CERME 13
13TH CONGRESS OF THE EUROPEAN SOCIETY FOR RESEARCH IN MATHEMATICS EDUCATION
10-14 July 2023
Budapest
Hungary

Mathematical modelling as a research field: transposition challenges and future directions

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Outline

I. Research field on Mathematical Modelling

II. Brief journey through TWG Applications and Modelling

III. Systems, models and approaches to Modelling

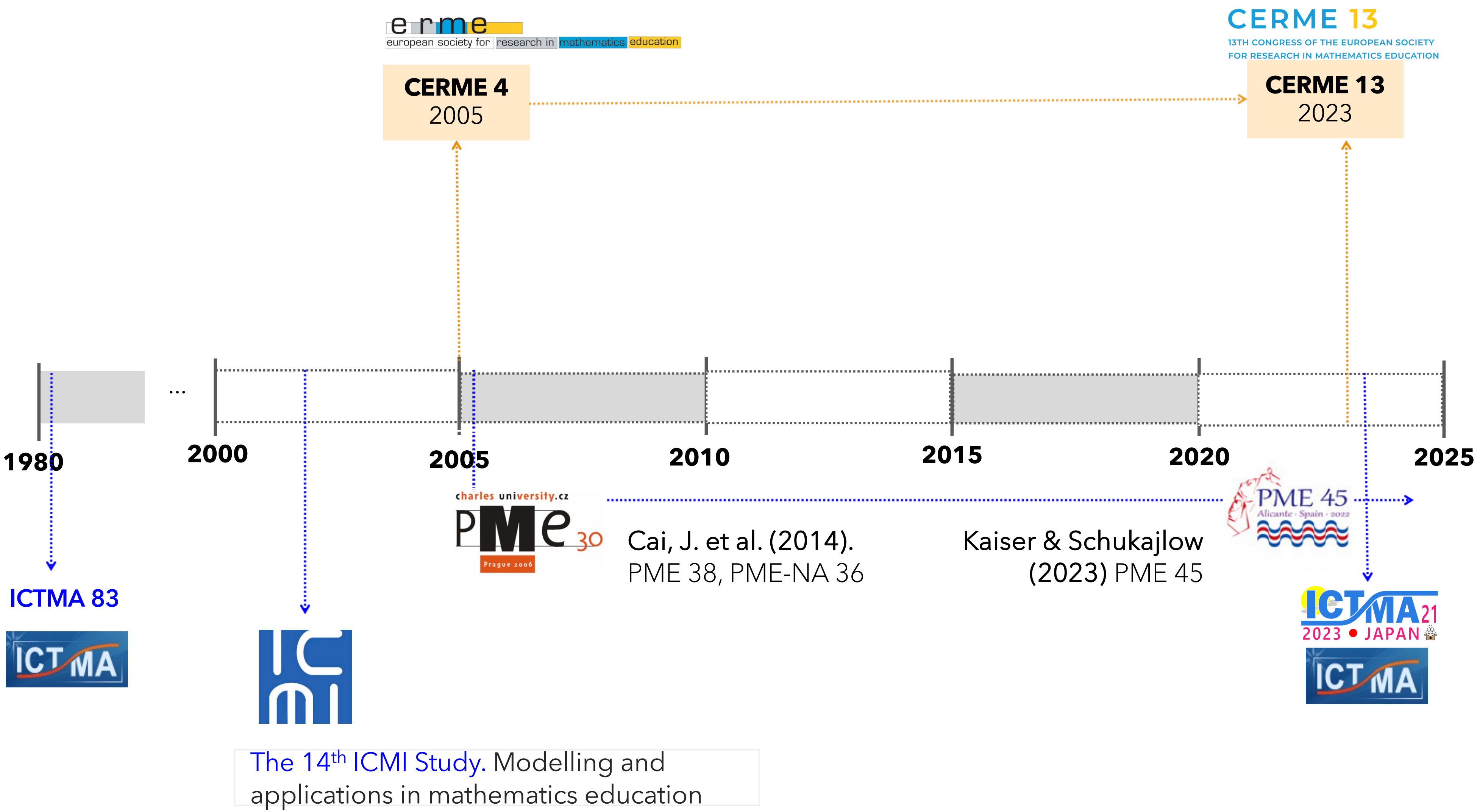
IV. Teaching modelling through Study and Research Paths

V. Conclusions

I. Research field on Mathematical Modelling

- In the last decades, research about **Applications and modelling** has grown in the research community and in curricular reforms.
- Origins and development in the International Research Community
  - Initial works of F. Klein as 1st president of ICMI, Freudenthal (1968) and Pollak (1968) in a symposium '*Why to teach mathematics so as to be useful*'.
  - Followed by the creation of the **ICTMA Conferences** – *International Community on the Teaching of Mathematical Modelling and Applications*–; and thematic working groups in **ICME** –*TSG 22 applications and modelling in mathematics education*– and in **CERME –TWG Applications and Modelling**.
  - Several attempts to analyse the **evolution of the research field in mathematics** education (Blum & Niss, 1991; Kaiser & Sriraman, 2006; Blum, 2015; Schukajlow et al. 2018).

I. Research field on Mathematical Modelling



I. Research field on Mathematical Modelling

erme
european society for research in mathematics education

CERME 4
2005

ERME Series
Dreyfus et al. (2019)
Developing Research in Mathematics Education. **20 Years of Communication, Cooperation and Collaboration in Europe**

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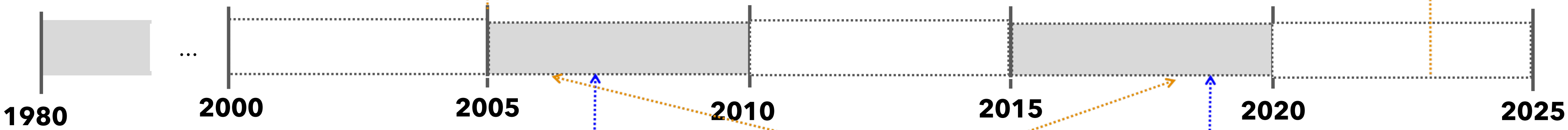
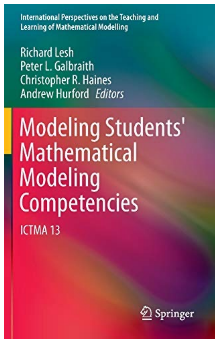
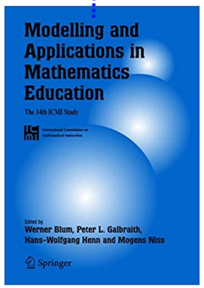
CERME 13
2023



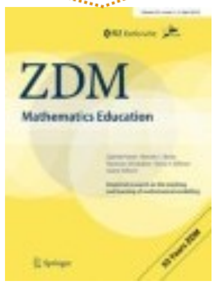
ICTMA

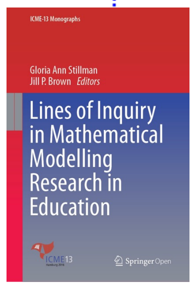


ICTMA series



Blum et al. (2007). Modelling and applications in mathematics education. **The 14th ICMI study.**

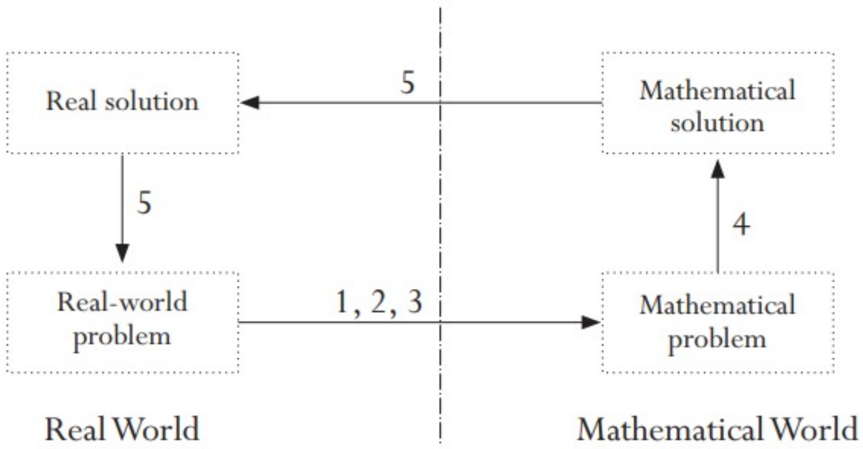




ICME Survey

ZDM – Mathematics Education
Sriraman, Kaiser, & Blomhøj (2006) Volume *38*(3) (Part A | B)
Modeling Research around the world
Kaiser, Borba, Schukajlow, & Stillman(2018)
Vol. *50*(1-2) (Part A | B). Empirical research on the teaching and learning of mathematical modelling

- **Rich transposition interaction** with educational institutions
  - **OECD / PISA** [T]he notion of **mathematical modelling**, which has historically been a cornerstone of the **PISA framework for mathematics** (OECD, 2004), into the PISA 2012 definition of mathematical literacy [..] The **modelling cycle** is a central aspect of the PISA conception of students as active problem solvers; however, **it is often not necessary to engage in every stage of the modelling cycle, especially in the context of an assessment** (Blum, Galbraith & Niss, 2007, pp. 3-32)." OECD (2019, p.75-76)



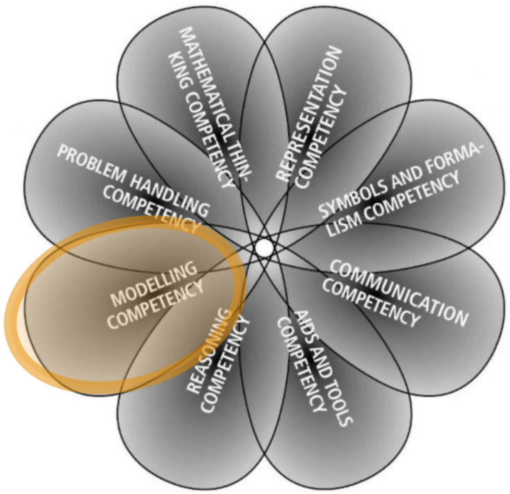
The mathematization cycle (OECD, 2003, p. 38)

I. Research field on Mathematical Modelling

Curricular reforms around the world

- Curriculum in Europe

  Modelling is included in the language of competencies (Danish KOM project, Niss 2003)



- Outside Europe: Common Core Standards in the USA

  "Modeling is best interpreted not as a collection of isolated topics but rather in relation to other standards. Making mathematical models is a Standard for Mathematical Practice, and specific modeling standards appear throughout the [rest of] high school standards […]" CCSO, Common Core State Standards in Mathematics

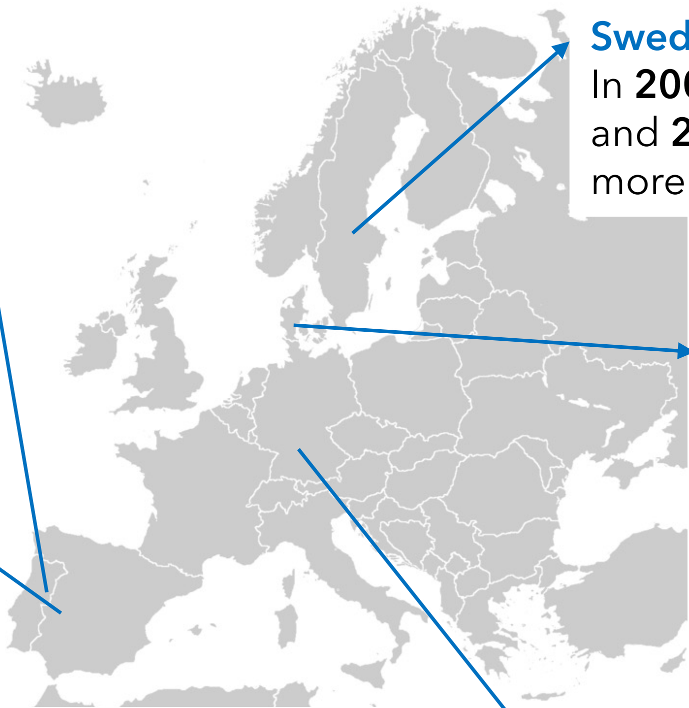
I. Research field on Mathematical Modelling

Curricular reforms in Europe → Some voices from **European researchers**

When did mathematical modelling first become part of your curriculum?

Portugal (S. Carreira)
In the **60s** in the experimental curriculum proposed by Sebastião and Silva.
It **re**appears in the early **90s** **linked to real-life situation.**

Spain (I. Ferrando, C. Segura)
In **2007** and **2014**, isolated and partial references to modelling. Explicit role in the latest curriculum reform in **2020.**



Sweden (J. B. Ärlebäck)
In **2000** at the lower Secondary. In **2011** and **2022** at upper Secondary, with more explicit references to models/ling.

Denmark (B. Jessen)
In **1976** at Primary and lower Secondary. In **1984-87** at Upper Secondary.
Earlies **2000s**, KOM framework.

Germany (G. Greefrath)
In **2003** at lower Secondary.
In **2012** at upper Secondary education.

I. Research field on Mathematical Modelling

Curricular reforms in Europe → Some voices from **European researchers**

What *role* has modelling played in the mathematics curricula?

Portugal **(S. Carreira)**
"It has changed over the years: as an **aim of teaching mathematics**, or as a **transversal competence** to facilitate connections. Recently, modelling appears closely linked to **interdisciplinarity**".

Spain **(I. Ferrando, C. Segura)**
Modelling appears as a **specific competence**. It often appears linked to the **domain of algebra**, but also as **cross-disciplinary** knowledge and to connections between mathematics domains.

Sweden **(J. B. Ärlebäck)**
"Some **tension in curricular descriptions** between: problem solving, applications and modelling".

Denmark **(B. Jessen)**
One of the **8 competencies constituting mathematics subject** (Jessen & Kjeldsen, 2021).

Germany **(G. Greefrath)**
Since 2003, modelling has been described as **1 of the 6 general mathematical competencies.**
In 2022, a clearer description of the **educational standards reform.**

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II. Brief journey through TWG Applications and Modelling

From CERME 4 in 2005 — **To CERME 13** in 2023

CERME 4

European Research in Mathematics Education IV

Proceedings of the Fourth Congress of the European Society for Research in Mathematics Education

Sant Feliu de Guíxols, Spain - 17 - 21 February 2005

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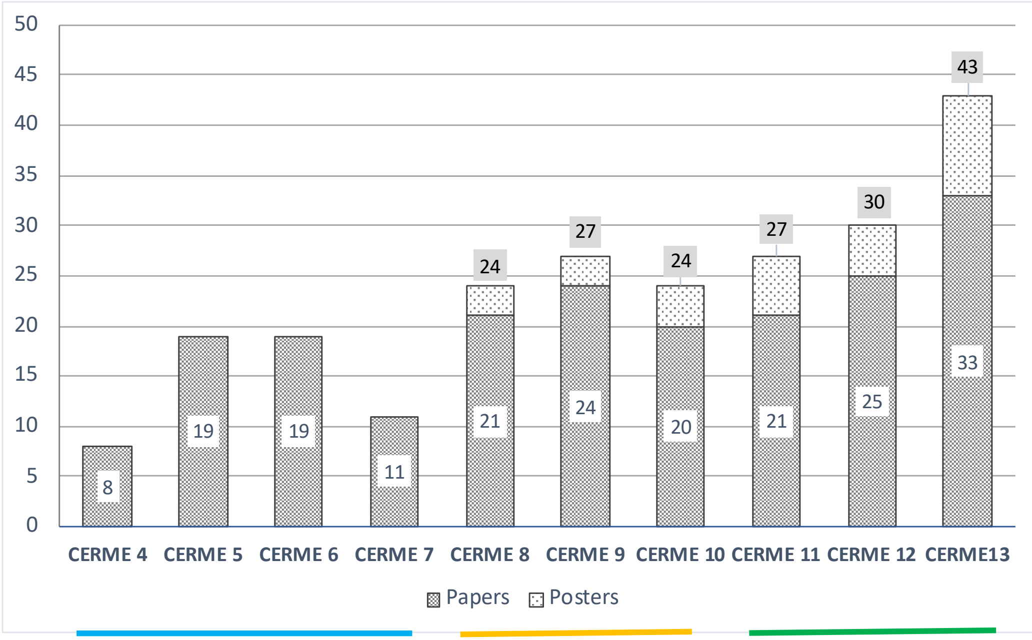
- **Increasing number** of participants and of contributions presented.
- A total of **198 contributions**, from **CERME 4** to **CERME 12**.
- More than **25 countries** represented.



Period 1 — Period 2 — Period 3

Period 1

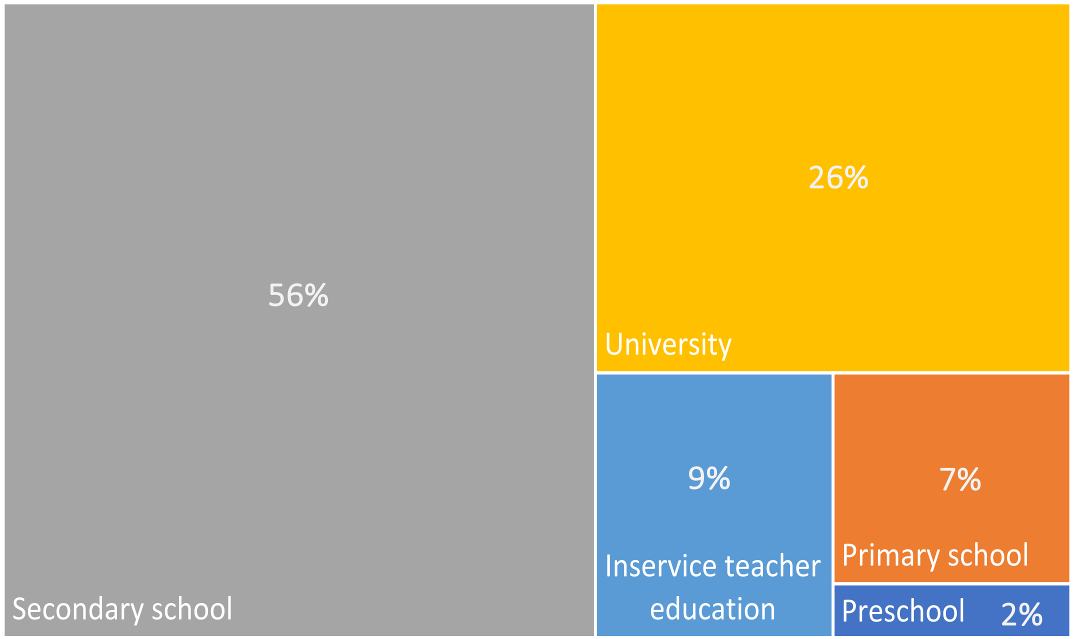
CERME 4 → CERME 5

- Different approaches, with **no homogeneous understanding of what modelling is**.
- Need of **classifying different approaches** and research aims.

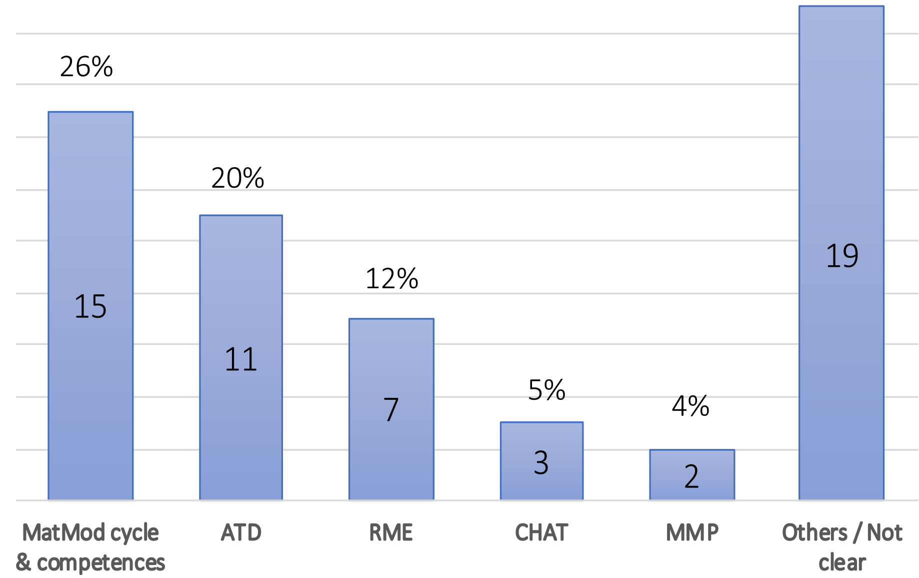
CERME 6 → CERME 7

- The contributions revealed some **salient themes** and **theoretical approaches**.

School levels



Use of theoretical frameworks

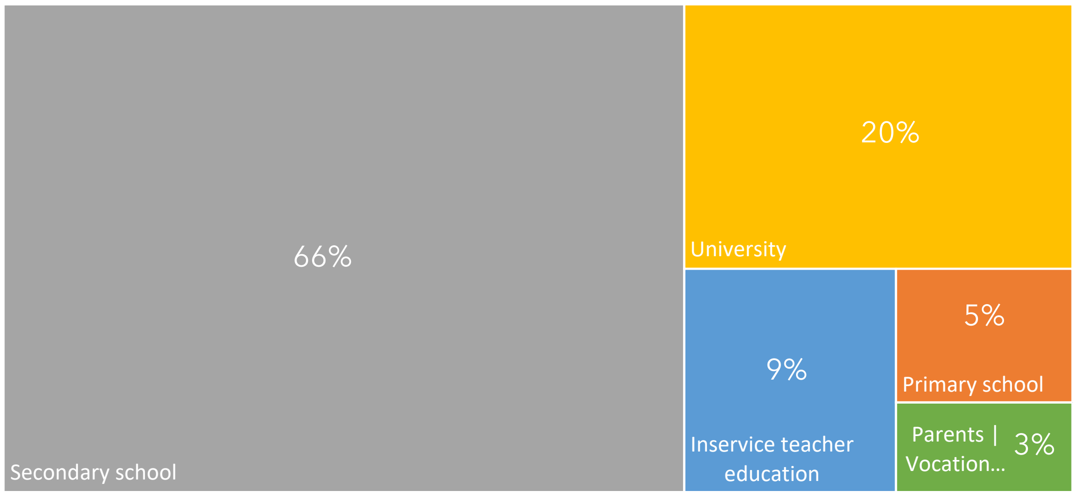


Period 2

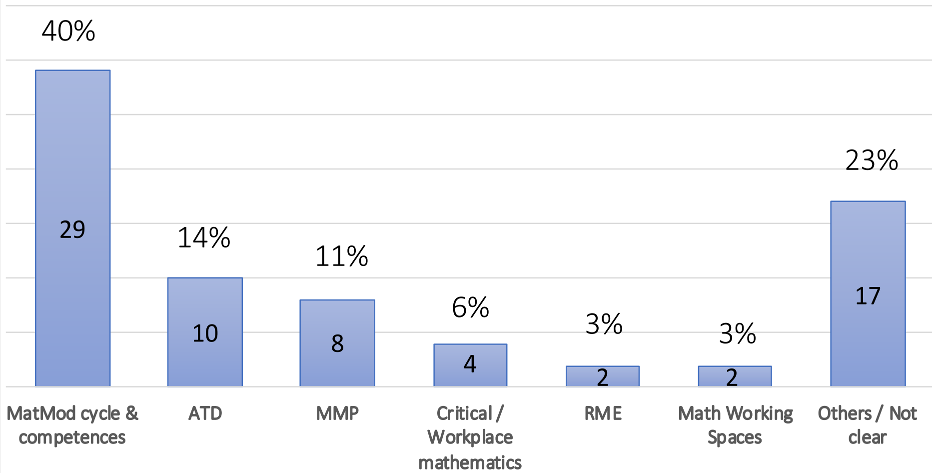
CERME 8 → CERME 10

- **Diversity of approaches** remains a feature of the group.
- Three salient themes:
  - Mathematical modelling related to **problem-solving**, **project-based** and **inquiry-based** approaches.
  - Authenticity of modelling tasks and tools for the design and analysis.
  - Theory and practice on modelling for **teacher education** and **mathematics educators**.

School levels



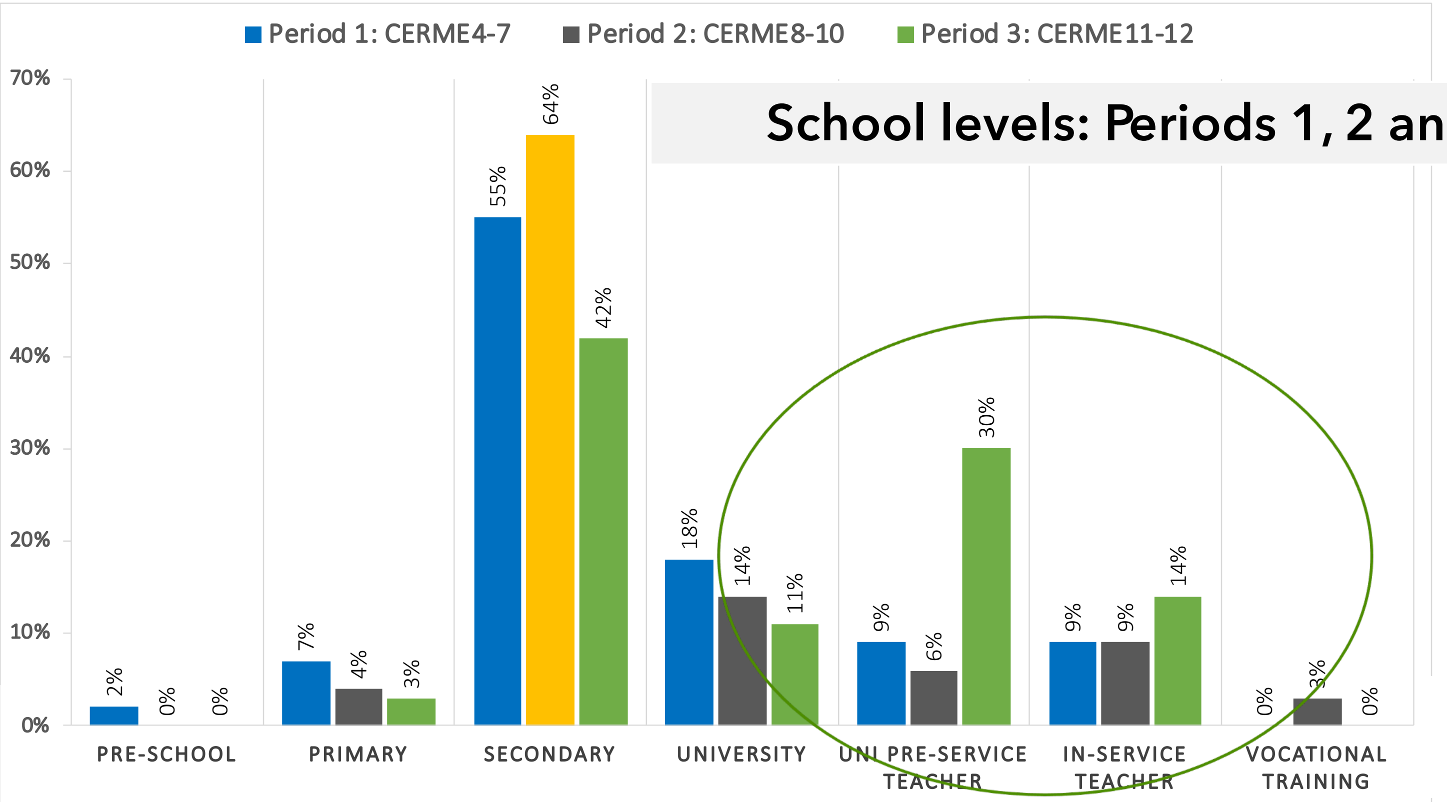
Use of theoretical frameworks



Period 3

CERME11 → CERME12 CERME13

- **Relevance of modelling and applications** after important societal phenomena
  - Data science, forecasting and simulations
  - Scientific community working on modelling for decision-making (such as COVID pandemic)
- Increase of research focus on **Teacher Education for mathematical modelling**



School levels: Periods 1, 2 and 3

Outline

Possible divergences?

- Diversity of **theoretical approaches** with different **understandings about what mathematical modelling is**.
- Variety of **research questions** and **methodological tools** grounded on the theoretical approaches.
- Different **units of analysis** are considered: empirical domains **not easily comparable**.

Systems, models and their dialectic (Chevallard, 1989)

- **A simple and flexible perspective**
  - Two main elements: that of the **system** and of the **model**
  - The notions of **system** and **model** are **functions**, not qualities or entities

Systems ⇔ **Models**

- **A unifying and general perspective**
  - **Modelling** in mathematics as in any **scientific activity** (including **Didactics**)

How do different research frameworks on modelling interpret the relation between systems and models?

III. Systems, models and approaches to modelling

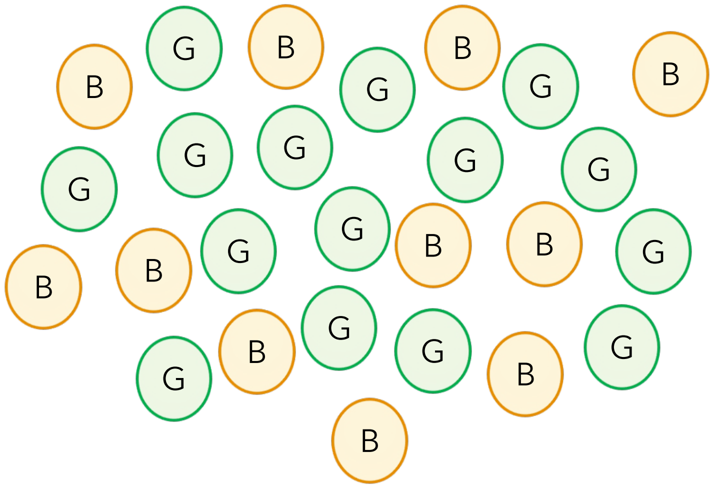
Systems ⟺ **Models**

- **The nature of Systems**
  - A **system** is considered as a piece of reality, which can be separated from everything else (hypothetically).

- **The function of Models**
  - The interest and richness of a model lies in its capacity to **produce knowledge about the system being modelled.**
  - The problems of **adapting, contrasting, validating models against the system** are the driving forces of the modelling activity.

Two central properties of the relation system-model

- **Recursivity of the modelling process.** Working on the model can lead to the construction of successive models, better adapted to the system.



15

11

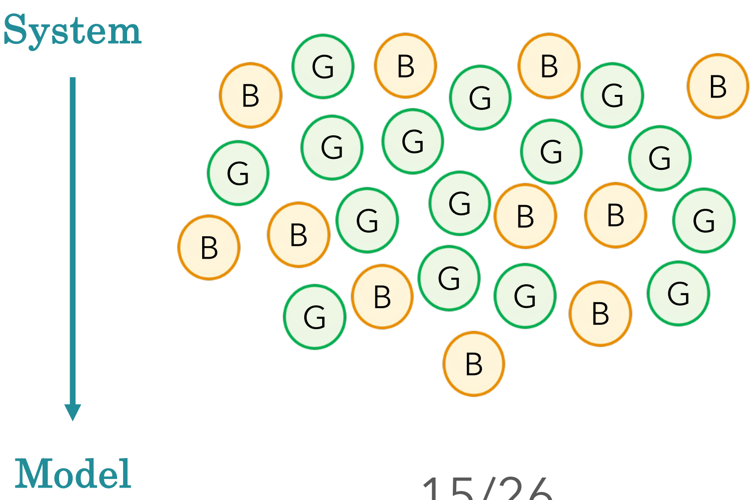
15/26 and 11/26

System M1 M2 M3 M4

58% and 42%

Two central properties of the relation system-model

- **Recursivity of the modelling process.** Working on the model can lead to the construction of successive models, better adapted to the system.
- **Reversibility of the modelling relationship.** The link between system(s) and model(s) can be inverted. The system can appear as a model of its model.



15/26 < 16/27

III. Systems, models and approaches to modelling

Two central properties of the relation system-model

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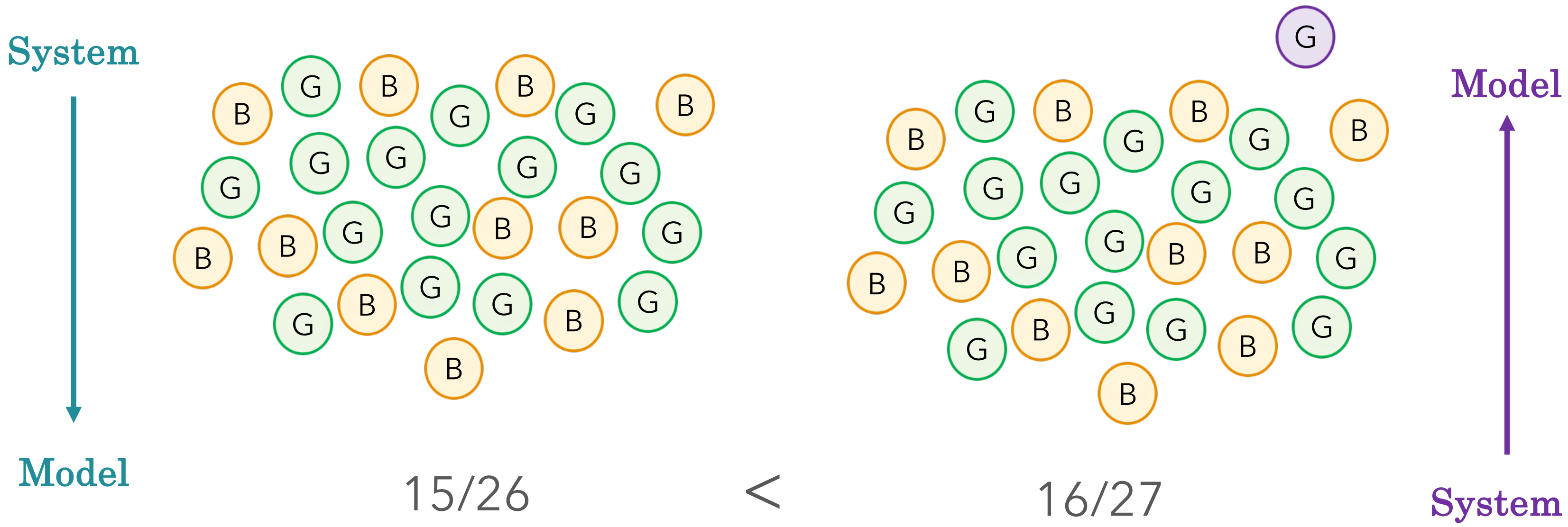

Possible convergences?

- Research on mathematical modelling provides evidence of **strong institutional constraints** hindering its **broad and long-term dissemination**

> We know how to teach modelling, have shown how to develop the support necessary to enable typical teachers to handle it […] The bad news? 'Many' is compared with one; the proportion of classrooms where modelling happens is close to zero. (Burkhardt, 2008, **CERME6**)
>
> The difficulties of implementing widely-agreed changes [such as modelling] seems to be a property of school systems and the way 'this kind of organism' functions. (Ibid, 2018, p.74)

Tensions in discourses about modelling (Galleguillos & Borba, 2018)

Barriers and **Levers** (Burkhardt, 2008)

Counter-arguments of students (Blum, 1991)

Teacher's beliefs obstacles (Kaiser & Maaß, 2007)

Teachers' dilemmas (Blomhøj & Kjeldsen, 2006)

→ Detection of constraints, but they are neither structured as research questions, nor approached with specific analysis tools

III. Systems, models and approaches to modelling

Scholarly knowledge		Knowledge to be taught		Taught knowledge		Learn, available knowledge
Institutions producing & using M	⇄	Educational system, "Noosphere"	⇄	Classroom, teaching	⇄	Community of study

Chevallard (1985), Chevallard & Bosch (2020)

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How to make explicit the implicit? Barquero, Bosch & Gascón (2019), Barquero & Jessen (2019)

Epistemological dimension

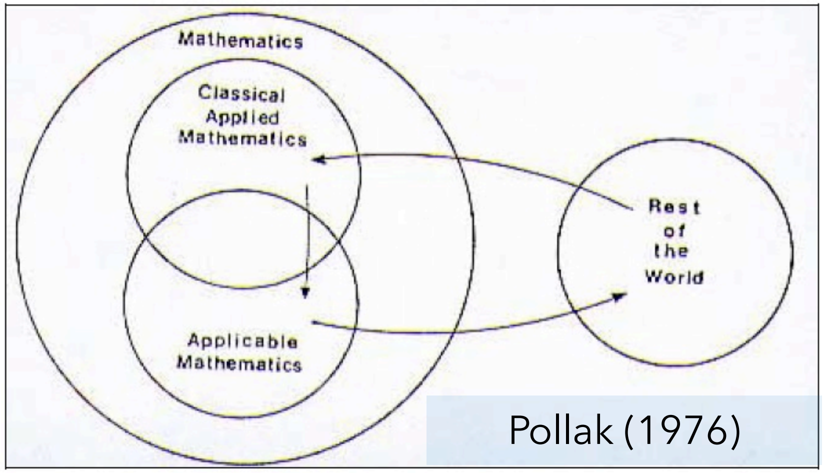
- What are the epistemological conceptions of mathematical modelling?
  How to interpret the relation between systems and models?

Systems ⟺ **Models**

Ecological dimension

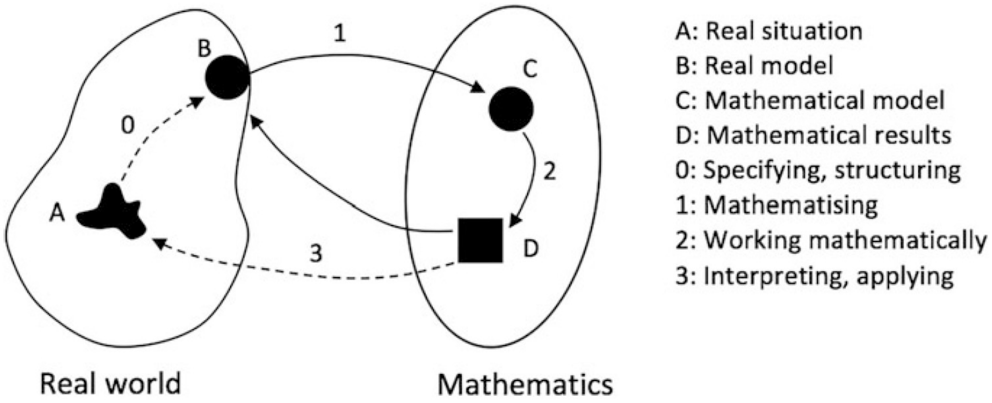
- What are the **conditions and constraints** discussed? What agents and institutions are observed/analysed?

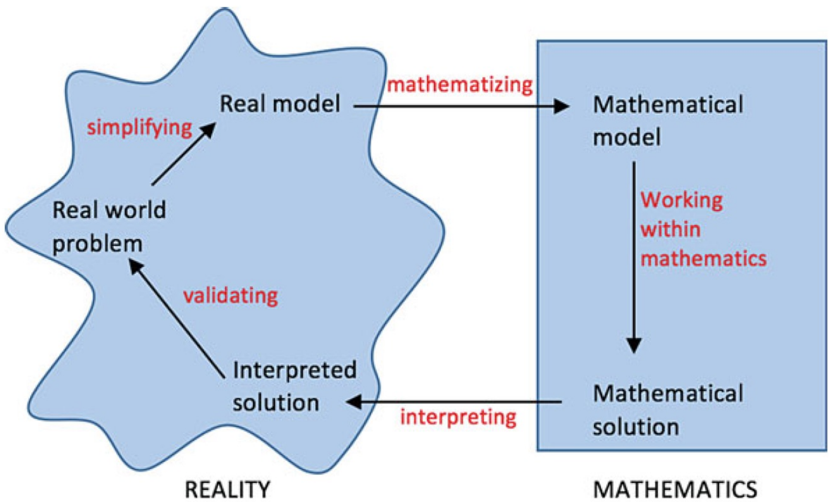
Greefrath & Vorhölter (2016). Teaching and Learning Mathematical Modelling. ICME-13 Surveys.



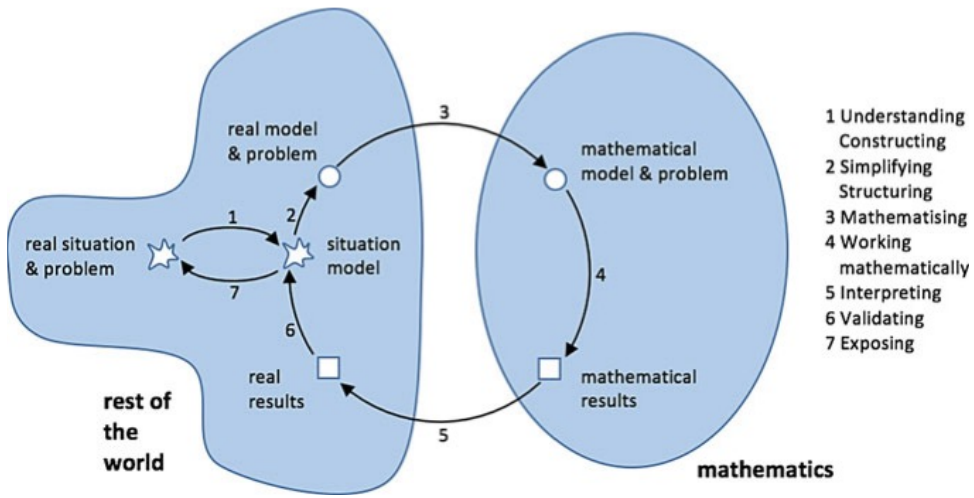
Pollak (1976)

Blum (1985), Kaiser-Meßmer (1986)





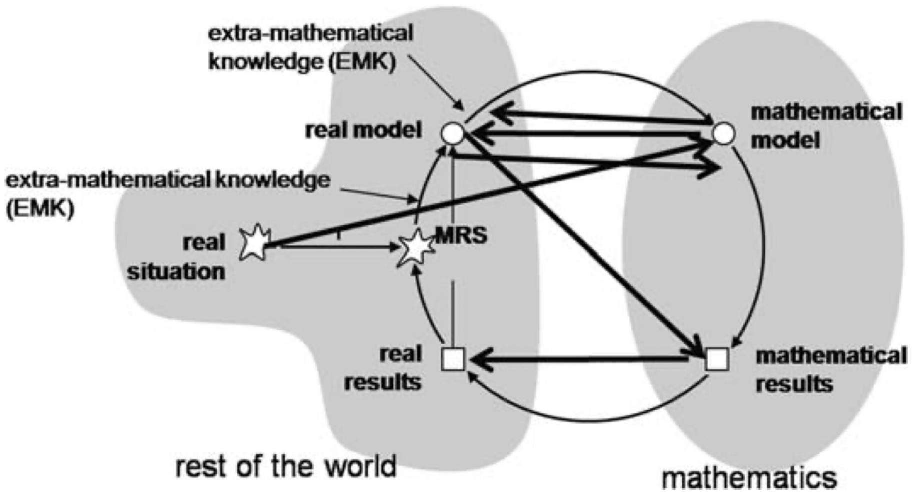
Maaß (2006)



Blum & Leiß (2005), Borromeo Ferri (2006)

Case 1: **Modelling cycle approach** → Epistemological dimension

- Modelling cycle(s) seems particularly useful to **analyse cognitive processes** followed by students and teachers.



Modelling cycle to analyse modelling routes
(Borromeo Ferri, **2007-CERME5**, 2010)

- **Research questions:** How do students solve modelling tasks? What are the influences of the mathematical thinking style of students on the modelling process? Which are the individual modelling routes? […]

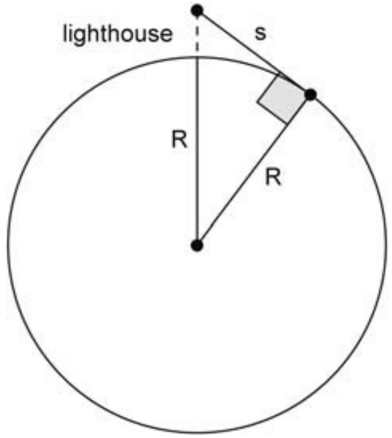
Case 1: Modelling cycle approach

Context: 10th grade, 3 modelling tasks, 90 min class sessions (Borromeo Ferri, 2010)

Lighthouse

In the bay of Bremen, directly on the coast, a lighthouse […]. How far was a ship from the coast when it saw the lighthouse for the first time?

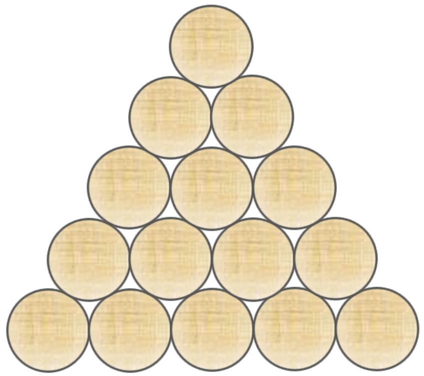
(in Borromeo Ferri, 2010, p. 109-110)



Bales of straw

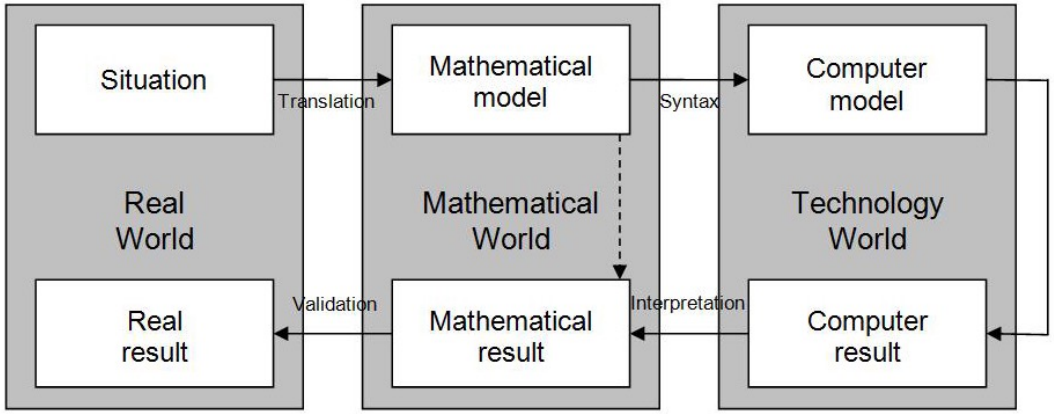
Straw bails are piled up that in the bottom line are five, in the next four, then three, then two and on the top one ball. Try to find out exactly, how high this mountain of straw bales is.

(task in Borromeo Ferri, 2007, p. 2084)

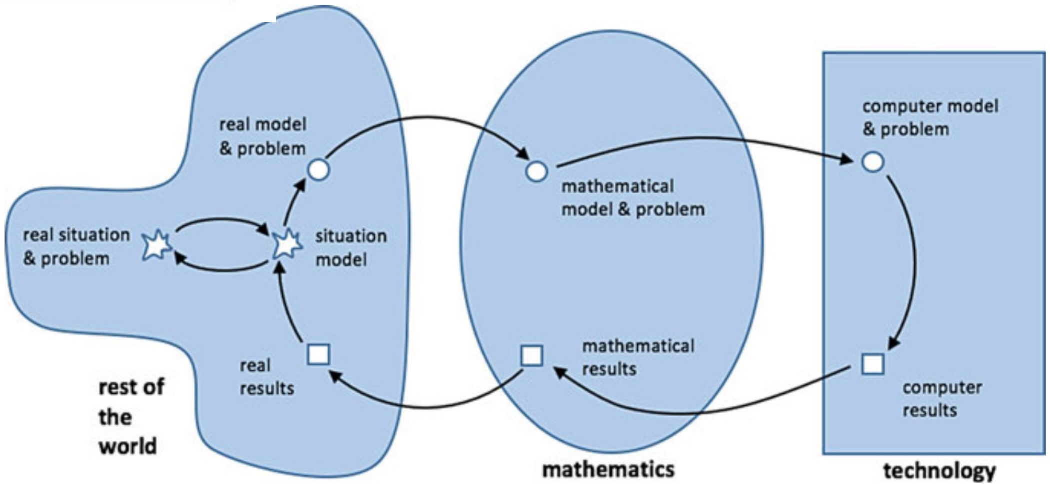


Case 1: Modelling cycle approach extended with technology

- The use and role of technology in modelling processes and the extension of the modelling cycle to include the 'technology world'.



Possible use of digital tools in modelling cycles (Greefrath, 2011, p. 303)



Extended modelling cycle – regarding technology when modelling (Siller & Greefrath, 2010–**CERME6**)

Case 1: **Modelling cycle approach** → Ecological dimension

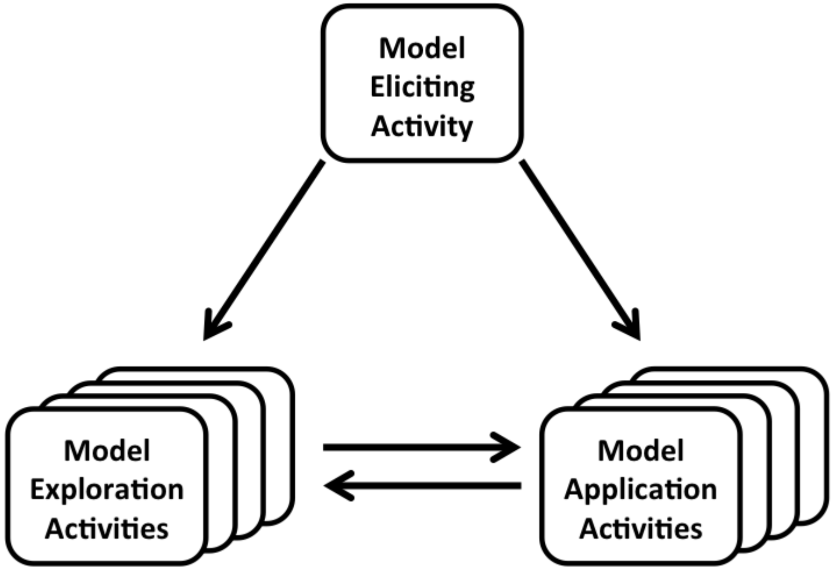
- The **unit of analysis** chosen focuses on student and/or teachers learning and teaching modelling processes.

Scholarly knowledge	⇄	Knowledge to be taught	⇄	Taught knowledge	⇄	Learn, available knowledge
Institutions producing, using		Educational system, "Noosphere"		Classroom, teaching		Community of study

- The **conditions** and **constraints** are coherently discussed about individuals (students or teachers) reacting in classroom settings or training contexts.
  - **Kinds of blockages** of students advancing in modelling (Galbraith & Stillman, 2006)
  - Mathematical **teachers' or students' beliefs** when modelling (Kaiser & Maaß, 2007)
  - **Teachers' beliefs** on the use of technology (in modelling) (Siller & Greefrath, 2010)

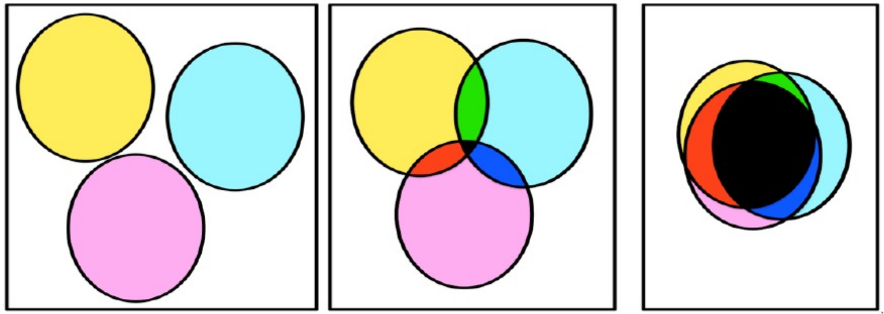
Case 2: **Models and modelling perspective** → Epistemological dimension

- In the Models and Modelling Perspective (MMP), mathematical modelling is described as a sequence of model developments, involving different types of activities: **model creation, model exploration** and **model adaptation** (Lesh et al., 2003).



General structure of a model development sequence (Doerr & English, 2003)

Connecting, coordinating and integrating models
(Ärlebäck & Doerr, 2015, CERME 9)



[T]he different transitions should not be thought of as carried out sequentially, but rather as processes fundamentally evolving simultaneously, nested and organically (Ärlebäck & Doerr, 2015)

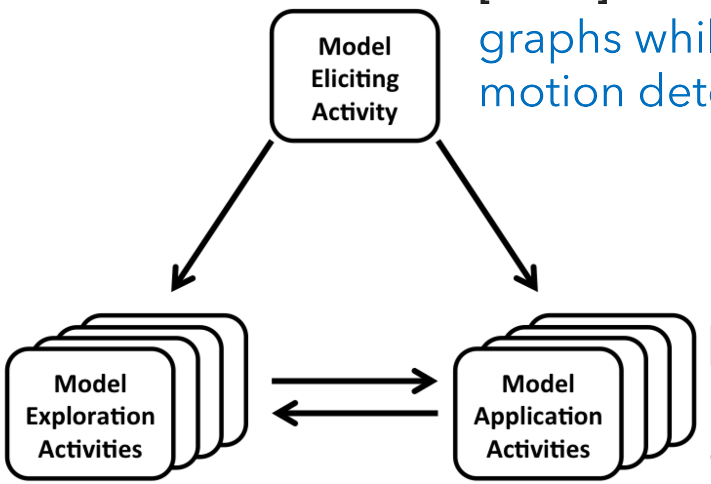
III. b. Advances and contributions from the MMP

Case 2: Models and modelling perspective

Ärlebäck, Doerr & O'Neil (2013), Ärlebäck & Doerr (2015 and 2018)

- **Research Question:** How do **students interpret average rates of change** related to decreasing functions? How can the **design of a model development sequence** about negative rates of change?
- **Context:** A six-weeks entrance course on mathematics at university.

[MEA] Creating linear graphs while using a motion detector

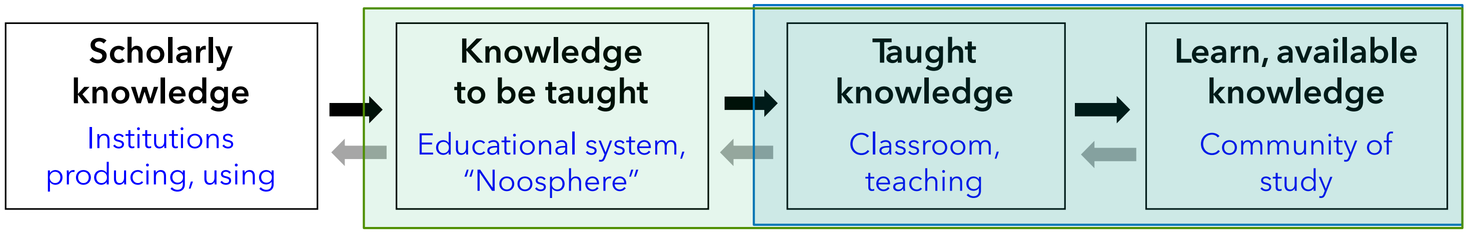


[MXA] Representational systems to describe change and rates of change

[MAA] Applying emerging models about rates of change in new contexts

Case 2: **Models and modelling perspective** → Ecological dimension

- Need to create **alternative epistemological models** to describe the knowledge to be taught → **covariational framework** (Carlson et al., 2002)



- Detection of important didactic phenomena and associated constraints:
  - **Lack of terminology** to refer to variation and co-variation.
  - **Students' difficulties in communicating** about the context of changing phenomena.

Case 3: **Modelling in the Anthropological Theory of the Didactic (ATD)**

- Main steps in the modelling process (Chevallard, 1989)

INITIAL QUESTION

- Delimitation of the **system to be studied**, specifying its relevant aspects.

Questions about the system

- **Model construction**, work **on(within** the model

Questions about the model

- **Work with the model** to produce knowledge about the system

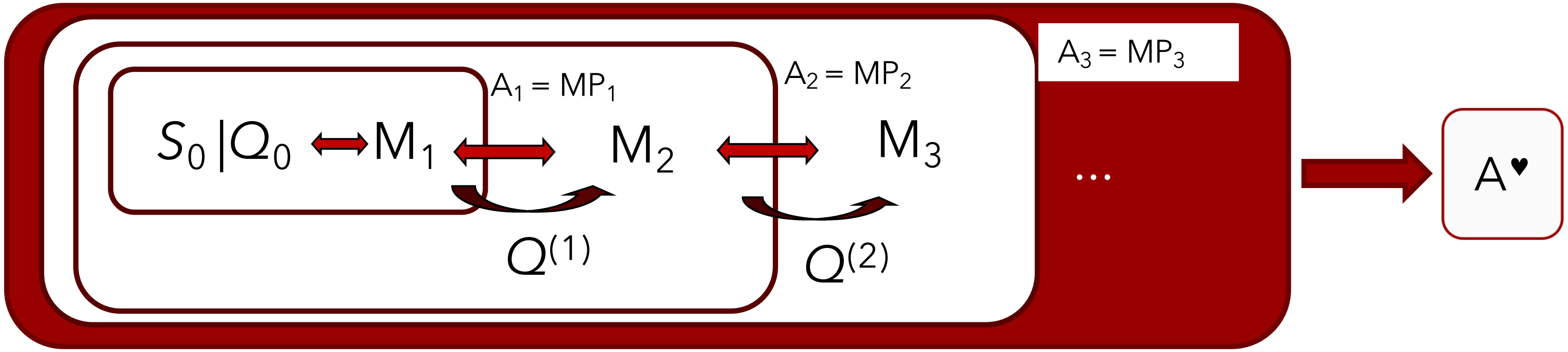
Questions about the systems and models

FINAL ANSWERS and new questions

III.c. Advances and contributions from the ATD

Case 3: Modelling in the Anthropological Theory of the Didactic

- In the ATD, modelling is reformulated as **a process of constructing and articulating mathematical praxeologies in order to answer some initial questions** (Barquero, 2009; García et al., 2006).



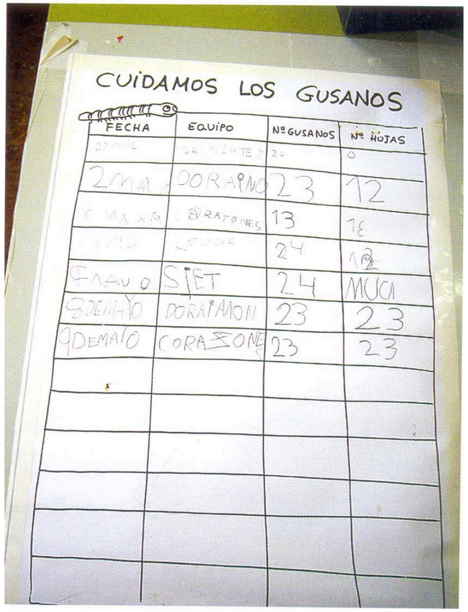
García & Ruiz-Higueras (2010, CERME 6). More than silkworms

Initial system $\mathbf{S_0}$

Q_0 How many leaves do we need to feed the silkworms?

Model 1 $\mathbf{M_1}$ (t, s(t)) → L(s(t))

M_1 Counting and tabular models for (t, s(t)) → L(s(t))



Q_1 If we have cocoons, how does it change the situation?

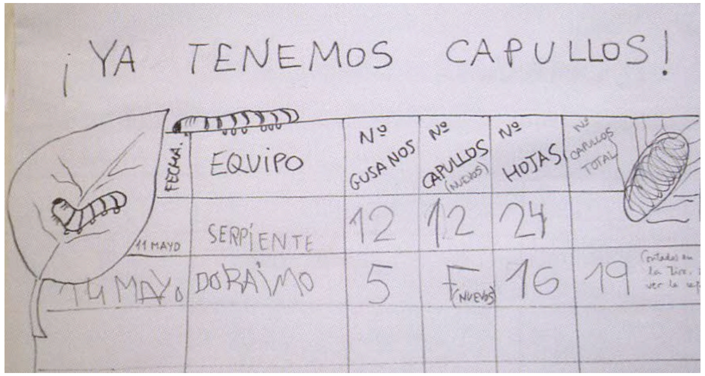
Model 2 **M2** (t, s(t), c(t)) → L(s(t))

System 1 **S1**

System S_0

M1 Counting and tabular models for (t, s(t)) → L(s(t))

Q$_1$ If we have cocoons, how does it change the collection count?



M2 Counting sub-collections and tabular models (t, s(t), c(t)) → L(s(t))

Q$_2$ And, if we start having butterflies?

III.c. Advances and contributions from the ATD

Model 3 **M3**

(t, s(t), c(t), b(t))

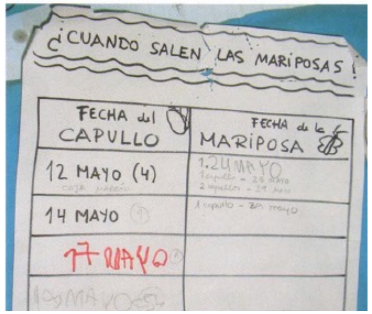
System 2 **S2**

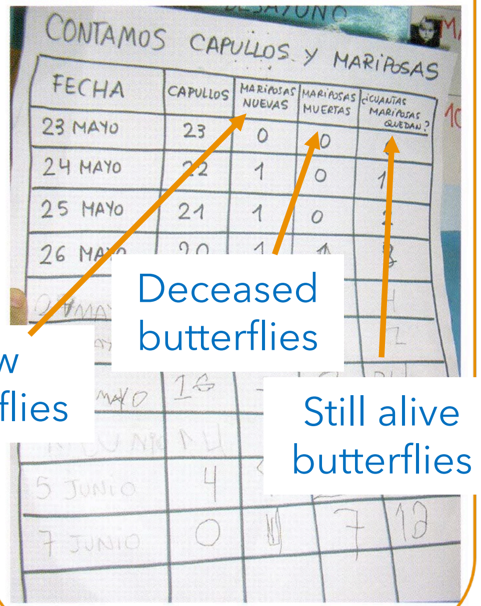
System $\mathbf{S_0}$

M1 Counting and tabular models for (t, s(t)) → L(s(t))

System 1 **S1**

M2 Counting and tabular models for (t, s(t), c(t)) → L(s(t))





New butterflies

Deceased butterflies

Still alive butterflies

Q_2 What happens when we start having butterflies?

Recursivity in the modelling process

III.c. Advances and contributions from the ATD

Reversibility

Model 1 **M_1**

(t, s(t)) → L(s(t))

Model 2 **M2**

(t, s(t), c(t)) → L(s(t))

Model 3 **M3**

(t, s(t), c(t), b(t)) with

$b(t) = b_{new}(t) + b_{alive}(t) + b_{dead}(t)$

The ecological dimension at the core of the ATD

Scholarly knowledge	→ ←	**Knowledge to be taught**	→ ←	**Taught knowledge**	→ ←	**Learnt knowledge**
Institutions producing, using		Educational system, "Noosphere"		Classroom teaching		Community of study

Prevalence of **theoretical construction** of knowledge

Curriculum as a set of conceptual organisations

Rigidity of the conceptual organisation of mathematical knowledge

"Applicationism" as dominant epistemological models

Isolation of modelling

Fake inquiries, fake models and modelling as a means to study concepts

Where do they come from?

Outline

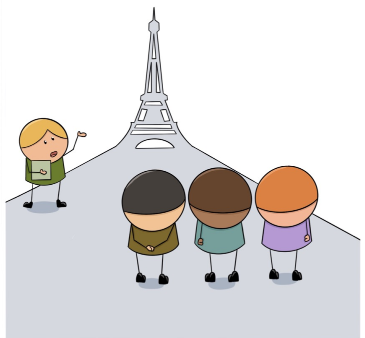
Chevallard (2006, 2015)

The paradigm of **visiting works**

Programmes as a set of answers

Programmes = { ~~Questions~~ , Pre-established answers}

A secondary role of mathematical modelling

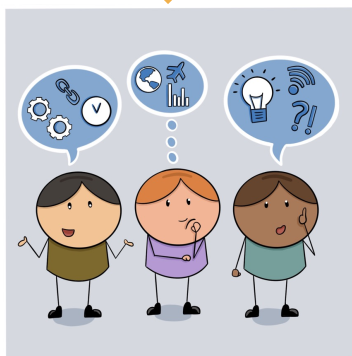


The paradigm of **questioning the world**

Programmes as a set of questions and answers

Programmes = { Questions, Answers to Q }

Primordial role of mathematics as a modelling tools to inquire into Q



IV. Teaching modelling through Study and Research Paths

Research hypothesis: Study and Research Paths (SRP) are proposed as teaching devices (Chevallard, 2005, 2006, 2015) to:

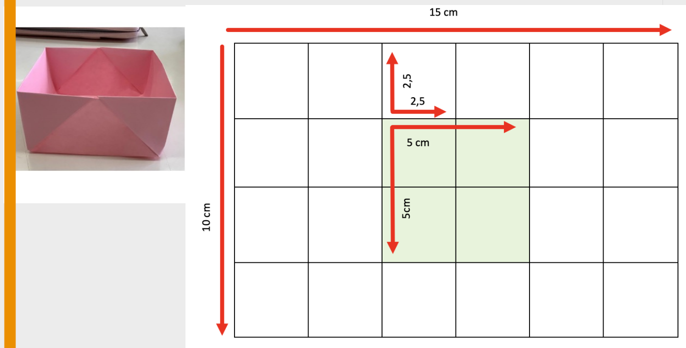
- Address **didactic phenomena** linked to the prevailing **paradigm of visiting works**
- Create the **conditions** facilitating the implementation and short- and long-term dissemination of **mathematical modelling practices**

IV. Teaching modelling through Study and Research Paths

SRP_1 Something more than silkwarms
Preschool (4-5)

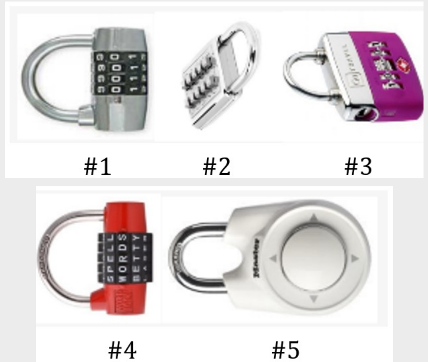
Garcia & Ruiz-Higueras (2010)

SRP_2 The cake box
Primary school (9-12)



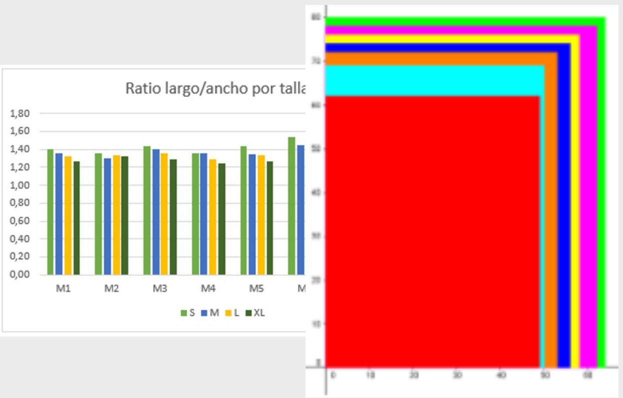
with Bosch & Wozniak (2019, in press)

SRP_3 What padlock is safer?
Secondary school (15-16)



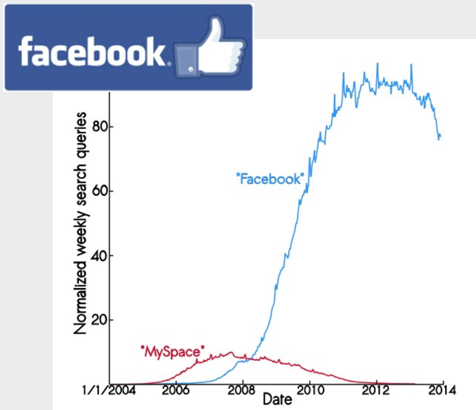
Vásquez et al. (2021)

SRP_4 T-shirt sizing
Primary-Secondary school



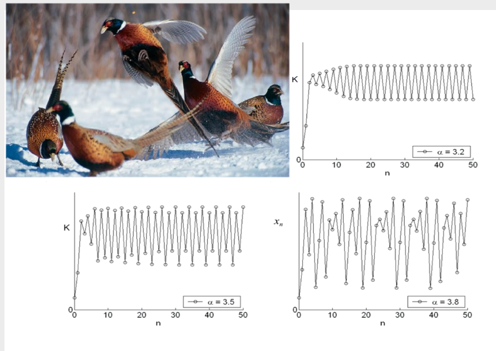
Barquero & Bosch (2023)

SRP_5 Facebook users
Secondary school-University



with Ruiz-Munzón & Serrano (2021)

SRP_6 Dynamic populations
University – Maths courses

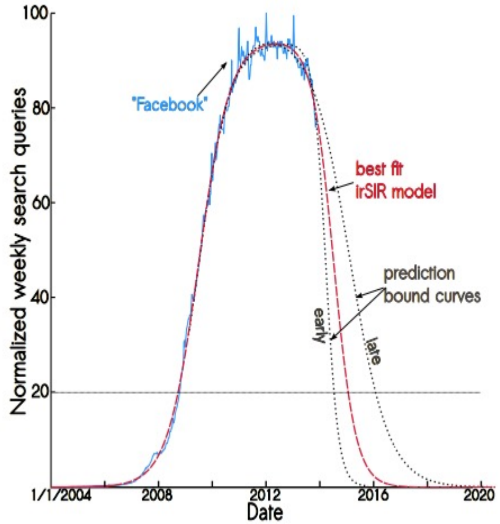


Barquero (2009)

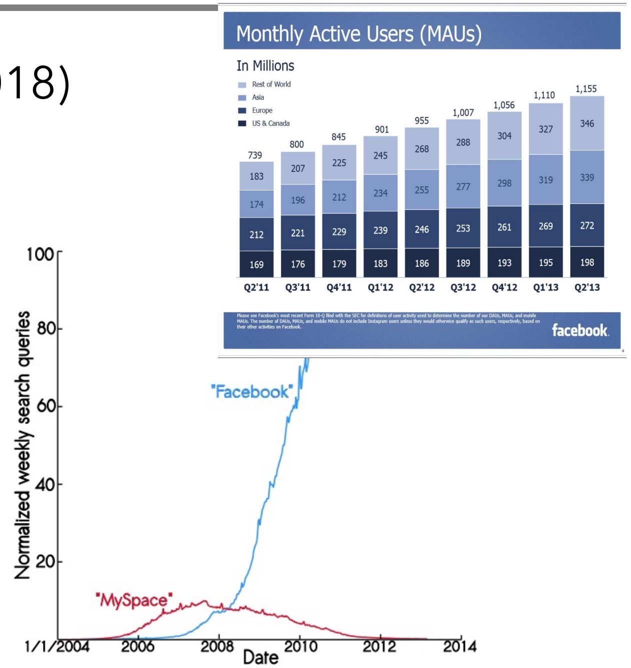
Princeton researchers predict Facebook will have 80% less users by 2017

News By Jeff Belanger - January 25, 2014 - no comments

Email article | Print article



Barquero, Monreal, Ruiz-Munzón, & Serrano (CERME10–2017, 2018)



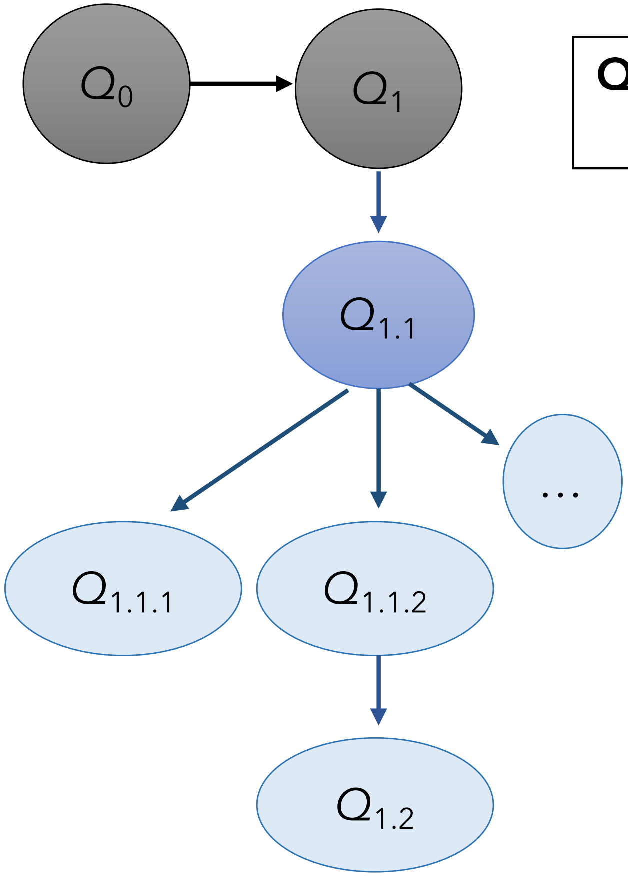
Generating question of the SRP

Can the forecasts published by Princeton in 2014 about the future evolution of Facebook users be true? How can we model and fit real data from Facebook users to provide our forecasts and check them against Princeton's ones?

Conditions for the implementation

- With **1st year students of Business Administration** (UPF). Mathematics, from 2015/16 to 2017/18. Modelling workshops as complement to the course.
- With **in-service teachers of Secondary and University**, in the module of experiencing an SRP. From 2018/19 to 2022/23.

IV. Teaching modelling through Study and Research Paths



Q_1 What data on Facebook users can we use? What hypothesis and models can we use to predict how users will evolve?

$Q_{1.1}$ What to select and organise the data?

$A_{1.1}$ Data-driven decisions-making

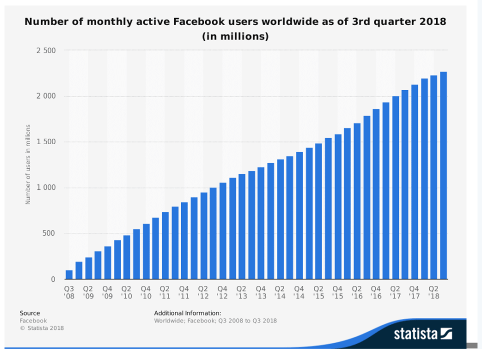
$Q_{1.1.1}$ What variables to be considered?

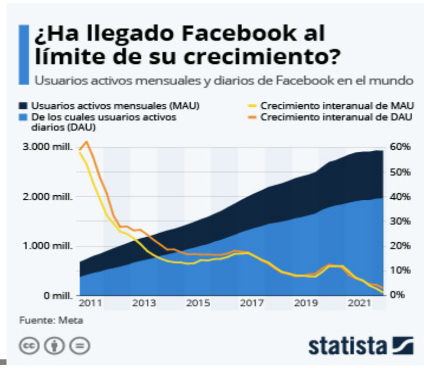
$Q_{1.1.2}$ Any specific hypotheses to investigate?

$Q_{1.2}$ What has been the historical trend in the data? What other answers exist?

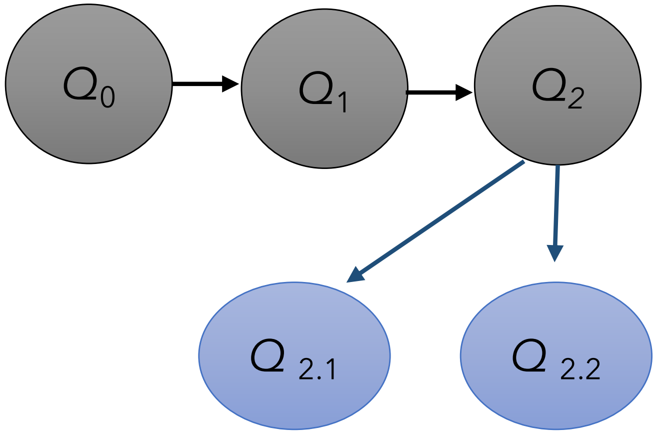
$A_{1.2}$ Search for fitting / forecasting models → **Models$_1$**

Q_2 What models, based on what assumptions?





IV. Teaching modelling through Study and Research Paths

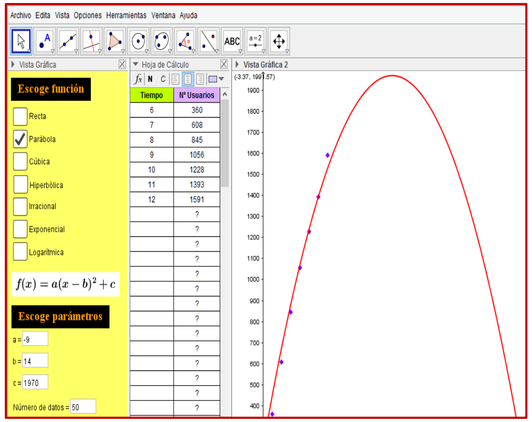


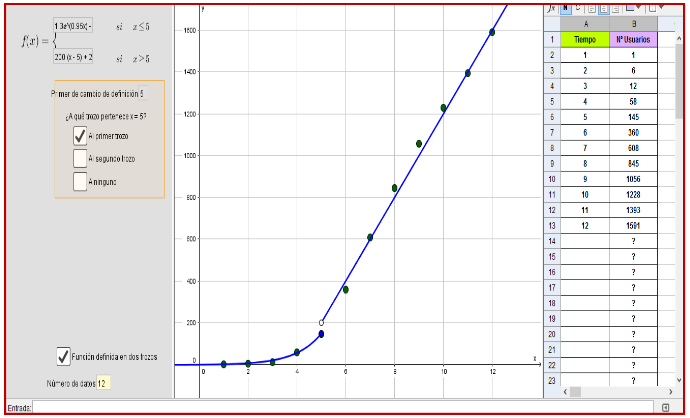
Q_2 Which mathematical models fit the data?

$Q_{2.1}$ What family of functions does it make sense to consider? What are the 'best' functions to choose?

$Q_{2.2}$ How can the coefficients of these models be determined and interpreted in this context?

A_2 Decision-making on the 'best' models and interpreting the coefficients → **$Models_2$** and **Q_3**

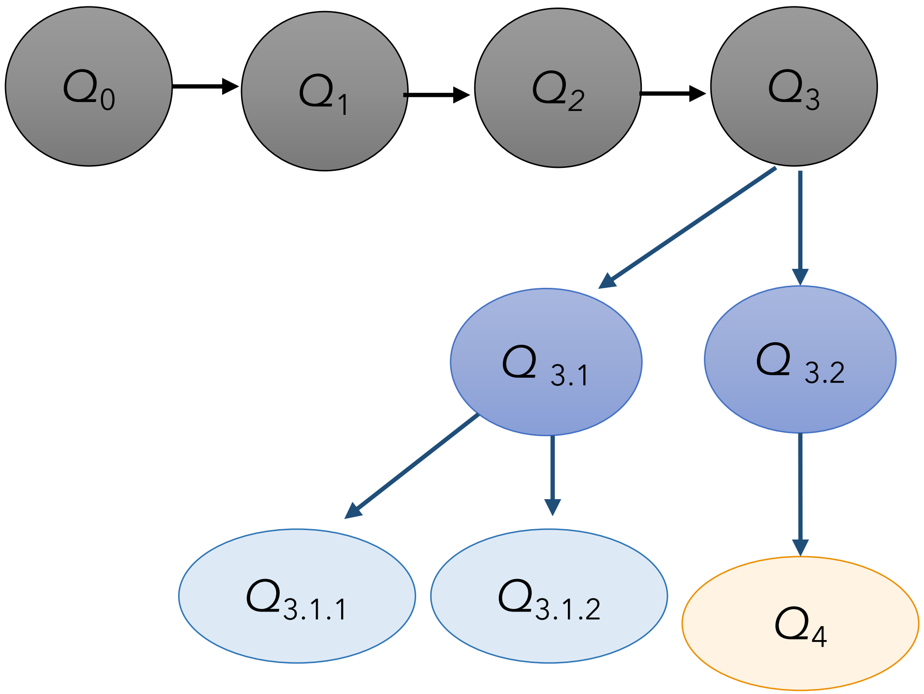




Parameters that define the funtion	
a	1,9
b	-6
c	1100

REAL DATA		CUBIC		
x (terms)	y (real data)	y (model)	Absolute_error	Quadratic_error
0	800	689,6	110,4	12188,16
1	845	862,5	17,5	306,25
2	901	978,4	77,4	5990,76
3	955	1048,7	93,7	8779,69
4	1007	1084,8	77,8	6052,84
5	1056	1098,1	42,1	1772,41
6	1110	1100	10	100
7	1155	1101,9	53,1	2819,61
8	1189	1115,2	73,8	5446,44
9	1228	1151,3	76,7	5882,89
10	1276	1221,6	54,4	2959,36
10	1317	1221,6	95,4	9101,16
			65,2	**5116,6**

IV. Teaching modelling through Study and Research Paths



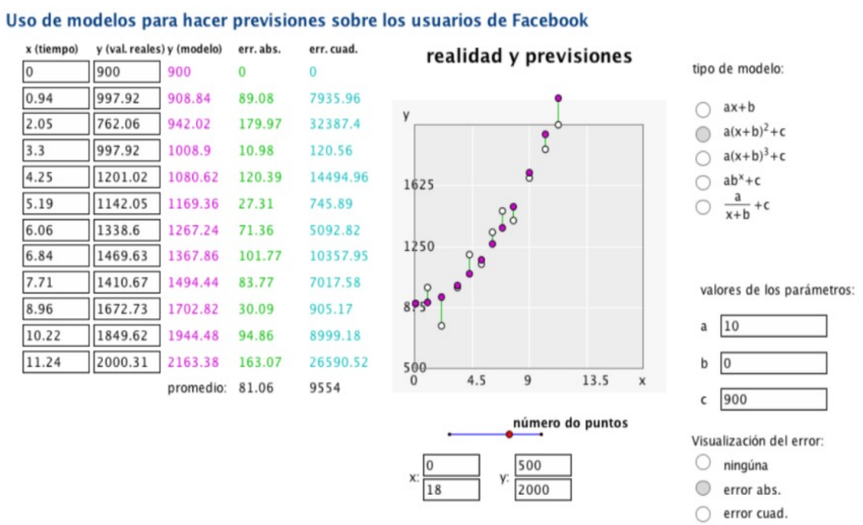
Q_3 What does it mean to have a 'good' model? How do we choose the 'best' model?

A_3 Models to fit | Models to forecast → **Models$_{2'}$**

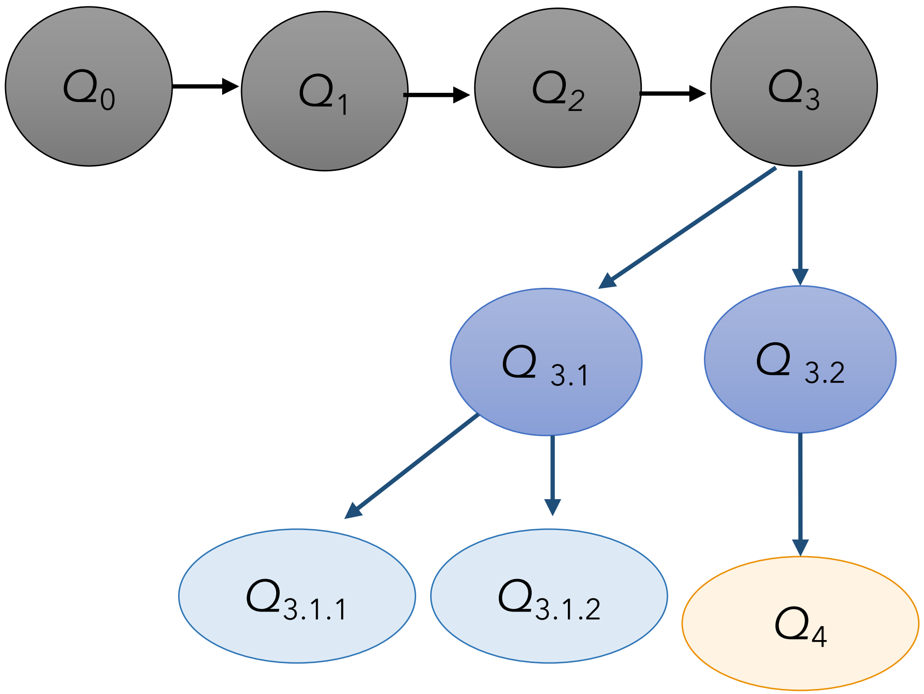
$Q_{3.1}$ How to calculate and interpret the fitting errors made when comparing simulations with data?

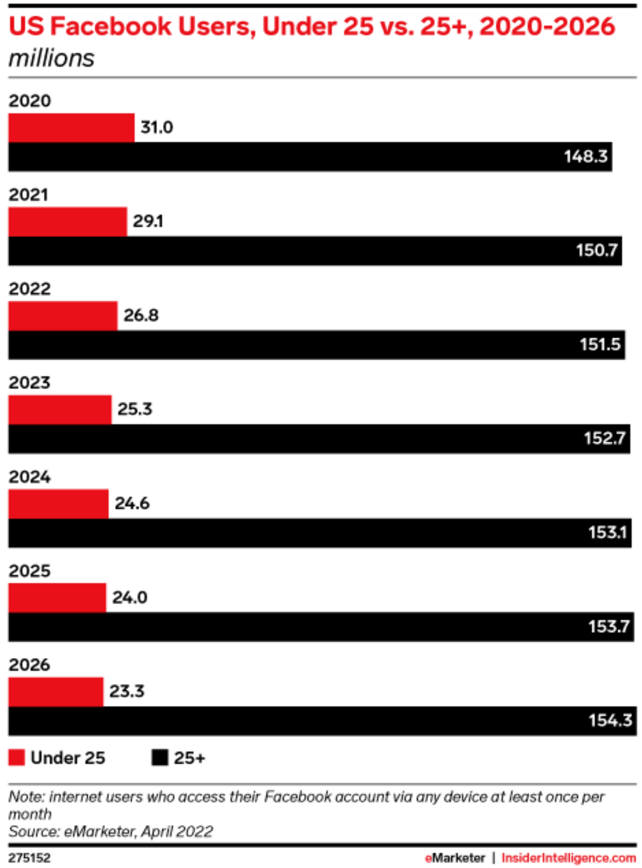
$Q_{3.2}$ How to use models about data variation to make decisions? **(Serrano, 2010, CERME6) → Models$_3$**

Q_4 How to validate short- and long-term model forecasting?


Uso de modelos para hacer previsiones sobre los usuarios de Facebook

x (tiempo)	y (val. reales)	y (modelo)	err. abs.	err. cuad.
0	900	900	0	0
0.94	997.92	908.84	89.08	7935.96
2.05	762.06	942.02	179.97	32387.4
3.3	997.92	1008.9	10.98	120.56
4.25	1201.02	1080.62	120.39	14494.96
5.19	1142.05	1169.36	27.31	745.89
6.06	1338.6	1267.24	71.36	5092.82
6.84	1469.63	1367.86	101.77	10357.95
7.71	1410.67	1494.44	83.77	7017.58
8.96	1672.73	1702.82	30.09	905.17
10.22	1849.62	1944.48	94.86	8999.18
11.24	2000.31	2163.38	163.07	26590.52
		promedio:	81.06	9554





TECHNOLOGY The Washington Post

Facebook loses users for the first time in its history

Facebook parent Meta's stock suffered its biggest single-day loss yet as the company refocuses on the 'metaverse'

By Elizabeth Dwoskin, Will Oremus and Rachel Lerman

Updated February 3, 2022 at 4:44 p.m. EST | Published February 2, 2022 at 4:35 p.m. EST

Feb 2022

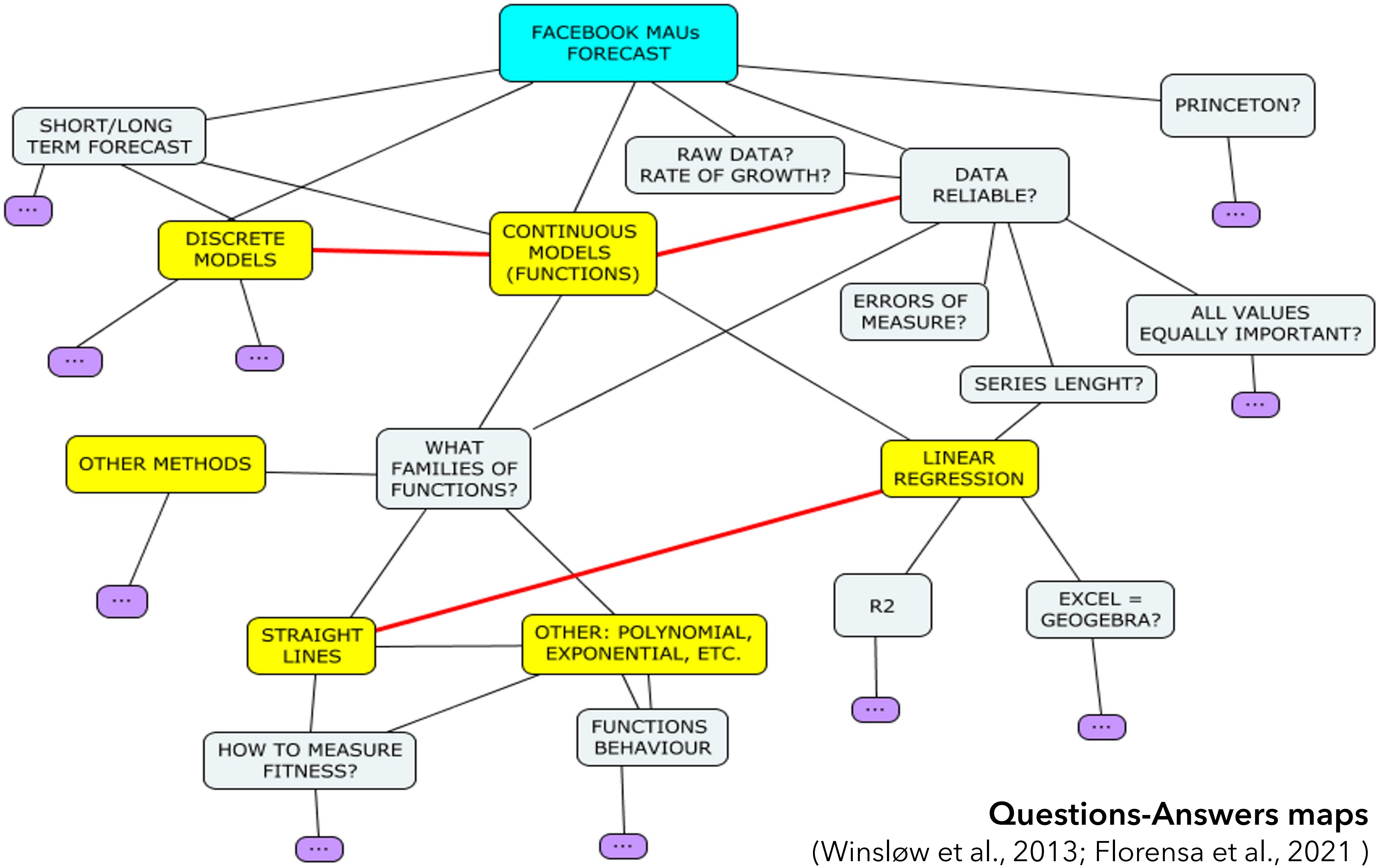
INSIDER INTELLIGENCE | eMarketer

New forecasts from 2023-2026

The question is still open… (to be continued)

IV. Teaching modelling through Study and Research Paths

Paradigm of questioning the world → Infinite recursivity



Questions-Answers maps

(Winsløw et al., 2013; Florensa et al., 2021)

Paradigm of questioning the world → Emergence of constraints

Many constraints for modelling at different levels of the scale…

Civilizations
⇅
Societies
⇅
Schools
⇅
Pedagogies
⇅
Didactic system $Q_i \hookrightarrow A^{\heartsuit}$
⇅
Disciplines ⇔ Domains ⇔ Sectors ⇔ Themes ⇔ Tasks

The society of trivial pursuit

Curricula as a set of 'works'

'Applicationism' as prevailing epistemological model

Disciplinary confinement

Difficulties in managing didactic time

Strong changes on the **didactic contract**

Lack of **routines** and **devices** to make some gestures possible

Lack of terminology for students and teachers about modelling

Rigidity of the conceptual organisation of mathematical knowledge

Levels of didactic codeterminacy
(Chevallard, 2002)

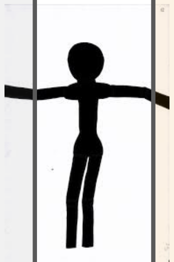
V. Conclusions: Parallel and complementary worlds

What is mathematical modelling and how is it conceptualised?

… as an object to be taught and learnt or as a means to teach mathematics

… from research, from curricula, from the schools' context

Collective construction of an epistemological understanding



How to diffuse mathematical modelling as a normalised activity?

… **at Preschool, Primary, Secondary school and University**

↕

… **in Teacher Education**: pre-service or in-service teachers

Collective construction of educational infrastructures and identification of conditions/constraints

Epistemological needs

Systems ⇔ **Models**

Recursivity and Reversibility

Didactic needs
Ecological needs

Scholarly knowledge (Institutions producing, using) ⇄ **Knowledge to be taught** (Educational system, "Noosphere") ⇄ **Taught knowledge** (Classroom, teaching) ⇄ **Learn, available knowledge** (Community of study)

Thank you very much

Nagyon szépen köszönöm

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CERME 13 Budapest, July 11 2023