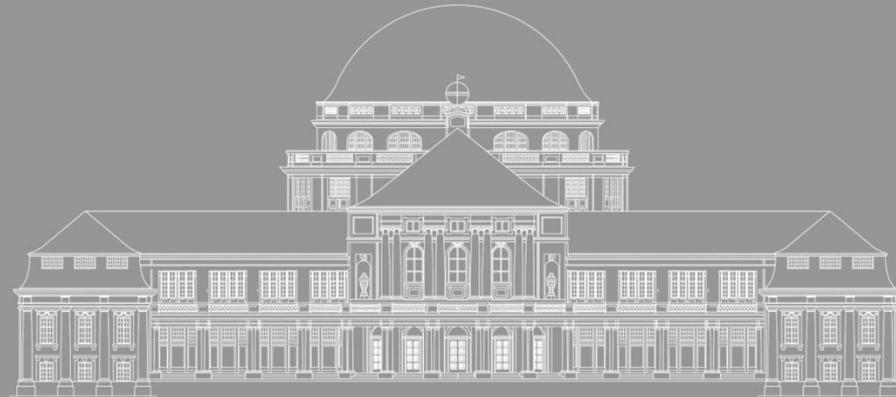# *Quod erat demonstrandum*:

Understanding and explaining equations in physics teacher education

Ricardo Karam[1] & Olaf Krey[2]

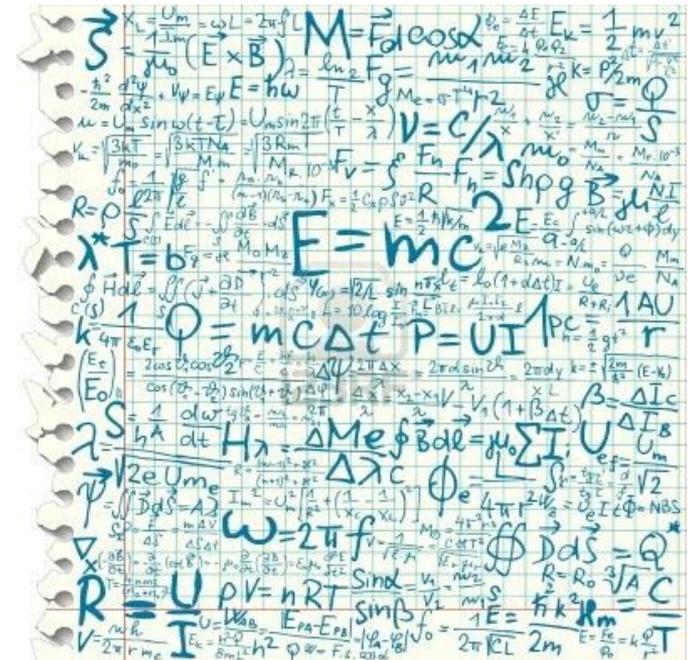**[1] Universität Hamburg – ricardo.karam@uni-hamburg.de**

[2] Universität Halle – olaf.krey@physik.uni-halle.de

Role of equations in physics lessons

- Calculation tools *(Plug-and-Chug)*

- Description of empirical regularities

- Belief in the authority of formulas

- Lack of understanding (Why?)

- Teachers are an **essential** part of the solution!

Seminar for teacher students

Epistemological Motivation

In the further development of science, we want more than just a formula. First we have an observation, then we have numbers that we measure, then we have a law which summarizes all the numbers. But the real glory of science is that we can find a way of thinking such that the law is evident (Feynman, 1964)

Pedagogical Motivation

PCK includes the most useful forms of representation, the most powerful analogies, illustrations, examples, and demonstrations […] Since there are no single most powerful forms of representation, the teacher must have at hand a veritable armamentarium of alternative forms of representations (Shulman, 1986)

Part 1: History and Philosophy (6 h)

Text 1: Consequences of the mathematization of physics (1700-1900): Social, Epistemological und Ontological (Gingras)

Text 2: Significance of some basic mathematical concepts (multiplication, function, real and complex numbers) for Physics (Bochner)

Text 3: The interplay of physics and mathematics (Feynman)

- Role of Mathematics in Physics and vice-versa;

- Mathematics as a language and/or reasoning

- Different thinking of mathematicians and physicists

Part 2: Explanations repertoire (4 x 3 h)

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Part 2: Explanations repertoire (4 x 3 h)
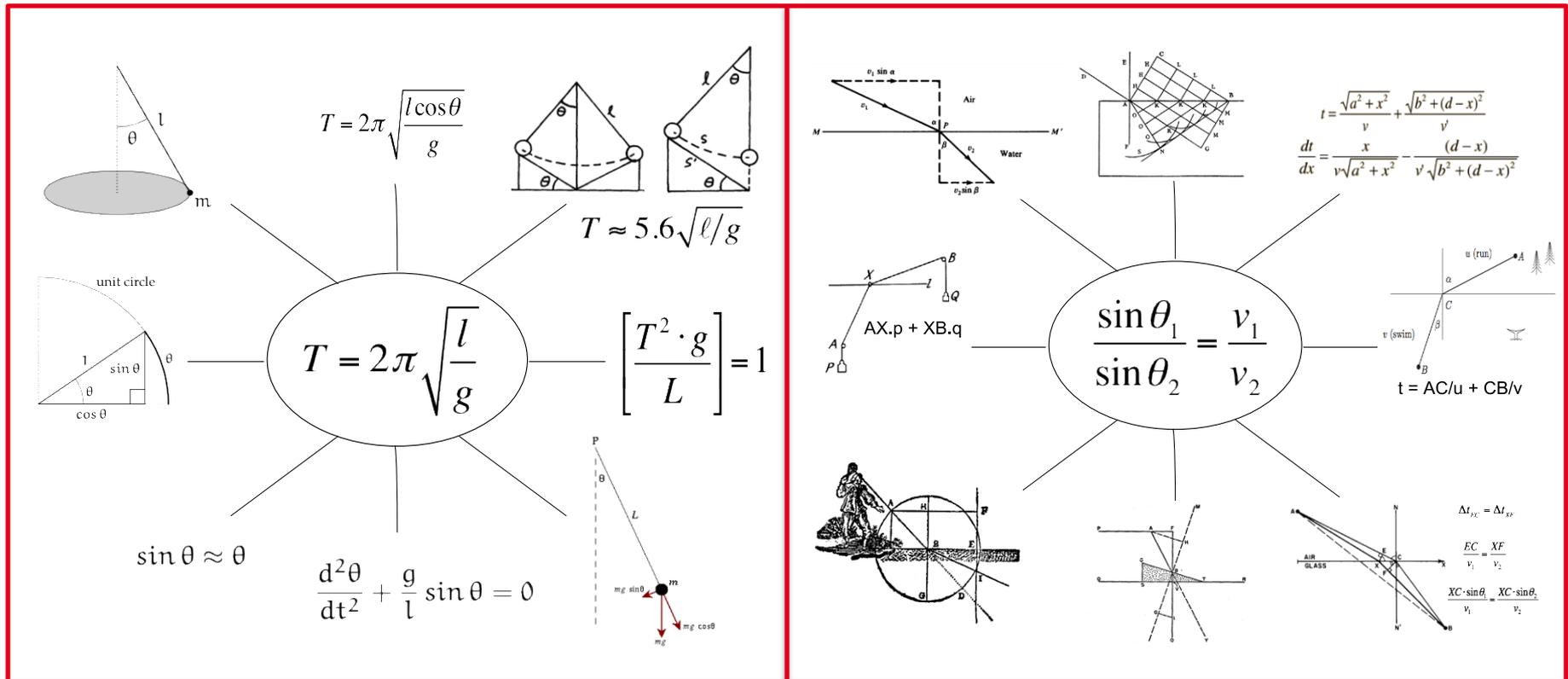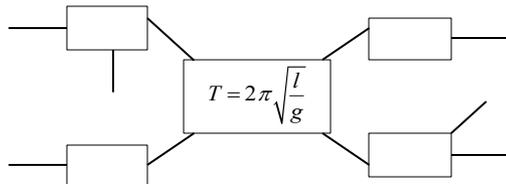
Research questions

1) Are there changes in the students' ideas about:

1.a) **The relationship between physics and mathematics**?

1.b) **The role of formulas/derivations in physics lessons**?

2) How did the students use the learning opportunities of the seminar? (Case study basis)

Data (written)

1) Questionnaire

Mathematics in Physics (Krey, 2012)	⟷	Understanding equations	⟷	Explaining equations
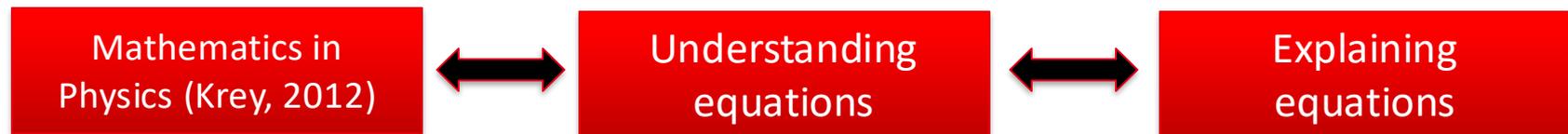
2) Mind maps and explanations repertoire

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

One of your students asked : "Why does the equation have this structure?" Please sketch **different ways** to answer this question. The more, the better.

3) Reflection portfolio

10 min in the end of each meeting – Register the learning process

- What did you learn today? What did you dislike? Which questions were left unanswered?

Data (Video)

4) Recordings of the seminar

- Discussions: Learning difficulties; Pre-requisite; Curriculum
- Reasons for preferring one derivation

5) Interviews with 4 students

before   during   after

- Justify answers (written) and manifestations in class
- Evaluate the seminar regarding contributions for future work as teachers

The case SDX78 - Michael

- Emphasis in high-school: Physics & German; 2nd topic: History

- Small interest (2) for theoretical physics

- **Negative attitude** towards mathematics:

"Mathematics brings students to despair and is responsible for many conflicts in German families" (Pre)

- After questionnaire (Pre) in the **reflection portfolio**:

"I found the questions about how to explain equations quite difficult. I mean, we often calculate with them, but rarely know where they come from"

Role of mathematics in physics

| Metaphor (Pre)	Metaphor (Post)
Mathematics is for physics like…	*Mathematics is for physics like…*
a foothold to study nature *impossible to get along without it* *barrier: prevents normal people from understanding physics*	*a language to categorize natural phenomena* *a structure that provides new knowledge*

Deriving formulas

The function of derivations of formulas in physics is to show that it is ok to use them. (Pre: Strong agreement; Post: Slight disagreement)

*Interview: "We often asked ourselves: What is actually behind this formula? The most important thing was to **learn to ask these questions**; where does this and that come from? Derivations are very important for this purpose [...] My favorite formula is now the centripetal acceleration: I know where it comes from, I know what is behind it and I can derive it in a meaningful way. And that is when we really understand a formula."*
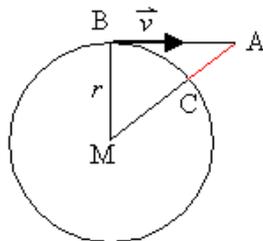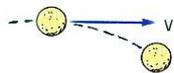
$$\overline{BA} = v \cdot \Delta t \qquad \overline{AC} = \frac{1}{2} a_z \cdot \Delta t^2$$

$$v^2 = r \cdot a_z + \frac{1}{4} a_z^2 \cdot \Delta t^2$$

for small Δt

$$r^2 + (v \cdot \Delta t)^2 = \left(r + \frac{1}{2} a_z \cdot \Delta t^2 \right)^2$$

$$a_Z = \frac{v^2}{r}$$

Explaining a = v²/r in physics lessons

a = v²/r (Pre)	a = v²/r (Post)
1) Meaning of each symbol	*1) Example (Moon around Earth)*
2) Analyze what happens when one magnitude varies	*2) Problem: What is the earth were not there?*
3) Explanation of the formula with drawings and examples	*3) Derivation using Pythagoras*
4) Discuss its use in everyday life	*4) a to the center (F_G to Earth)*
Exp repertoire: a = v/t und v = s/t ; a = v²/s (s = r)	**Exp repertoire**: 3 Derivations
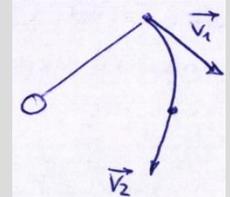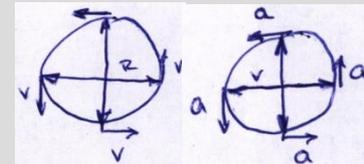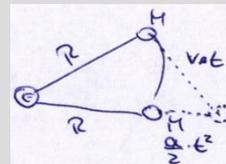
Conclusions & Perspectives

- Equations in physics lessons: from describe/calculate to explain/understand

- Seminar for teacher students: HPS + Explanations' repertoire

- Case-study (SDX78)

    - Better attitude regarding mathematics in physics
    - Connection between understanding and deriving equations
    - From describe/calculate to derive equations in physics lessons

- General evaluation of the seminar and improvements

- Understanding and explaining equations in school: "Didactics of Formulas"