Teaching and learning chemical kinetics as part of a physical chemistry course to chemistry majors

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Physical Chemistry

- G. K. Vemulapalli, *Invitation to Physical Chemistry*, Prentice-Hall, 2010:

"Physical chemistry has a reputation for being fascinating and fearsome"

Physical Chemistry

- **Moore and Schwenz (1992):**

This course ''sets the tone'' of the chemistry major.

Moore R. J. and Schwenz R. W., (1992), The problem with P. Chem., J. Chem. Educ., 69, 1001–1002.

- **Wilhelm Ostwald** (1853–1932) devoted much of his life to the study of energy, and received the Nobel prize in chemistry in 1909 for his work on catalysis, chemical equilibria, and reaction velocities, areas that are central in the study of phenomenological chemical kinetics`.

- Two other pioneers of the development of chemical kinetics were **Peter Waage** and **Cato Guldberg** who formulated the law of mass action in 1864.

- Tsaparlis G. (2019).

Teaching and learning electrochemistry

(Review article in Special Issue: Chemistry Education,
Eds. R. Blonder & R. Shenhar).

Review article (Bain and Towns, 2016) of the literature on the teaching and learning of chemical kinetics.

Concluded with directions for future research and implications for practice.

More research at the undergraduate level was needed on more advanced kinetics concepts, such as reaction order, mechanism, the steady-state approximation, and enzyme kinetics.

- **K. Bain and M. H. Towns (2016).** A review of research on the teaching and learning of chemical kinetics, *Chem. Educ. Res. Pract.*, 17, 246–262.

Justi (2002) had previously reviewed this topic:

- **R. Justi (2002). Teaching and learning chemical kinetics, in** *Chemical Education: Towards Research-based Practice*, ed. J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust and J. H. Van Driel Springer, Dordrecht, 2002, pp. 293–315.

Two areas of work emerged from the **Bain** and **Towns** review:

(a) **student understanding and misconceptions**, and

(b) **instructional approaches to teaching.**

- A heavy emphasis on identifying **misconceptions**.
- **Macroscopic modeling** was typically used by students when solving **chemical kinetics problems**, rather than **theoretical** or **particulate modeling**.
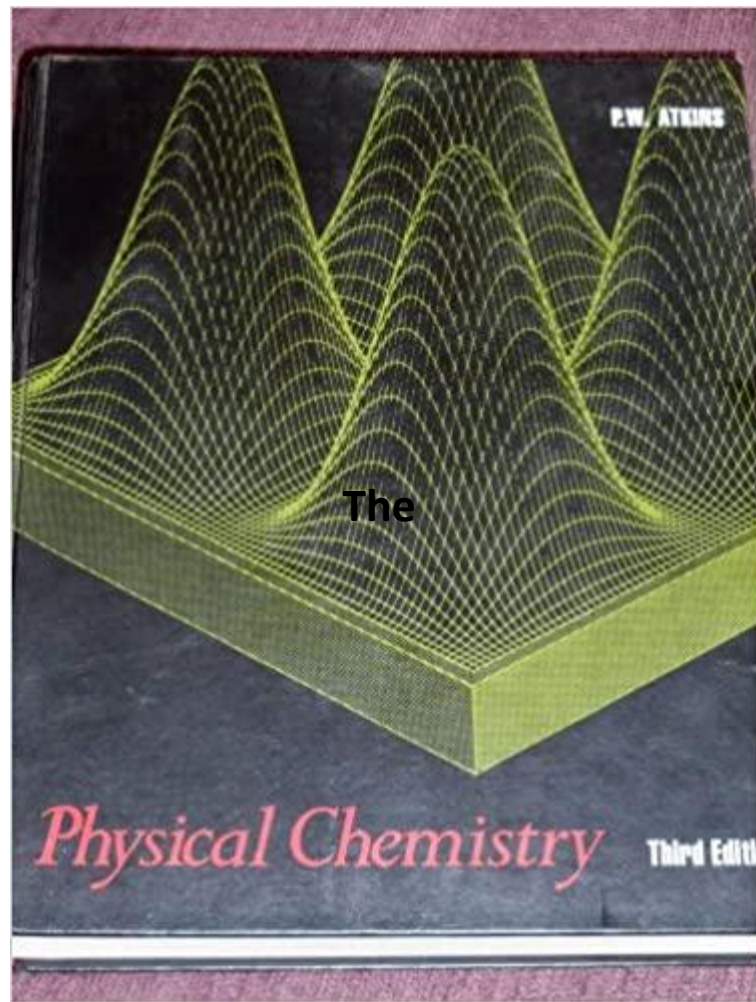
- The studies examined basic concepts and aspects, such as **defining reaction rate, explaining effects of variables** (e.g., temperature, concentration, and catalyst), and **understanding activation energy**.

- Some studies investigated more complex concepts involving **multi-step reaction mechanisms** and **reaction order**, but at a relatively simple level (due to the context of the studies, largely being at the **secondary** or **introductory tertiary levels**).

Chemical kinetics topics covered in the study include:

- instantaneous rate of production (dP/dt) and the extent-of-reaction (ξ) variables;
- half-life time of a reaction;
- integrated first and second-order rate laws;
- calculation of the reaction rate constant on the basis of experimental rate data;
- experimental and theoretical reaction rate laws;
- the pre-equilbrium condition and the steady-state approximation;
- the Michaelis-Menten mechanism;
- the Lindemann-Hinshelwood mechanism;
- chain-reaction mechanisms;
- the Arrhenius equation.

- The course followed closely **Peter Atkin**'s approach from a Greek translation distributed freely to the students:

P. W. Atkins (1989). Physical chemistry, 3rd edition (translated in Greek). Crete University Press.

The

Physical Chemistry **Third Edition**
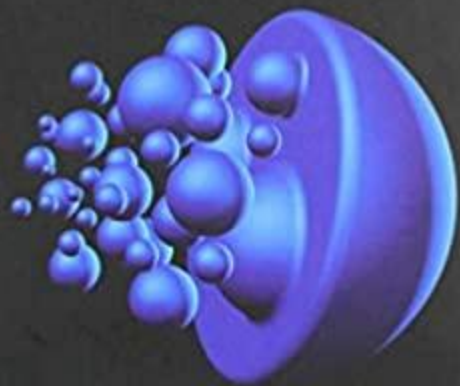
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Aim of the study

- to **analyse**, **evaluate** and **interpret** students' answers to the **final examination** in chemical kinetics.

- The ***results of the study of students' errors and conceptual difficulties*** are reported, which resulted from the recording, statistical analysis and evaluation of the students' responses in **eight (8) consecutive final examinations**.

Mark range*	30-39%	40-54%	55-69%	70-79%	80-100%
N = 328**	71 (11.9/21.6%)	96 (16.4/29.2%)	75 (12.8/22,8%)	46 (7.8/14%)	40 (6.7/12.2%)
Mean Standard deviation	34.1% (2.7%)	46.8% (4.3%)	61.5% (3.9%)	73.6 (2.3%)	87.0% (6.3%)

* Maximun mark = 100.0
** From a total of 584 students, 328 (56.2%) got a mark ≥ 30.0

Three performance groups were identified

- Group A, high performance:

(a) characterization of the steps in a chain-reaction mechanism (N = 26, M = 88.5%),

(b) integrated first- and second-order rate laws (N = 117, M = 83.2%); and

(c) the Lindemann-Hinshelwood mechanism (N = 24, M = 82.2%).

The average performance of these three groups was ≈85%.

- Group B, intermediate performance:

 (a) half-life time of a reaction ($N = 62$, $M = 77.9\%$),

(b) instantaneous rate of formation and the extent-of-reaction variable ($N = 60$, $M = 75.3\%$),

(c) the Michaelis-Menten mechanism ($N = 93$, $M = 74.0\%$)and

(d) theoretical rate law not asking for a final formula($N = 120$, $M = 67.7\%$).

The average performance of these four groups was ≈ 74%.

- Group C, low performance:

(a) determining the experimental reaction rate law and calculating the reaction rate constant on the basis of an experimental-data table ($N = 10$, $M = 59.5\%$),

(b) extracting the theoretical rate law ($N = 258$, $M = 53.5\%$), and

(c) the Arrhenius equation ($N = 60$, $M = 60.2\%$).

The average performance of these three groups was ≈54%.

Students' errors and misconceptions have also been identified.

- "**Systematic**" errors are caused by learning difficulties or failures in understanding the underlying theory, concepts or procedures. This is commonly referred to by the term "**alternative conceptions**" or "**alternative ideas**" or simply as "**misconceptions**".

- "**Random**" errors are caused not by lack of knowledge or misunderstanding, but by haste or carelessness or overload of "working memory" or by the "field effect" (or by a combination of the above factors).

- A greater variety of errors and misunderstandings occurs in the case of **problem solving** by students.

Definition of reaction rate and integrated rate laws (1st and 2nd order)

- *Errors with instantaneous formation rate and the extent of reaction variable ξ: wrong formula for ξ or without employing ξ or by deriving the rate law based on the total, stoichiometric equation of the reaction and not on the mechanism.*

- *1st order reaction rate law: small numbers of errors - most common mathematical errors in logarithmic operations.*

Half-life time

- Small numbers of errors. With greater frequency (50%): an **error** in the **numerical substitution**.

- High frequency (36%): **incorrect logarithmic operations**.

Arrhenius equation

- Errors mainly based on **lack of knowledge**.

Michaelis-Menten equation

- Wrong definition for the **Michaelis K_M constant** (or it is not used).

- To a lesser extent, the **steady-state approximation** (SSA) is not applied.

- More frequent: students come to the wrong conclusion about the **maximum reaction rate**.

Lindemann-Hinshelwood Mechanism

- Significant percentages refer to a thought jump in the student response and absence of assumptions before the application of the SSA or incorrect approaches /simplifications are made.

Definition of reaction mechanism and characterization of stages

- Students incorrectly characterize the stages (elementary reactions) or even misinterpret the definition of the mechanism.

- A common error: neglecting the stoichiometric factor in the reaction rate law.

- An exponent is omitted at a concentration that participates in the rate law, while stages in the reaction are not taken into account, usually the fast stage.

Problems with theoretical rate law calculation (without arriving at final formula).

- A significant percentage of errors: omission of a stoichiometric coefficient in the expression of the rate law.

- Most errors: omissions when writing the kinetic equation, followed by errors in formulating the rate law.

- Less common: errors in the hypotheses or simplifications of the theoretical law, errors indicating confusion between the kinetic equation and the total reaction, and errors relating to the two approximation methods, the equilibrium condition and the SSA with regard to the application and justification of valid conditions.

Problems of theoretical rate law calculation (arriving at a final formula).

- The largest percentage of errors.

- 1st Group of errors: errors in the formulation of the rate law.

- 2nd Group: confusion of the kinetic equation and the overall reaction.

- 3rd Group: choosing the appropriate method or comparison as well as justification.

Conclusions (1)

- **Confirmed**: the teaching of chemical kinetics presents significant problems of understanding and / or confusion of basic concepts.

- It is **necessary for teachers** to know the potential of students, the **difficulties** and **possible misunderstandings** but also the **teaching approaches** that may contribute to **overcoming** the problems. The study of the relevant educational literature is obviously useful and necessary.

Conclusions (2)

- **Laboratory experience** can cause cognitive conflict and lead students to the desired conceptual change - finding out for themselves their errors through conducting the experiment (**constructivist learning model**).

Conclusions (3)

- The teaching of chemical kinetics must place great emphasis on **problem solving** and the systematic training of students with a **variety of problems**.

- It is very important, that **the students themselves try to solve the problems**.

Conclusions (4)

- **Also very important**: help students with **guidance** and **suggestions** from the **teachers**, as well as encourage **collaborative learning** in groups.

Endpoint

- The **attendance of the lectures** by the students must be **regular/compulsory** and **NOT minimal** or even **non-existent**.

- *This is an old problem for theoretical courses (lectures) in the Greek universities*.

Endpoint

- *The system of organization and operation of university departments must therefore be radically changed*.

Endpoint

- **Exercises** and **home assignments** should also be used (with **encouragement** and **collaboration** among students) by **all faculty**, so that *students are taking seriously their studies*. In other words, there must be such a radical change in the **organization** of the **departments**, in the **teaching methods**, but also in *the way the students themselves deal with the lectures*.

Σας ευχαριστώ