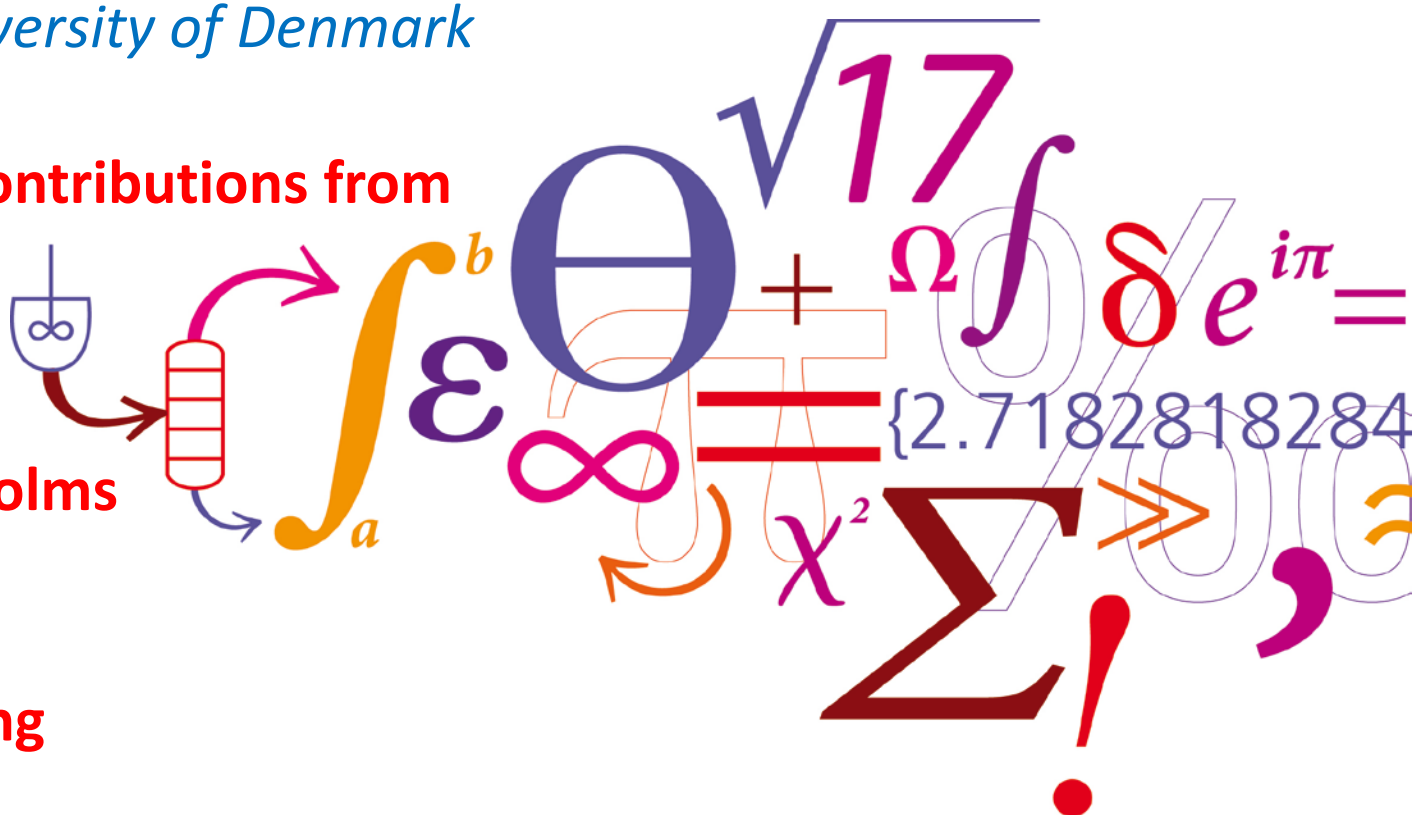
Teaching Chemical Engineering Thermodynamics at DTU

How, Why, Impressions, Some Personal Thoughts

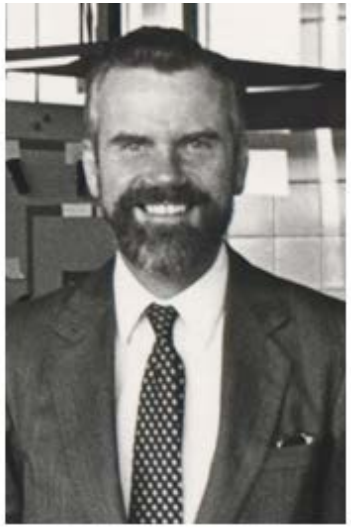
Georgios M. Kontogeorgis
Center for Energy Resources Engineering (CERE)
Department of Chemical and Biochemical Engineering
Technical University of Denmark

With great contributions from All "Thermo" Teachers:

Nicolas von Solms
Kaj Thomsen
Wei Yan
Xiaodong Liang



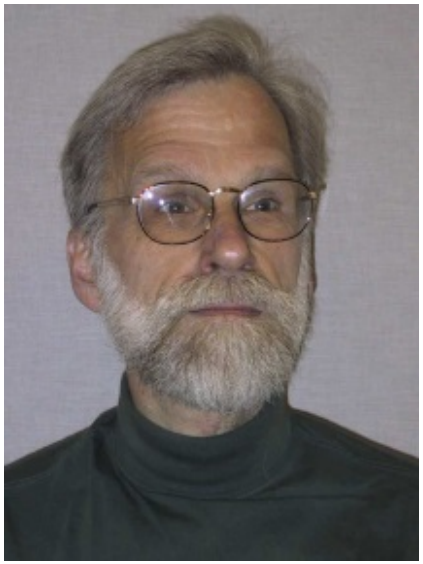
The old guard (our/my teachers)



Fredenslund

Rasmussen

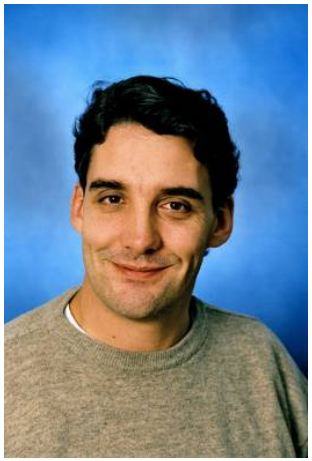
Michelsen



Mollerup

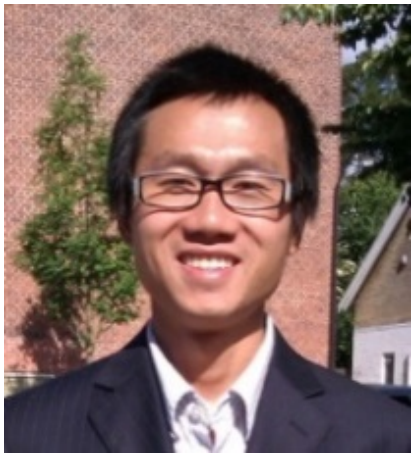
The new generation

Thomsen



von Solms

Yan



Liang

Outline

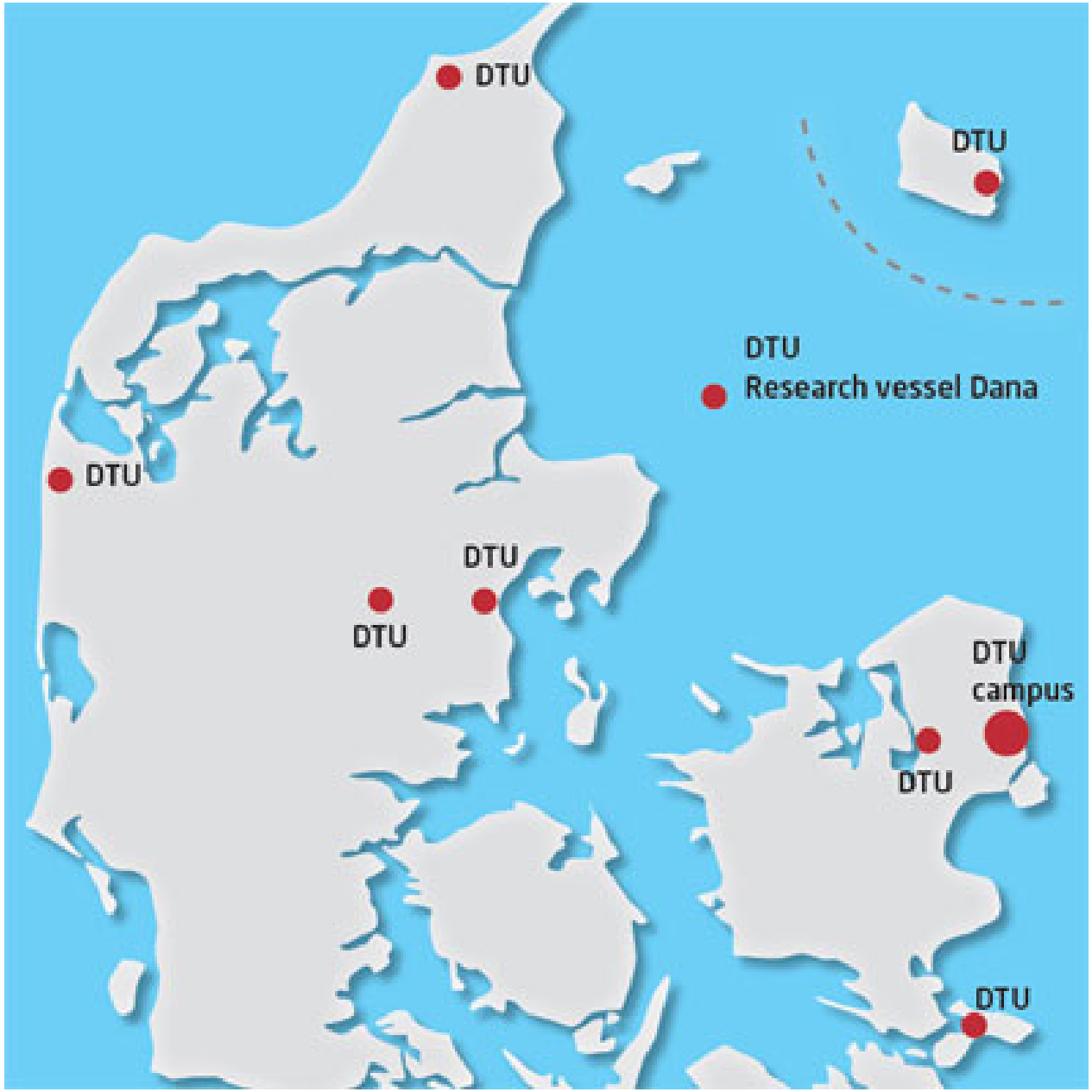
- Education and Teaching at DTU
- Teaching of Thermodynamics at DTU
- Comparison to other places (vs. survey from WP – *Chem.Eng.Educ., 2010, 44(1): 35*)
- Impressions and personal thoughts
- Outlook for future and

Conclusions

DTU

- Founded in 1829 by the Danish physicist Hans Christian Ørsted
- Moved to Lyngby in the sixties - 10 km north of Copenhagen
- Leading centre of engineering education and research in Denmark
- Focus on Education – Research – Innovation and Service to authorities
- 6000 students
- 700 Ph.d. students
- 4600 employees
- 19 departments
- Education: 9 B.Eng., 15 B.Sc., >30 M.Sc.

DTU is a National university with several locations



DTU's 19 Departments

DTU Chemical Engineering

DTU Chemistry

DTU Civil Engineering

DTU Environment

DTU Systems Biology (now 2)

DTU Food

DTU Physics

DTU Electrical Engineering

DTU Fotonik

DTU Nanotech

DTU Energy Conversion

DTU Aqua

DTU Management Engineering

DTU Mechanical Engineering

DTU Wind Energy

DTU Space

DTU Transport

DTU Veterinary

DTU Compute

14 challenges of engineering in the 21st century

- Make solar energy economical
- Provide energy from fusion
- Develop carbon sequestration methods
- Manage the nitrogen cycle
- Provide access to clean water
- Restore and improve urban infrastructure
- Advance health informatics
- Engineer better medicines
- Reverse-engineer the brain
- Prevent nuclear terror
- Secure cyberspace
- Enhance virtual reality
- Advance personalized learning
- Engineer the tools of scientific discovery

http://www.engineeringchallenges.org/cms/challenges.aspx
(US Academy of Engineering)

Education at DTU

- Bologna system: 3 (BSc) + 2 (MSc) + 3 (PhD)
- Alternatively 3.5 B.Eng. (Diplom)
- Education belongs to DTU – not the Departments !
- All students choose a BSc/B.Eng., then M.Sc.
- B.Sc./B.Eng. in Danish (in principle)
- M.Sc. in English – many foreign students (> 30%)
- No Tuition Fees for EU students
- 3-year PhD studies after M.Sc.
- 5 year studies from abroad recognized as M.Sc. at DTU

Udenlandske studerende strømmer til Danmark

Uddannelse. I løbet af 10 år er antallet af internationale studerende, der tager hele deres uddannelse i Danmark, mere end tredoblet.

PELLE DAM
pelle.dam@mx.dk

JEPPE FINDALEN
jeppe.findalen@mx.dk

Antallet af udenlandske studerende, der tager hele deres uddannelse i Danmark, er mere end tredoblet i løbet af 10 år. Det viser nye tal fra Uddannelsesministeriet, og den nyhed vækker begejstring på begge sider af det politiske spektrum.

»Det viser, at det fokus, som København har haft de seneste år på at få flere internationale studerende til byen, er lykkedes. Vi har brug for internationale studerende og erhvervsfolk for at skabe mere vækst og flere job i Danmark,« siger Københavns socialdemokratiske overborgmester, Frank Jensen.

Venstres SU-ordfører, Mads Rørvig, er på samme linje:

»Forudsætningen for, at vi kan blive klogere, er, at vi har noget input fra udlandet, så det synes jeg er rigtig, rigtig fint,« siger han.

Hvorfor Danmark

Men hvorfor vælger de unge lige præcis Danmark? Medlemmerne af netværket Youth Goodwill Ambassador Corps, der består af 200 internationale studerende fra hele verden, angiver tre grunde:

Det danske velfærdssamfund. Den grønne agenda – vindmøller, elbiler og folk, der cykler rundt i rene gader. Samt læringsformen, der er meget løsningsorienteret og anvender masser af gruppearbejde.

Det forklarer Nikolaj Lubanski, der snart tiltræder som direktør for Copenhagen Capacitys talentområde og dermed blandt andet er ansvarlig for netop ambassadørnetværket.

»En ting er, at det er dødinteressant, at de tager hele deres uddannelse i Danmark, men det, der jo også er interessant, er at få dem integreret i arbejdsmarkedet, så de bliver her bagefter og bidrager til samfundsudviklingen,« påpeger han og tilføjer:

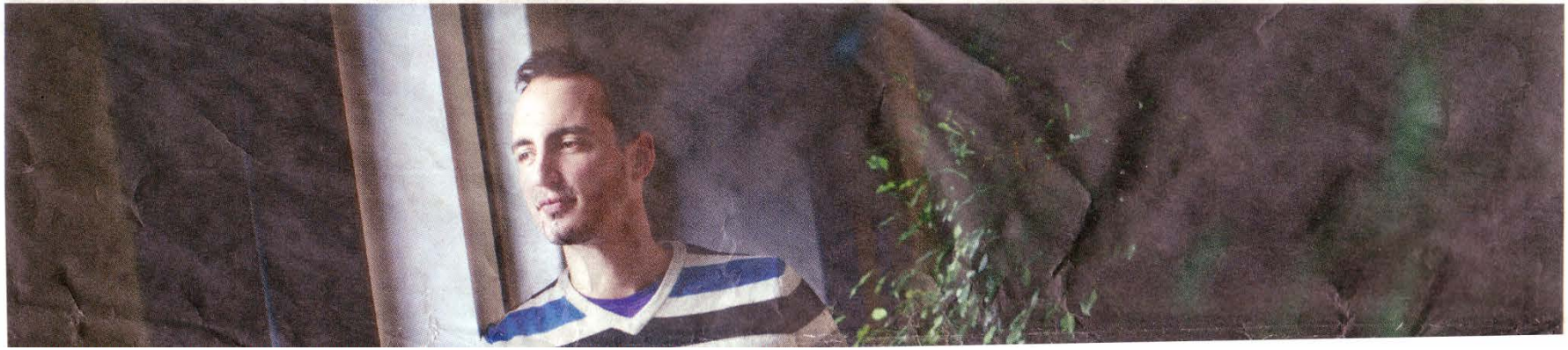
»Det handler om at lave kontakter mellem uddannelsesmiljøerne og virksomhederne. For eksempel at give mulighed for, at man kan tage praktik eller lave opgaver på virksomheder.«

Et af de steder, hvor antallet af udenlandske studerende, der færdiggør hele deres uddannelse i Danmark, er eksploderet, er VIA University College i Midtjylland, hvor man kan læse en lang række korte og mellemlange videregående uddannelser.

»Vi håber meget, at de bliver i Danmark og bidrager til arbejdsstyrken bagefter,« forklarer Konstantin Lassithiotakis, direktør i Teknisk/Merkantil Højskole, som er en del af VIA og et af de steder med stor koncentration af udenlandske studerende.

»Vi har et tæt samarbejde med virksomheder, som er interesserede i udenlandske studerende. Både i forhold til praktik og med henblik på at ansætte dem, når de er færdiguddannede – enten i Danmark eller i den studerendes hjemland, hvor den danske virksomhed så er etableret,« tilføjer han.

VIA regner med, at mindst en tredjedel af de udenlandske studerende ender med at blive ansat i en dansk virksomhed – enten i Danmark eller i udlandet.



Thanos Arvanitidis, DTU M.Sc. student

B.Sc. 15 programs

- Bioteknologi
- Byggeteknologi
- Bygningsdesign
- Design og innovation
- Elektroteknologi
- Fysik og nanoteknologi
- Geofysik og Rumteknologi
- IT og kommunikationsteknologi
- Kemi og teknologi
- Matematik og teknologi
- Medicin og teknologi
- Miljøteknologi
- Produktion og konstruktion
- Softwareteknologi
- Teknisk biomedicin (tidl. Sundhed og Produktion)

Bachelor of Science (180 ECTS)

Bachelor of Science in Engineering = 180 points

Natural sciences 45 ECTS points	Projects and general courses 45 ECTS points
Technological specialisation courses 45 ECTS points	Electives courses 45 ECTS points

M.Sc. 28 programs (and more...)

Advanced and Applied Chemistry
Aquatic Science and Technology
Architectural Engineering
Biotechnology
Chemical and Biochemical Engineering
Civil Engineering
Design and Innovation
Earth and Space Physics Engineering
Electrical Engineering
Engineering Design and Applied Mechanics Engineering Management
Environmental Engineering
Food Technology
Materials and Manufacturing Engineering
Medicine and Technology
Petroleum Engineering
Pharmaceutical Design and Engineering
Photonics Engineering
Physics and Nanotechnology
Sustainable Energy
Systems Biology
Transportation and Logistics
Wind Energy

M.Sc. Structure (120 ECTS)

Master of Science in Engineering = 120 points

General competence courses 30 ECTS points	Master thesis project Min 30 ECTS points
Technological specialisation courses 30 ECTS points	Electives courses Max 30 ECTS points

Teaching at DTU – the 4-hour blocks!

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8.00-12.00	1A	3A	5A	2B	4B
13.-17.00	2A	4A	5B	1B	3B

5p. + 7.5p. courses: one module

10p. course: two modules

Grade scale

Old scale:	13-skala	00	03	5	6	7	8	9	10	11	13
New scale:	7-trins	-3	00	00	2	4	7	7	10	12	12

Karakter	Betegnelse	ECTS
12	Den fremragende præstation	A
10	Den fortrinlige præstation	B
7	Den gode præstation	C
4	Den jævne præstation	D
02	Den tilstrækkelige præstation	E
00	Den utilstrækkelige præstation	Fx
-3	Den ringe præstation	F

Special characteristics of teaching and examinations at DTU

- Campusnet – DTU intranet where all material is uploaded
- All courses are evaluated every semester (see next)
- Most exams are ”open book” exams
- Written 4-h exams in some courses
- Many project-related courses, some with group work (4-5 students)
- All project reports uploaded in Campusnet for ”plagiarism” check
- Typically for all examinations: answers corrected by the teacher(s) + external (outside DTU) examiner
- DTU often experiments with new things – now it is ”digital” (computer-based) exams (in few years for all written exams) – we have also midterm evaluation and exam evaluation

Show selected

Results : 28315 Applied Colloid and Surface Chemistry E12

Schema A

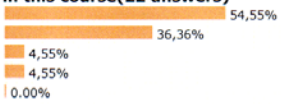
Course evaluation

Statistics

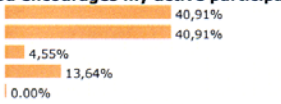
48 could answer this evaluation form
22 have answered this evaluation form
1 did not follow the course
45,83% answer percentage : 22 / (48 - 1)

1 Form A

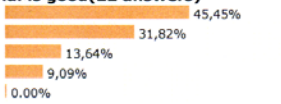
1 . 1 I think I am learning a lot in this course(22 answers)



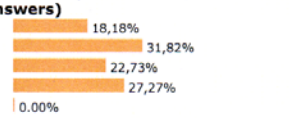
1 . 2 I think the teaching method encourages my active participation(22 answers)



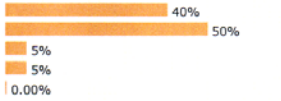
1 . 3 I think the teaching material is good(22 answers)



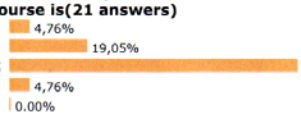
1 . 4 I think that throughout the course, the teacher/s have clearly communicated to me where I stand academically(22 answers)



1 . 5 I think the teacher/s create/s good continuity between the different teaching activities(20 answers)



1 . 6 5 points is equivalent to 9 hrs./week (45 hrs./week in the three-week period). I think my performance during the course is(21 answers)



1 . 7 I think the course description's prerequisites are(21 answers)

1 . 8 In general, I think this is a good course(22 answers)

Results : 28315 Applied Colloid and Surface Chemistry E12

Schema B

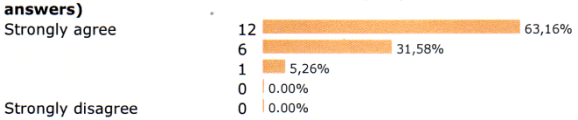
Georgios Kontogeorgis: Teacher

Statistics

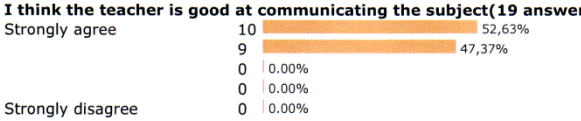
48 could answer this evaluation form
19 have answered this evaluation form
1 did not follow the course
39,58% answer percentage : 19 / (48 - 1)

1 Lecture/Classroom instruction

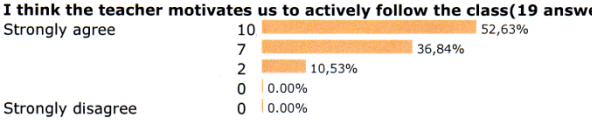
1 . 1 I think that the teaching gives me a good grasp of the academic content of the course(19 answers)



1 . 2 I think the teacher is good at communicating the subject(19 answers)

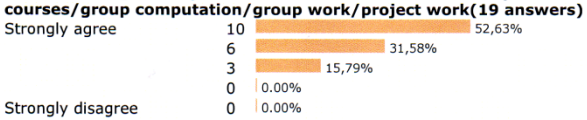


1 . 3 I think the teacher motivates us to actively follow the class(19 answers)

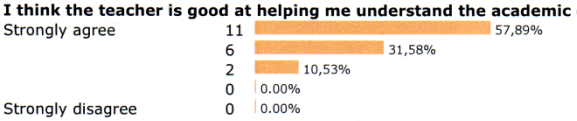


2 Practical assignments/Lab courses/Course tutorial/Group work/Project work

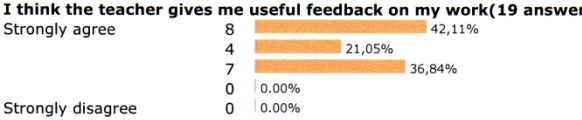
2 . 1 I think that I generally understand what I am to do in our practical assignments/lab courses/group computation/group work/project work(19 answers)



2 . 2 I think the teacher is good at helping me understand the academic content(19 answers)

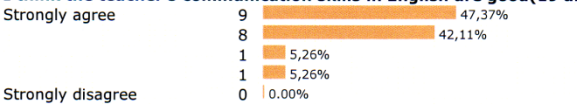


2 . 3 I think the teacher gives me useful feedback on my work(19 answers)



3 The teachers communication skills in English

3 . 1 I think the teacher's communication skills in English are good(19 answers)



4 Qualitative comments

4 . 1 You can write additional comments on the teaching of the teacher in question here(3 answers)

- Jeg er blevet overrasket over at vi skal lave så mange udledninger i regneopgaverne. Jeg skriver kommentaren her da det har været i dine regneopgave at udledningerne har været.

Results : 28315 Applied Colloid and Surface Chemistry E12

Schema C

Comments

Statistics

48 could answer this evaluation form
17 have answered this evaluation form
1 did not follow the course
35,42% answer percentage : 17 / (48 - 1)

1 Qualitative comments

1 . 1 What went well – and why?(6 answers)

- Generally, I like the course and how the topics are linked to industrial applications each lecture.
- Super kursus, som er rigtig spændende.
- Good lectures with variation between exercise and presentation. The topic is difficult with a lot of theory and equations, but it is given in a good way.
- Jeg synes forholdet mellem forlæsning og grupperegning er godt så man har god tid til at nå at regne opgaverne.
- Det er godt med de mange øvelser, så man forstår stoffet. En ren teoretisk gennemgang, ville ikke være tilstrækkeligt.

  Og det er ligeledes fint at lektionen deles op, så man først får undervisning, derefter regneopgaver, og derefter undervisning igen. Det holder een på dupperne.
- The course has a very good structure - alternating lectures and problem solving.

1 . 2 What did not go so well – and why?(4 answers)

- Unfortunately, I think the book is really difficult to read, but I like the notes.
- Some of the slideshows were long and contained some irrelevant slide, and also slides that basically said the same thing. You could make it a bit simpler and a bit more concrete.
- Der er ikke så meget ping-pong mellem lærer og elever.
  Underviserne kunne godt opfordre til flere spørgsmål undervejs.
- I did not particularly enjoy the course just because in general I find that I do not enjoy chemistry.
  Also, having a four-hour final exam worth 100% of the final grade is too stressful.

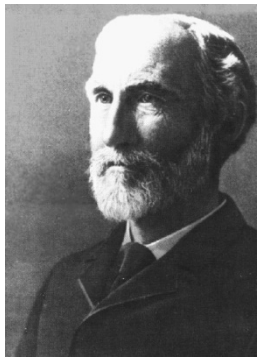
1 . 3 What changes would you suggest for the next time the course is offered?(6 answers)

- I would prefer one calculation session each time instead of two separate sessions.
- Jeg vil foreslå at fjerne de blyanter, der er på slides og i bogen. De kan godt få det til at virke lidt uoverskueligt.
- You tend to lose the big picture during the semester due to all the equations and teory. (Especially in the major topics as stability which is divided in four part). After each topic make an overview of the essential containing the must important equations and when to use them. Hand it out to the students, and it will be a valuable tool for the exam and the future.
- Søren Kiil viste ved første undervisningsgang hvordan mælk kan klumpe sammen, ved blot at ændre pH værdien. Dette lille eksempel var godt, og nogle flere tilsvarende eksempler kunne være interessant/relevante.
- possibly try to phase out the book and make the notes a bit more in depth.. having two sets of literature where there are fairly many overlaps gives a bit much unessesary reading. could be nice to have the answers to the problems in the notes as well so it is easily seen if the problem is solved correctly (and still having the full solutions uploaded later..)
- Offer assignments that are worth a certain percentage of the course grade so that the exam is not fully weighted.

Teaching Thermodynamics – at a glance !

Course Number	Name	Type (ECTS)	Content
28221 28322	Chemical Eng. Thermodynamics	BSc (5) Beng (5)	Properties of pure compounds and mixtures, Laws of thermodynamics
28423	Phase Equilibria for non-ideal mixtures	MSc (5)	Thermodynamic models
28909	Thermodynamic models: Fundamentals and Computational aspects	PhD (7.5) – August course	Coding models, flash routines
28928	Electrolyte Thermodynamics	PhD (7.5) - Any time	Electrolytes
28917	Statistical Thermodynamics	PhD (5)	Statistical aspects
26222	*Physical Chemistry 2*	*BSc (5)*	*Gibbs phase rule, Mixtures, activities, Electrochemistry*

Gibbs solved 2/3 of the thermodynamic problem 150 years ago!

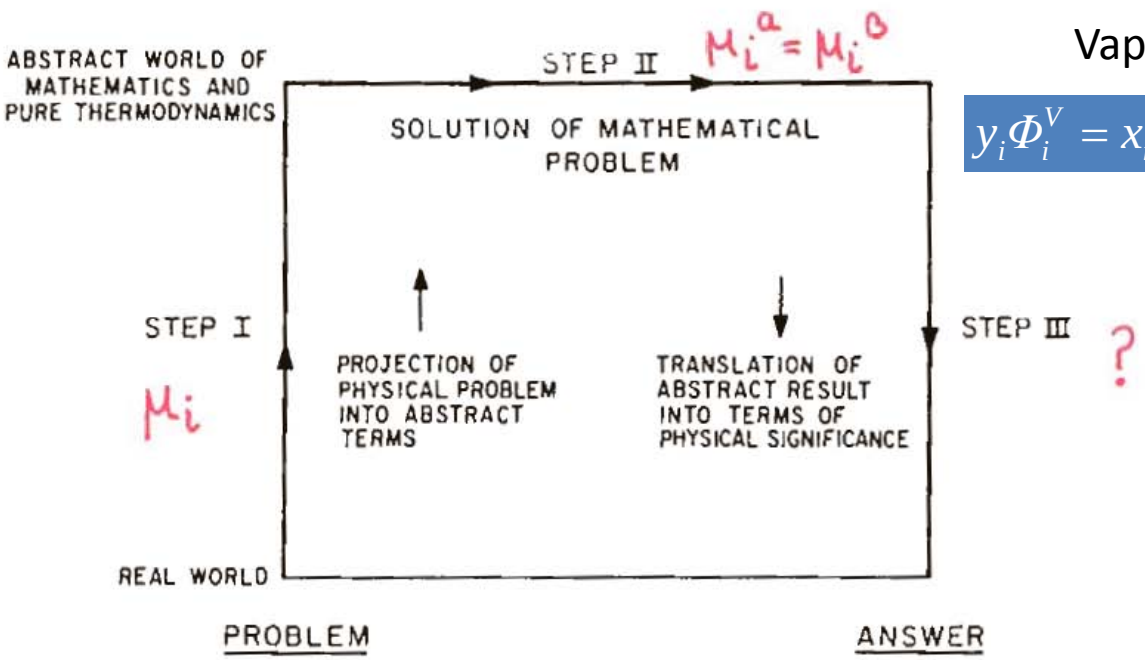


J.Willard Gibbs
One of the
Greatest
Scientists
Of All times!

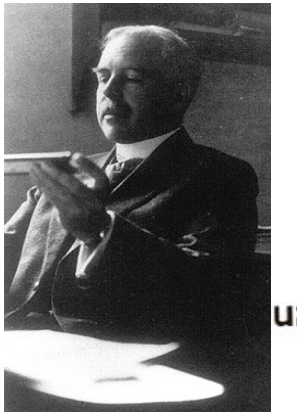
$$f_i^a = f_i^b \qquad i = 1,2,\ldots,N$$

Vapor-liquid equilibria

$$y_i \Phi_i^V = x_i \Phi_i^L \qquad i = 1,2,\ldots,N$$



ure 1-3 Three-step application of thermodynamics to phase-equilibrium problems.



Gilbert Lewis
(1875-1946)

We are still struggling with the third step !!

Teaching Thermodynamics – Content

Course Number	Name	Content
28221 28322	Chemical Eng. Thermodynamics	Pure compounds, mixtures, cycles, flash calculations, process applications e.g. refrigeration, ternary LLE, acivity coefficient models
28423	Phase Equilibria for non-ideal mixtures	Cubic and non-cubic EoS (SAFT, CPA), mixing rules for cubic EoS, polymers, environmental thermodynamics, electrolytes
28909	Thermodynamic models: Fundamentals and Computational aspects	Computational methods : PT flash, Multiphase flash, stability analysis, chemical equilibrium
28928	Electrolyte Thermodynamics	Electrolytes fundamentals, phase diagrams and models
28917	Statistical Thermodynamics	Fundamentals, CS EoS, Monte Carlo simulations, SAFT

Teaching Thermodynamics – How

Course Number	Name	Teaching form	Assessment
28221 28322	Chemical Eng. Thermodynamics	Lectures + computer-based problems using spreadsheets (excel) for simulation	Reports + oral examination
28423	Phase Equilibria for non-ideal mixtures	Lectures + classroom exercises + computer exercises (SPECS)	Evaluation of exercises + final report (on topic of interest of students)
28909	Thermodynamic models: Fundamentals and Computational aspects	Lectures + computer exercises in teams of two – own programming	Evaluation of exercises + reports
28928	Electrolyte Thermodynamics	Own study of Notes	Evaluation of exercises + reports – takes 2-3 months to complete the course
28917	Statistical Thermodynamics	Lectures, projects, homework problems, self-study	Evaluation of exercises + reports - projects

Teaching Thermodynamics – Special Issues

Course Number	Name	Special Issues	Comments
28221 28322	Chemical Eng. Thermodynamics	Use of excel modules No written examination – only reports	Own teaching material + one other book
28423	Phase Equilibria for non-ideal mixtures	Use of SPECS	Own teaching material
28909	Thermodynamic models: Fundamentals and Computational aspects	Own coding (Fortran, MATLAB), many externals incl. Industrial participants	Own teaching material
28928	Electrolyte Thermodynamics	On-line course	Own teaching material
28917	Statistical Thermodynamics	Sometimes student-defined projects	Book from literature

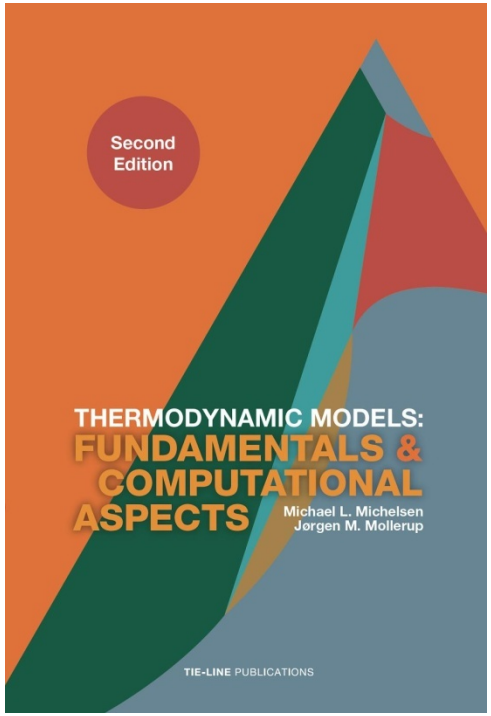
Teaching Thermodynamics – Book

Course Number	Name	Book
28221 28322	Chemical Eng. Thermodynamics	Elliott & Lira + Michelsen Notes
28423	Phase Equilibria for non-ideal mixtures	Kontogeorgis & Folas K. Thomsen Notes
28909	Thermodynamic models: Fundamentals and Computational aspects	Michelsen & Mollerup
28928	Electrolyte Thermodynamics	K. Thomsen Notes
28917	Statistical Thermodynamics	McQuarrie

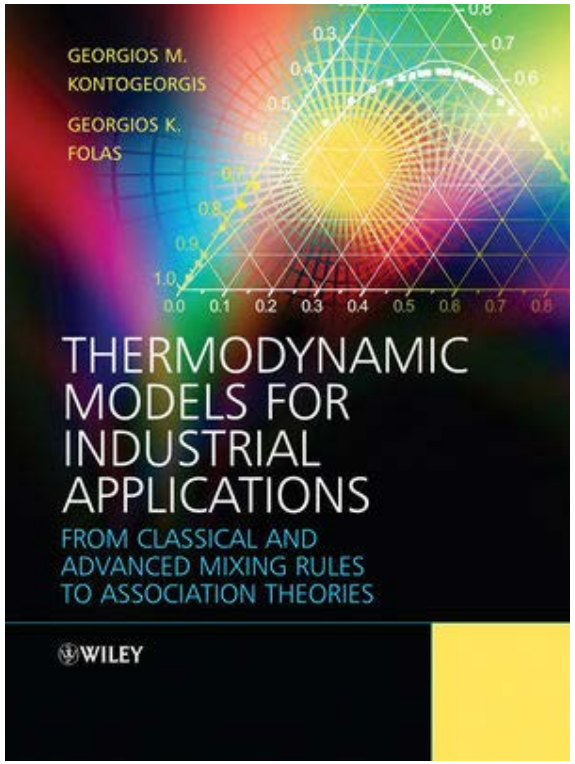
Books in Thermodynamics (by CERE staff)

Mostly used in the PhD Course:

28909 (2007)



28423 (2010)



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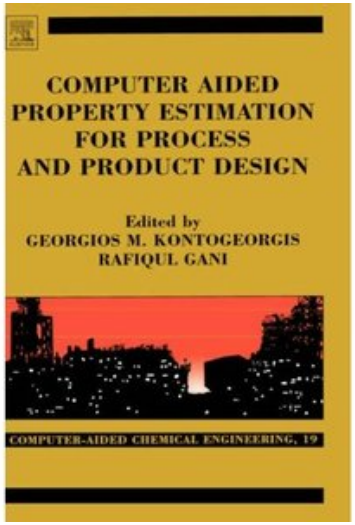

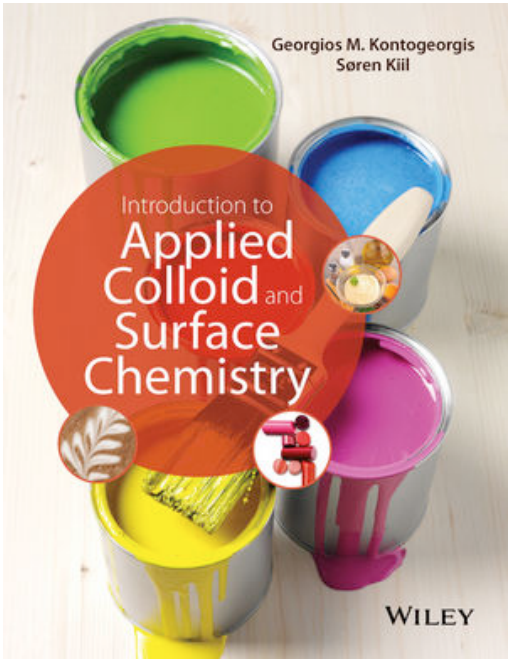

Kaj Thomsen : Notes on Electrolyte Thermodynamics (very extensive) + special course with exercises

M.L.Michelsen : Notes on Applied Thermodynamics with exercises

The Michelsen course… without Michelsen (for second time)

24 participants, 4 from companies, 8 countries

+ Xiaodong
Alexander
Philip
Duncan
Louise
Christian

Photos: Christian Carlsson

Algorithms-Models PhD Course

Participants from 25+ Different Countries in 6 years!

	2008	2009	2010	2011	2012	2014	2015
Participants – Total	24	29	17	26	18	29	23
From Industry	4	13	8	9	8	4	2
From academia	14	9	3	14	5	17	10
From CERE	3	5	4	2	3	8	5
From DTU – other	3	2	2	1	2	-	6
How many countries-Affiliation	10	10	9	12	8	10	9

DTU vs. Rest of the world (survey)

- We have also ”the two basic” courses – but also a PhD course on computational aspects
- We have more additional specialized thermodynamic courses
- Not much on biological systems (similar to Europe)
- SM and MS – to limited degree but we have them
- Similarly to others, no experimental element in the courses (despite much experimental thermodynamics in research)
- More PBL in USA than in Europe – we also are based much on PBL

DTU vs. Rest of the world (survey) – The Books

- We use Elliott and Lira like 14 US and none European universities – in one of the courses
- We do not use Sandler and have abandoned long time ago the most popular Smith-van Ness-Abbott book
- We recommend Prausnitz el al. in our advanced courses
- Atkins is used in Physical Chemistry courses – not in thermodynamics
- We have lots of own books/own book material

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Industrial Requirements for Thermodynamics and Transport Properties

Eric Hendriks,*,† Georgios M. Kontogeorgis,‡ Ralf Dohrn,§ Jean-Charles de Hemptinne,∥ Ioannis G. Economou,⊥ Ljudmila Fele Žilnik,# and Velisa Vesovic∇

Shell Global Solutions, Shell Technology Centre Amsterdam, Grasweg 3, 1031 HW Amsterdam, The Netherlands, Centre for Energy Resources Engineering (CERE), Department of Chemical and Biochemical Engineering, Technical University of Denmark, DK-2800, Lyngby, Denmark, Bayer Technology Services GmbH, Process Technology, Kinetics, Properties & Modeling, Building B310, D-51368 Leverkusen, Germany, IFP, 1& 4 Avenue de Bois-Préau, 92852 Rueil-Malmaison Cedex, France, The Petroleum Institute, Department of Chemical Engineering, P.O. Box 2533, Abu Dhabi, United Arab Emirates, National Institute of Chemistry, Department of Catalysis and Reaction Engineering, P.O. Box 660, SI-1001 Ljubljana, Slovenia, and Department of Earth Science and Engineering, Imperial College London, London SW7 2AZ, United Kingdom

Project carried out by the Task Group on Industrial Perspectives under the Working Party on Thermodynamics and Transport Properties (http://www.wp-ttp.dk) of EFCE

Education - I

Education: Make people aware of the practical consequences of good and wrong thermodynamics – at all levels (undergraduate, postgraduate, professional)

"The students should e.g. be taught in which cases results are reliable and how to distinguish between a good and a bad process"

Molecular simulation: A true effort is needed in order to make these tools readily available to industry (non-experts) – Currently Molecular simulation techniques do not appear to receive high industrial interest

What can be done next ? – Bridge the gap between academia and industry

- Education
  - Define some minimum knowledge required for Chem Eng, and propose ways to achieve it
  - Promote the employment of young experts (PhD) by chemical industries
  - Propose short courses for professionals to the basics of molecular thermodynamics & more
- Continue and improve communication
  - National WP meetings & co-ordination with EFCE
  - European workshop (ProcessNet in Würzburg Feb 2010) & coming ones (Lyon, 2012, March 19-20)
- More discussion with industry – more/encourage participation of industrial experts in Conferences on Thermodynamics and Transport properties *(do we have too many conferences ?)*

Conclusions & Some personal thoughts

- At DTU we have three basic thermodynamic courses at BSc/BEng, MSc and PhD level
- About 15-30 students/semester follow these courses
- It is actually possible to graduate as Chemical Engineer from DTU without any of these ”basic” thermodynamic courses (due to the system we have)
- Courses at DTU are not always taken at a ”specific order” (for the BSc and MSc levels)
- Computational tools and PBL are used in all of these courses - diverse tools are used (Excel modules, FORTRAN, MATLAB, in-house software/SPECS,…)
- All of these courses are assessed based on exercises/reports, etc. and none of them has a written examination

Conclusions & Some personal thoughts

- We have several specialized thermo courses as well as several physical chemistry courses (1,2,3..) with substantial thermodynamic content
- Molecular simulation courses have been given as PhD courses with guest teachers (Economou, Mavratzas)
- We have found it difficult to teach based on ”previously published” books and we have abandoned Smith et al. book many years ago
- Teaching is very much based on ”own” material and this includes two own books and two sets of ”almost book-form” based Notes on Electrolytes (Kaj Thomsen) and Basic Thermodynamics (Michael L. Michelsen)