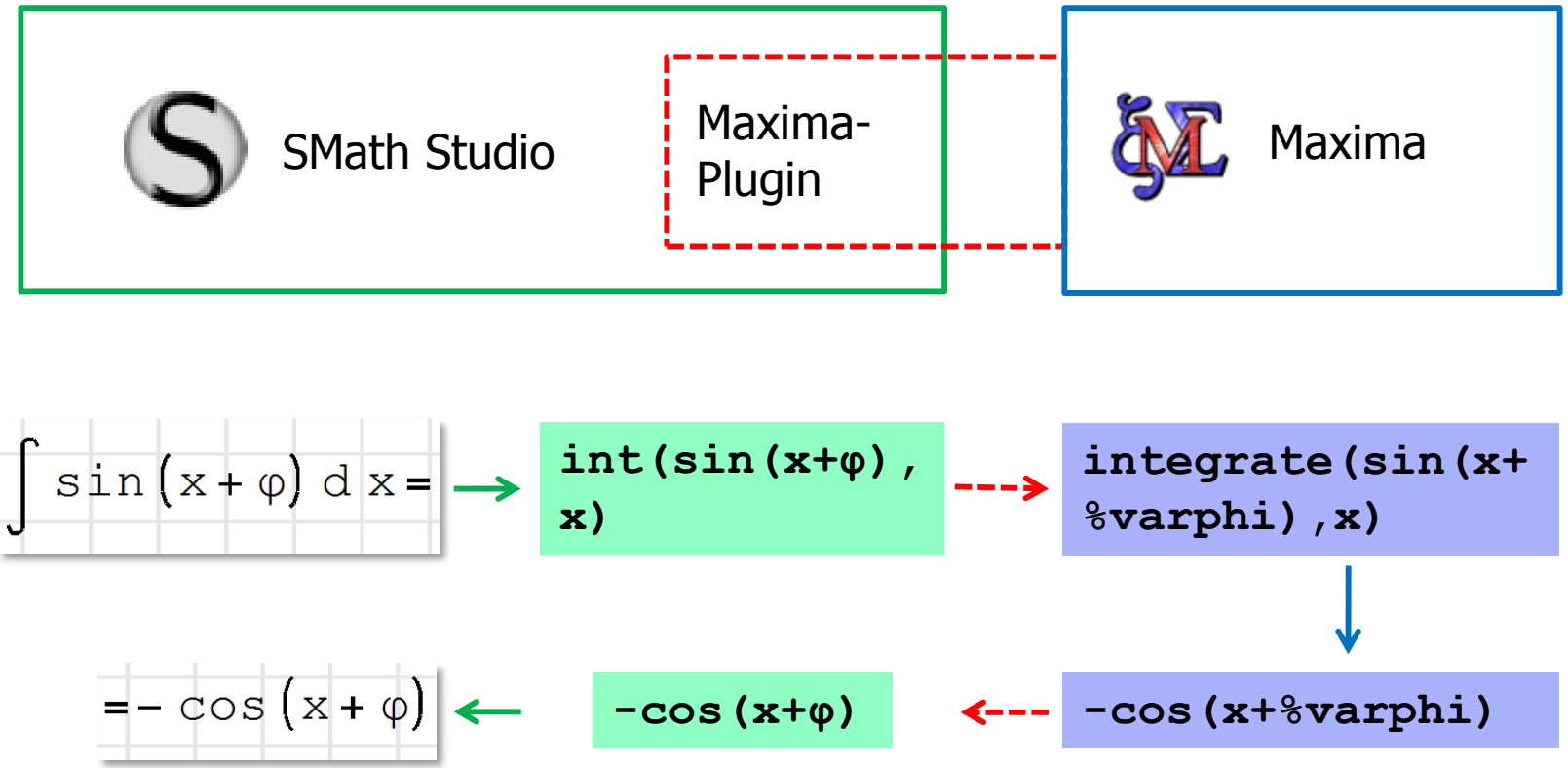
Maxima interface (free CAS-system)

Contribution 1: SMath Studio Support Page

- Interactive tutorial (bi-lingual, appr. 2h)
- Handbook (introduction and reference, in German)
- Interactive handbook (help system, bi-lingual)
- Pre-configured portable package (for use on USB drive)



Contribution 2: SMath With Maxima

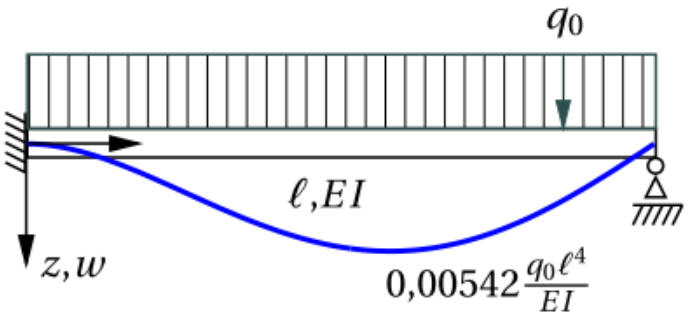


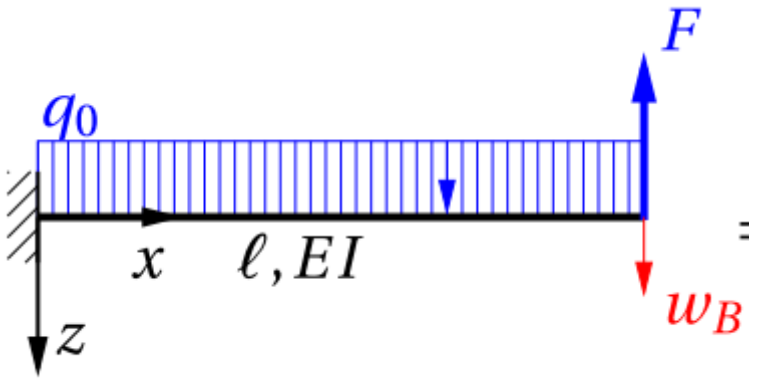
Implemented by Kay Graubmann, student at THB, Innovationspreis 2013

SMath Studio Development smath.info

SMath Studio With Maxima

Application: Symbolic solution of systems of equations:





$$w'(x) := \frac{1}{EI}\cdot\left(\left(-\frac{q_0}{6}\right)\cdot(L-x)^3 + \frac{F}{2}\cdot(L-x)^2\right) + C_1$$

$$w(x) := \frac{1}{EI}\cdot\left(\frac{q_0}{24}\cdot(L-x)^4 - \frac{F}{6}\cdot\left((L-x)^3\right)\right) + C_1\cdot x + C_2$$

$$\text{Solve}\left(\begin{cases} w(0)=0 \\ w'(0)=0 \\ w(L)=0 \end{cases} ; \begin{cases} C_1 \\ C_2 \\ F \end{cases}\right) = \begin{cases} \left(C_1 = \left(-\frac{q_0\cdot L^3}{48\cdot EI}\right)\right) \\ \left(C_2 = \frac{q_0\cdot L^4}{48\cdot EI}\right) \\ \left(F = \frac{3\cdot q_0\cdot L}{8}\right) \end{cases}$$

SMath Studio and FEA

Gesamtbreite der Federblätter $b := 250\ mm$

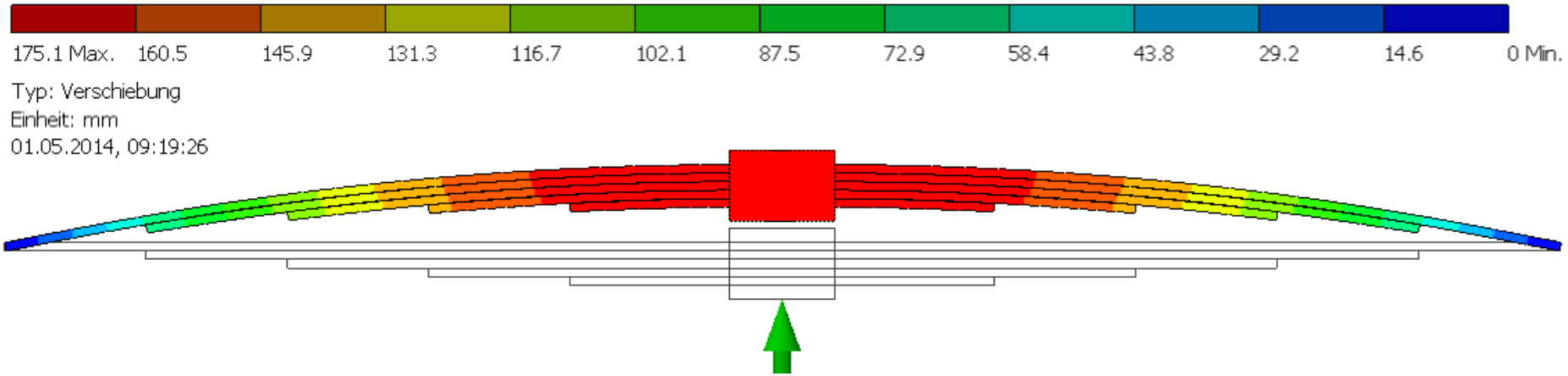
Dicke der Federblätter: $t := 6\ mm$

E-Modul $E := 210\ GPa$

Kraft am Federende $P := \frac{5000}{2}\ N$

Freie Federlänge (einseitig) $L := \left(\frac{1100}{2} - 37{,}5\right) mm = 512{,}5\ mm$

Durchbiegung $w := \frac{6 \cdot P \cdot L^3}{E \cdot b \cdot t^3} = 178\ mm$



Hand Calc Replacement with SMath Studio

Application in the Mech.Eng. Program:

- Engineering Mechanics 1 und 2 (Prof. Kraska): Reference solutions for exercises
- Mechanical Design (Hr. Rotsch): Application for part dimensioning
- Product Development (3. term): Introduction to SMath as a tool for documenting engin. calculations
- Finite Elements Methode (6. term): Analytic double-check of simulations
- Students use SMath Studio for projects in various subjects

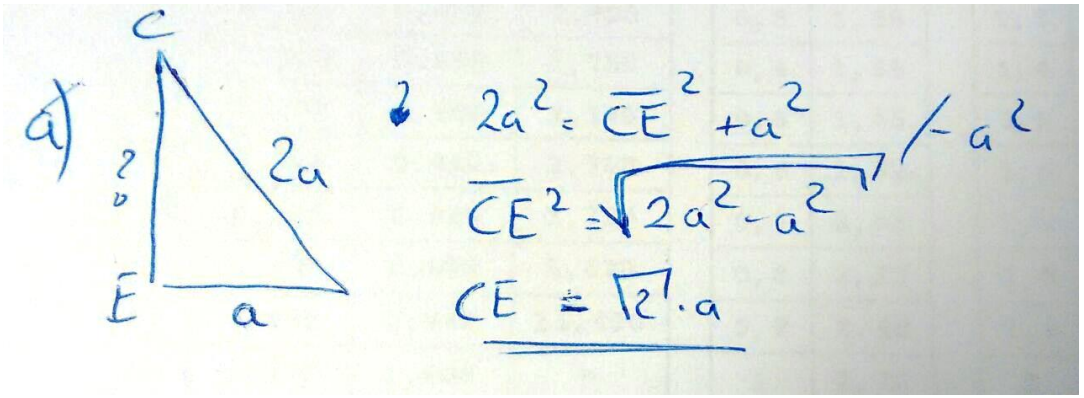
So everyone is happy now?

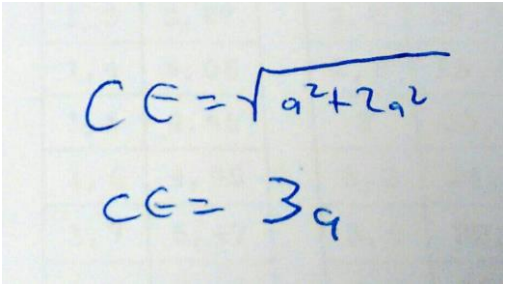
Dawn of the Reality

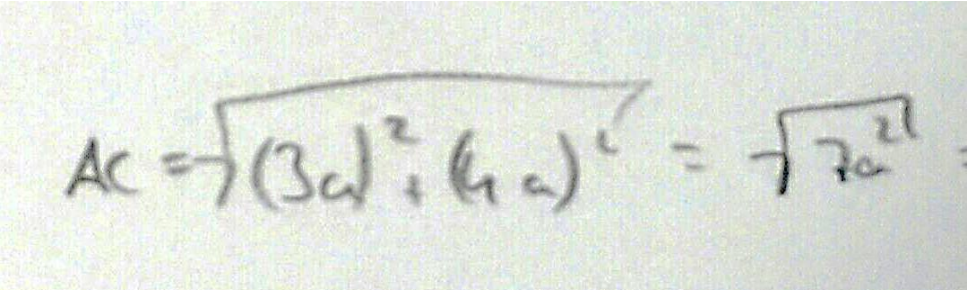
- THB students are very heterogeneous
- Formal requirements for entry do not imply fitness for anything
- Choosing engineering as subject does not imply
  - any particular skill in that area
  - any idea of what engineering is
  - the awareness of how important math is
  - readiness for hard work

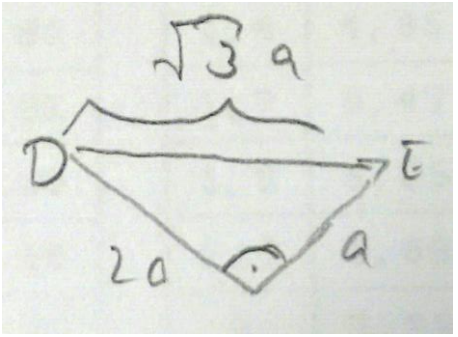
Observations – best of

1st year exam of Engineering Mechanics





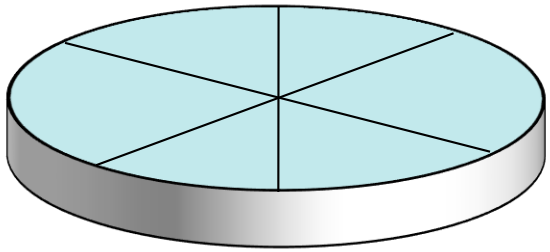




Observations

Considerable amount of first year students show

- No active skills of hand calc (very slow, many mistakes)
- Dependence on pocket calculator even for trivial operations like 1/2+1/3
- No sketching skills (in particular 3D views)



Where Math Software Doesn‘t Help

$$\frac{c_{critTi}}{c_{critSc}} = 79,3719$$

„The critical crack length of Ti is 79% higher than that of Silicon carbide“

$$\frac{c_{critTi}}{c_{critSc}} = 79,3719$$

Die kritische Risslänge der Titanlegierung ist 79% größer als die des Siliciumcarbids. Es ist also deutlich zäher.

Resulting Problems

Teacher/student speed mismatch in lectures:

- Ideal: Understanding while taking notes
- Real: Don‘t keep up, no questions, smartphone screenshots

Complaints on high workload

- Homework assignments take a lot of time
- Frustration by poor performance

Slow hand calc means slow thinking

- Bad performance in exams
- Resistance to establish and use math models
- Low ability and eagerness to critically judge results

Consequence

We can't tolerate slow hand calc!

- No account for slow thinking in lectures and exercises
- Communicate the essential set of skills and facts to know by heart
- **Ban of pocket calculators from exams**

Those who can't keep up:

- Need problem-awareness
- Need training

→ **Boot Camp**

http://i41.tinypic.com/x3wufl.jpg

Pocket Calculator Ban

Challenges to the teacher:

- Don‘t waste time in exercises and lectures.
- Provide and demonstrate techniques for efficient estimates (cheat sheet)
- Provide mnemonics
- Use handcalc-friendly figures
- Appropriate evaluation of exams
    - Deriving equations versus making estimates,
    - Handling of mistakes

Pocket Calculator Ban

Substitutes

- Approximate division and multiplication

$$\frac{a + x\%}{b + y\%} \approx \frac{a}{b} + x\% - y\%$$

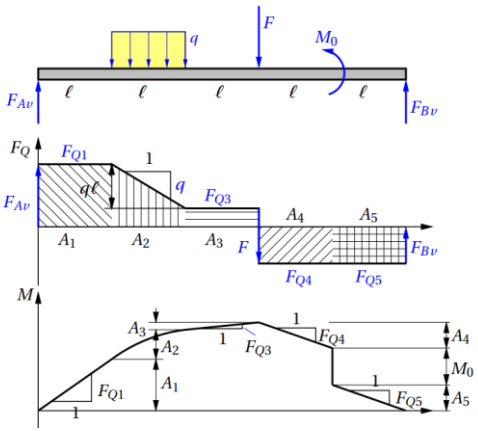
- Linearizations

$$\sqrt{a^2 + x} \approx a + \frac{1}{2} \cdot \frac{x}{a}$$

- Tables and interpolation

$\frac{\varphi}{°}$	$\frac{\varphi}{rad}$	sin(φ)	tan(φ)
0	0,000	0,000	0,000
10	0,175	0,174	0,176
20	0,349	0,342	0,364

- Graphical Methods



Pocket Calculator Ban

Chances

- Surprise: Wow, how close these estimates can be!
- Pride: Wow, I can do math!
- Increasing mental fitness and self confidence
- Students get used to linearisations as a powerful tool from the very beginning

To Learn By Heart

n	1	2	3	4	5	6	7	8	9	10
1	1	2	3	4	5	6	7	8	9	10
2		4	6	8	10	12	14	16	18	20
3			9	12	15	18	21	24	27	30
4				16	20	24	28	32	36	40
5					25	30	35	40	45	50
6						36	42	48	54	60
7							49	56	63	70
8								64	72	80
9									81	90
10										100

n	n^3	$1/n$
1	1	1,000
2	8	0,500
3	27	0,333
4	64	0,250
5	125	0,200
6	216	0,167
7	343	
8	512	0,125
9	729	
10	1000	0,000

π	3,14
2π	6,28
$\pi/2$	1,57
$\sqrt{2}$	1,414
$\sqrt{3}$	1,732

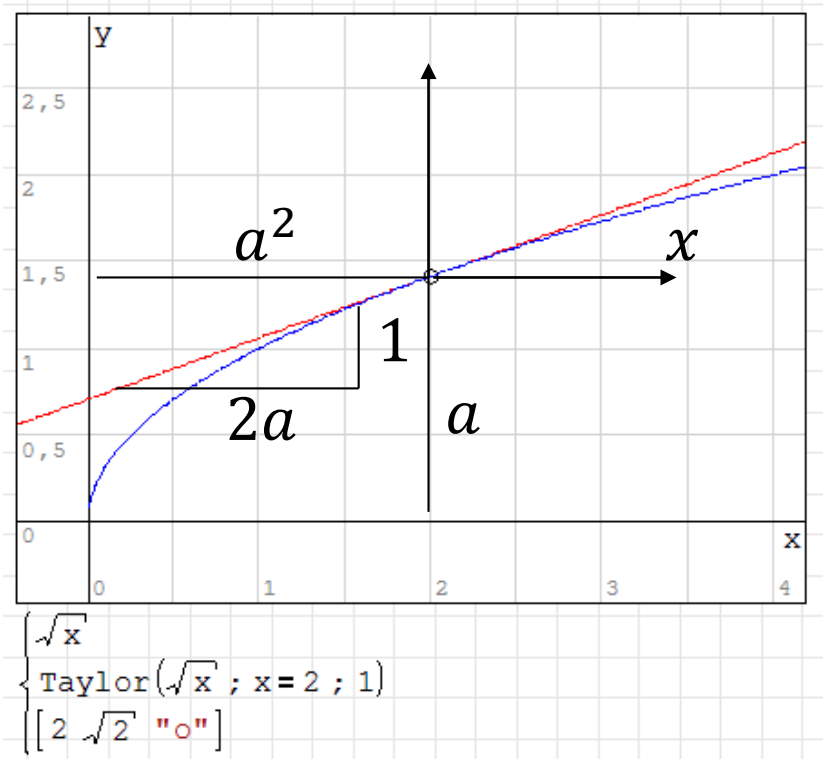
To Learn By Heart

Grad	rad		sin			cos	tan
0°	0	0,00	$\sqrt{0}/2$	0	0,000	1	0
30°	$\pi/6$	0,534	$\sqrt{1}/2$	$1/2$	0,500	$\sqrt{3}/2$	$1/\sqrt{3}$
45°	$\pi/4$	0,785	$\sqrt{2}/2$	$1/\sqrt{2}$	0,707	$1/\sqrt{2}$	1
60°	$\pi/3$	1,05	$\sqrt{3}/2$	$\sqrt{3}/2$	0,866	$1/2$	$\sqrt{3}$
90°	$\pi/2$	1,57	$\sqrt{4}/2$	1	1,000	0	∞

mnemonic

Square Root Demo

$$\sqrt{a^2 + x} \approx a + \frac{1}{2} \cdot \frac{x}{a}$$



$$\sqrt{71} = \sqrt{64 + 7}$$

$$\sqrt{71} = \sqrt{64 + 7} \approx 8 + \frac{1}{2} \cdot \frac{7}{8}$$

$$\sqrt{71} = \sqrt{64 + 7} \approx 8 + \frac{1}{2} \cdot \frac{7}{8} \approx 8{,}5$$

$\sqrt{71} = 8{,}4261$

Summary

- Part of the first year students of engineering is close to **mathematical illiteracy**
- **Initial expectation**: Math software compensates for weak math skills and let the engineers focus on the design.
- **Observation**: Weak math skills strongly correlate with slow thinking and lack of critical review.
- **Training** is worth the effort.
- **Impact of math software** (like with many other tools)
  - Strong engineers become more efficient and powerful. SMath Studio is for them!
  - Weak engineers become… Dangerous!

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Vielen Dank für Ihre Aufmerksamkeit

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