Phenomena of a candle – helping students to perceive, wonder and ask: an updated Victorian teaching example

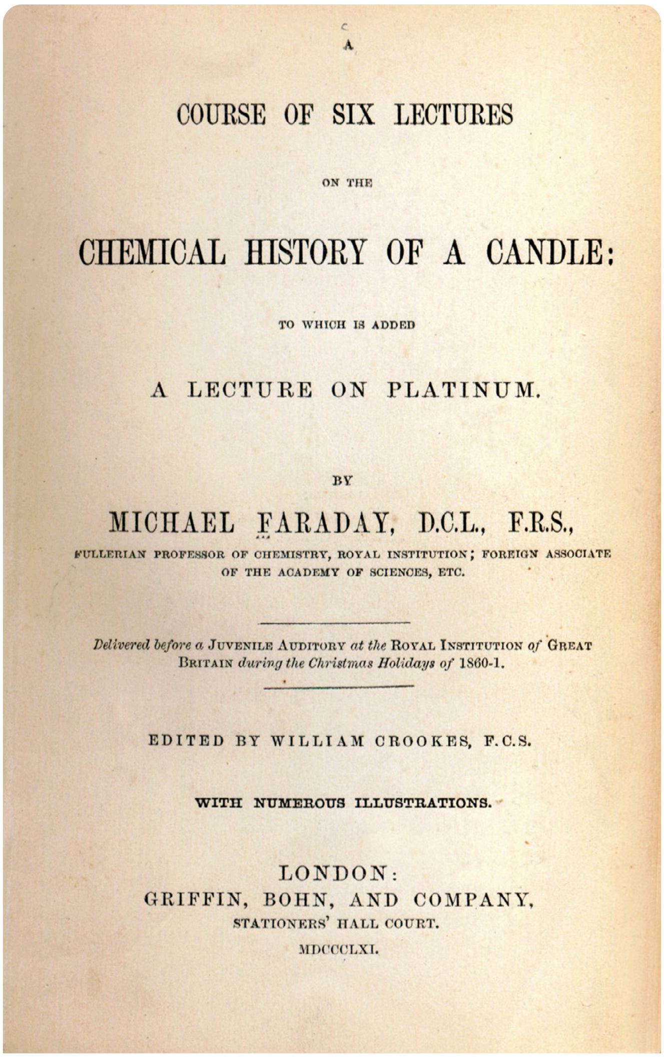
Markus Emden, Mario Gerwig, Michael Jänichen and Susanne Wildhirt

Abstract Martin Wagenschein's ideas of prioritising phenomena in making sense of science processes have influenced the German *Lehrkunstdidaktik* (art of teaching) approach. This article sketches a *Lehrkunstdidaktik* teaching unit inspired by Michael Faraday's *Chemical History of a Candle*. It shows how primary and lower secondary students (ages 10–13) understand scientific concepts through close observation. The seemingly trivial example of a burning candle teaches students to inquire into which burns – wick or wax, how the wax gets to the flame, and what happens to it once it gets there. By the end of the unit, students will have discovered for themselves the carbon cycle in the candle.

The year 2021 marks three anniversaries that are significant for science education in general and, especially, for German, Austrian and Swiss science education. This year marks the 230th birthday of Michael Faraday and the 160th anniversary of his famed series of six lectures on the *Chemical History of a Candle* (Figure 1), which he gave at the Royal Institution of Great Britain over the Christmas period 1860–1861. Thirdly, 2021 marks Martin Wagenschein's 125th birthday. His contributions to science education are pivotal in Germany, Austria and Switzerland. This article sketches how these three anniversaries make for a happy coincidence in science education.

Michael Faraday

Michael Faraday (1791–1867) was born the son of a blacksmith who settled in London around 1800 (Seeger, 1967). Originally, Michael was 'earmarked' for a career as a bookbinder, but he found the content of the science books he got in for binding interested him more than the craft itself. He studied science on his own and undertook to repeat many of the experiments that he had read about (Williams, 1960). When he was given a ticket to see Sir Humphry Davy lecture at the Royal Institution, he took his chance and applied for a job under Davy. In 1813, he was accepted and later accompanied Davy on a lecture tour of the Continent (Williams, 1960). After Davy's retirement from the Royal Institution, Faraday rose to become its first Fullerian Professor of Chemistry in 1833 (James, 2007). He 'invented' the now-famed Christmas Lectures for a 'Juvenile Auditory' in 1825 (James, 2007) and contributed 19 lecture series between 1827 and his retirement in 1862 (Royal Institution, n.d.). His fabled *Chemical History of a Candle* was presented twice at least (1848/49 and 1860/61) and dealt with scientific phenomena relevant to burning a candle. The 1860–61 series was documented by a shorthand writer (James, 2007) – otherwise they might have been lost for good – and has never been out of print since (Faraday,


A

COURSE OF SIX LECTURES

ON THE

CHEMICAL HISTORY OF A CANDLE:

TO WHICH IS ADDED

A LECTURE ON PLATINUM.

BY

MICHAEL FARADAY, D.C.L., F.R.S.,

FULLERIAN PROFESSOR OF CHEMISTRY, ROYAL INSTITUTION; FOREIGN ASSOCIATE OF THE ACADEMY OF SCIENCES, ETC.

Delivered before a JUVENILE AUDITORY *at the* ROYAL INSTITUTION *of* GREAT BRITAIN *during the Christmas Holidays of* 1860-1.

EDITED BY WILLIAM CROOKES, F.C.S.

WITH NUMEROUS ILLUSTRATIONS.

LONDON:
GRIFFIN, BOHN, AND COMPANY,
STATIONERS' HALL COURT.
MDCCCLXI.

Figure 1 The title page of the first edition of Faraday's *Chemical History of a Candle* (1861)

1861; James, 2011). The book has become a veritable classic of science education – so famed, indeed, that it could not pass by the attention of Germany's most influential science educator, Martin Wagenschein.

Martin Wagenschein

The German physicist and pedagogue Martin Wagenschein (1896–1988) chose to train as a physics teacher after completing his PhD in experimental physics. Thus he entered teaching with a different perspective from many of his peers, having experienced physics from the inquiring scientist's perspective. His first decade of teaching – at one of the prime centres of progressive education – conveyed yet another perspective: helping students understand physics rather than indoctrinating them. He developed a unique philosophy of science teaching and advocated it as a teacher educator, too, from the 1950s. His theories have influenced science teachers in Germany, Austria and Switzerland ever since. This article outlines Wagenschein's Principles of Teaching, introduces a related approach to teaching, and illustrates it by referring to a teaching unit for introductory science classes modelled on Faraday's lecture series on the candle.

Wagenschein's Principles of Teaching

One key principle was to expose children to phenomena to inspire them to ask questions that would be used to develop the teaching. A phenomenon, for Wagenschein, is an effect or a peculiarity one can observe in nature or the controlled laboratory, respectively. Wagenschein cherished young children's curiosity as a starting point for learning just as Faraday did:

> *At my juvenile lectures at Christmas time, I have never found a child too young to understand intelligently what I told him; they came to me afterwards with questions which proved their capability.* (Seeger, 1967: 109)

Wagenschein imagined the teachers' job to be supporting their students in understanding, that is, not to make them recall but to integrate new knowledge. In this endeavour he considered phenomena that allowed children immediate access to an inquiry into nature to be crucial (Wagenschein, 1976/2008). Above this, he considered three more Principles of Teaching to be essential: the Genetic, the Exemplary and the Socratic Principles:

- **The Genetic Principle** (Roth, 2015) denotes an approach that paces teaching with an aim to 'synchronize' student understanding with the actual evolution of knowledge. Optimally, nothing is imparted by teachers, but students generate knowledge from their own observations, questions and problem solutions. This might be facilitated by retracing the historical genesis of the content, following its milestones. If even scientists must depend on preceding knowledge, students must not be expected to understand the new before being acquainted with the traditional.
- **The Exemplary Principle** advises teachers to choose lesson content that is representative of, and allows building bridges to, other content. Exemplarity means that transferable knowledge and skills are learned, which can serve as a centre for further learning (Wagenschein, 1956/1999). The United States' Next Generation Science Standards' Disciplinary Core Ideas and Crosscutting Concepts (National Research Council, 2011) or Germany's Fundamental Science Concepts (Emden, Weber and Sumfleth, 2018) may be considered realisations of this Principle.
- **The Socratic Principle** encourages teachers to develop their topic through classroom discourse. Children are innately curious and clever in devising problem solutions – even if they are not scientifically accurate, their reasoning is logical. Teachers need to listen closely, ask for clarification, and support students in drawing their own conclusions.

Lehrkunstdidaktik

Lehrkunstdidaktik, the art of teaching approach, has been developed following Wagenschein's Principles since the late 1980s in Germany and Switzerland (Emden and Gerwig, 2020). *Lehrkunstdidaktik* designs, evaluates and perfects '*experienced, straight forward and playable teaching units, following Wagenschein's and his equals' ideas*' (Berg, 2004). *Lehrkunstdidaktik* often employs analogies from stage direction – 'playable' is the authentic quotation here, but might be better understood in terms of 'being fit to be staged', 'performable' or 'usable'.

Their basic suggestion is to design excellent teaching units (currently more than 50), to report these, to make the reports available, to encourage re-enactment of the same units, and then to refine the units iteratively. The teaching reports' conception is crucial: just as a theatrical script informs the staging of a play, providing its basic narrative and allowing for artistic licence, *Lehrkunstdidaktik*'s teaching unit reports are meant to inform teaching that allows for 'pedagogical licence' (hence, *playable* teaching units).

Wagenschein considered Michael Faraday's lecture series *on* the *Chemical History of a Candle* (Faraday, 1861) to be a prime example for teaching science and he claimed that each teacher (not each science teacher) should know it. Consequently, *Lehrkunstdidaktik* has adapted portions

Table 1 Consensus syllabus for The Candle; phenomena are translated from illustrating Lesson Plates (Wildhirt, 2008)

Lesson (duration/minutes)	Phenomenon	Leading question/Focus of Instruction – student performance
1 (45)		Candle: Where from? Where to? – reconstructing a candle's 'biography'
2 (90)	Recall candle	What does a candle flame look like? – sketching images of burning candles from memory
		Michael Faraday – listening to a biographical sketch including a short history of the Christmas Lecture
	Travelling flame	Can you light a candle from its rising vapours after blowing it out? – trying to reignite their own candles from as far from the wick as possible
3 (90)	Sea of flames	Which burns: wax or wick? – observing the difficult ignition of pure wax and the mere glowing of pure wick; observing a demonstration: ignition of molten wax that has been heated until vapours rise
	Dancing flame	Is there something inside the flame? – cutting open the flame by placing wire gauze in it, eventually lighting the rising wax vapours
4 (90)	Capillary attraction	How does wax get from the cup to the flame? – observing a demonstration of capillary attraction
	Filial flame	Is the vapour from inside the flame burning? – draining vapour through a glass tube and igniting it; bypassing vapour into an Erlenmeyer flask and igniting it
	Quenching the flame	What does the candle need for burning? – inverting a beaker over a burning candle suffocating the flame
5 (120)	Black soot	What emanates from a candle? – collecting soot from a candle flame on a white porcelain bowl
	Projected flame	Where is the black soot in a light-coloured candle? – observing the shadow that the luminous part of a candle flame casts in back projection
6 (60)	Fireworks	What makes the candle glow yellow? – sprinkling metal powders and soot into the flame of a burner (or observing a teacher demonstration)
7 (90)	Firewater	What else emanates from a candle? – inverting a beaker over a candle, observing the formation of condensation; collecting water from the burning candle with a vacuum pump and a steam trap
8 (90)	Carbon-air	What else emanates from a candle? – bubbling the candle's exhaust gases through limewater (demonstration); observing the resulting clouding
	Candle in the glass	What happens to 'used air' from a candle? – observing a demonstration of green plants (common laurel) regenerating oxygen from 'used air'
9 (90)		Closing the candle's carbon cycle – revisiting the candle's 'biography', realising that the two ends connect

from the lectures into a teaching unit for the primary and lower secondary levels since the late 1980s.

The Candle – a teaching sequence for understanding

Faraday's lectures provide a veritable cornucopia of scientific knowledge from biology, chemistry and physics, which is relevant when considering the processes inside a burning candle. He performs nearly 200 experiments to make abstract scientific concepts immediately perceivable to the senses and to make students wonder and ask questions.

Lehrkunstdidaktik's adaptation of Faraday's lectures preserves several of his experiments – a syllabus is outlined in Table 1. In the spirit of a script, this syllabus is open to variation ('artistic/pedagogic licence') and translates the candle lectures into discursive, student-centred lessons aligned with contemporary teaching theories.

Lesson 1

Students (grades 3–5; ages 10–13) sit in a circle watching four beeswax candles that have burnt to different lengths. The teacher asks them where the candles come from and they retrace the candles' production from the beekeeper, through the nectar-gathering bees, to the trees and flowers that need sun, water, soil and air to grow. During this discussion, the smallest of the candles expires. The teacher asks: '*Where has it gone?*' Students might say it has turned to carbon dioxide, to which the teacher then replies: '*What is this carbon dioxide? Where is it? I cannot see it; please, show me.*' Students are thus gently reminded to first rely on their senses and observation instead of referring to hollow, half-understood concepts.

Lesson 2

Students draw a candle flame from memory. As they have rarely *observed* a flame, although they have frequently *seen* one, they are challenged in several aspects: Which is the flame's exact shape? Is it oblong or is it a drop? What are its colours? Is it just yellow? Was there orange and blue, too? What about that darker portion in the flame's heart? Having completed their pictures, students contrast their visions of the flame with an actual candle: How do they compare? This exercise prepares them for accurate observation, which will be essential for the remainder of the sequence.

Only then are they introduced to Michael Faraday as a scientist who taught young students science through observation of a candle. Faraday will be their companion for the rest of the unit. The teacher – assuming Faraday's persona – will read from his lecture and help them to perform the demonstrations from his lectures.

Faraday introduces the students to the candle by virtue of '*a very pretty, but very common-place experiment*' (Faraday, 1861: 19). He gently blows out a candle and holds a lighted taper in the rising fumes, which makes the candle reignite – the flame might even travel some distance from the taper to the wick. Wagenschein, (1976/2008) stated, in relation to Brownian motion, '*This must be seen! It is hard to understand that all schools don't show this fundamental phenomenon to children*', but this is equally true of the travelling flame, which is a superb trigger for inquiring into nature. The wondrous 'jump' from taper to wick piques students' curiosity and the teacher must help them understand it by following this logical sequence: Blowing out the flame makes vapours rise from the wick. What are these? See, they can be ignited with a match. How far can it travel? What then is this vapour composed of? Why, it must be wax as it is white and feels fatty to the touch. Yet how does the wax get to rise from the wick?

Lesson 3

This lesson takes up the inquiry and investigates which burns: wick or wax. Igniting both leads to a glowing wick and blackened wax (paraffin). If we heat paraffin until smoking and ignite the fumes, however, there appears a veritable sea of flames – too wild for taming and thus too insecure for indoor use. Why then does a candle burn calmly? Maybe it is the pairing of wick and wax. So, is there really wax burning? How can we find out? We need to look inside the flame to see what is there where the burning takes place. Thus, Faraday helps students to 'cut open' a flame using wire gauze. They hold it in the flame, realising the flame is hollow and that the very same white vapour rises from it as from the wick. This vapour can be ignited and with some tender handling of the gauze a flame can even be suspended above it.

Through this activity, it becomes apparent that the wax, which originates in the candle stem, rises from the wick. On closer inspection, students realise that the candle stem melts into a wax lake at the wick's foot (which student has not dipped their fingers into it?). All that is left to learn is how the wax climbs up the wick to its tip so that it can be burned.

Lesson 4

Faraday's students did not know what capillary attraction is or how it comes to be (Faraday, 1861: 14–18), and neither do modern-day students. But they know related phenomena, for example soaking towels: Faraday and the teacher can bring them to see the working of capillary attraction by dipping a wick into coloured water. This will rise through the wick as presumably any liquid would. Wasn't there some liquid at the wick's foot?

Still, one might object that the vapour that can be seen when cutting the flame open is not actually burning (how would it exist inside the flame!). Students will therefore collect the wax vapour directly where it forms – at the wick inside the flame – with a heat-resistant glass tube and funnel it outside the flame. This vapour, rising from the glass tube, can be ignited, giving an orange flame as if it were a sibling of the candle ('filial flame'). Students will have followed the journey of the wax from stem to flame conclusively through their own senses and thinking.

Lessons 5–18

The scope of this article does not allow me to describe in detail each investigation the students perform. *Lehrkunstdidaktik*'s general approach probably comes across nonetheless: students are led from observation of phenomena, through an inquiry into causes and thence to an understanding of the science. Knowledge is rarely imparted if students can come up with it themselves – it is only in the later stages of the sequence that teachers need to provide information when pure observation proves futile as the submicroscopic level is addressed. Mostly, the teacher 'just' asks and triggers: they guide their students towards those experiments that they then can perform themselves. This takes time as each pair of students should have the chance to produce the respective phenomena, but the added time will pay off in terms of curiosity *and* retention. For example, students observe soot emanating from the flame by inserting a porcelain dish (Black soot from a white candle? Are you serious? Ah, wax is broken down by fire.). Or they wonder how water forms in a beaker inverted over the flame (Water inside a candle? Whoever heard of such a thing? Parts of the wax combine with the air to form water.). The students are not allowed to content themselves with the view that something just happens; they are urged to go the extra mile and ask: 'Why?'

Students, however, are *not* expected at this stage to invent their own investigations as they are usually not sufficiently prepared to do this (Emden and Gerwig, 2020). They cannot invent a suitable method to confirm water's identity as they know nothing of anhydrous copper(II) sulphate (greyish), nor of its water-containing twin (blue). Nonetheless, they can ask: '*Is there a way to know that this is water?*' and the teacher can respond: '*Yes, indeed, there is a way; let me show you*.' This is markedly different from introducing analytical tests for water several lessons before there arises a need for identifying water – because the question feeds from the students' interest and not 'merely' from the curriculum.

Neither can students spontaneously produce the idea that maybe different substances (magnesium, copper, soot, etc.) give different colours (white, green, orange, etc.) when burnt. Even if they have seen fireworks and sparklers, they have no knowledge of what causes these light effects. They will, however, realise from the sprinkling of several powders into the Bunsen burner's flame that only soot gives an orange flame – the very same substance they found previously in the flame when dipping a porcelain dish into it.

Lessons 19–20

Eventually, students will come to realise that the candle does not vanish, but that its wax is transformed by the flame into water (misting of an inverted beaker over the flame) and carbon dioxide (clouding of limewater by bubbling the gases and particles from the flame through it). They will learn that these are the substances that plants need to grow. And, thus, the question of where the candle goes to connects back to the question of where it comes from. In the end, students will have discovered the carbon cycle by themselves.

The students' view

Students regularly report having enjoyed this unit, but enjoyment is not synonymous with learning, nor, although admirable if achieved, is it the foremost purpose of teaching or an educational category. One of the authors asked her 10- to 11-year-old students after a three-month delay what they remembered of The Candle. Their replies evidence retention of quite detailed knowledge (e.g. it is not the wick that burns, the flame is hollow, water comes from the flame, '*Isn't it awesome that exactly where the flame shines the brightest, there is the black, dark soot*' [our translation from Wildhirt (2008)]). In addition, they appreciated that the course had allowed them to inquire ('*we found answers to each question with experiments as well as new questions*' (Wildhirt, 2008)) and they emphasised the surprise finding of the carbon cycle ('*Actually, almost everything was new-found for me, e.g. that hydrogen and carbon find a new partner – oxygen; but the best thing was that they come together again in the end*' (Wildhirt, 2008)). Beyond this, there has been consistent affirmation of the teaching unit's general appreciation for the past 30 years: hardly any student will forget when they first saw the inside of the hollow flame; they will not easily dismiss their confusion when they found black soot emanating from a white candle, or discovered that water could be collected from the flame – of all places.

The Candle – still a guiding light for contemporary science education?

How can *Lehrkunstdidaktik*'s candle contribute to contemporary science education? It is obvious that this course can be instrumental in developing those scientific attitudes that are needed to work scientifically. As in the National Curriculum in England for key stage 3 (DfE, 2013), students are encouraged to '*ask questions and develop a line of enquiry based on observations of the real world*', to '*select, plan and carry out the most appropriate types of scientific enquiries to test predictions*', to '*interpret observations*', and to '*present reasoned explanations*', as well as to '*identify further questions arising from their results*'. They learn basic science concepts regarding '*Material cycles and energy*' (photosynthesis), '*Particulate nature of matter*' (states of matter and their changes), '*Chemical reactions*' (combustion) and '*Earth and atmosphere*' (carbon cycle).

Admittedly, not all of these can be developed fully in an introduction to science, but at least a first acquaintance with some of these aspects might be facilitated. After all, we may take Faraday at his word:

> *There is not a law under which any part of this universe is governed which does not come into play and is touched upon in these phenomena. There is no better,* ***there is no more open door by which you can enter into the study of natural philosophy*** *than by considering the physical phenomena of a candle.* (Faraday, 1861: 1–2, emphasis added)

The metaphor of the open door through which to enter illuminates a crucial idea: observing, wondering and asking merely introduce us to science; the actual exploration continues indefinitely. Faraday's belief was that understanding science benefited from sensory input (Emden and Gerwig, 2020), that is, phenomena are suitable stepping stones to learning, a sentiment shared by Wagenschein and *Lehrkunstdidaktik*.

References

Berg, H. C. (2004) 'Lehrkunstdidaktik': framework and example of a definite 'Inhaltsdidaktik'. *Journal of Social Science Education*, **3**(1), 25–37.

DfE (2013) *National Curriculum in England Science Programmes of Study: Key Stage 3*. London: Department for Education.

Emden, M. and Gerwig, M. (2020) Can Faraday's *The Chemical History of a Candle* inform the teaching of experimentation? *Science & Education*, **29**(3), 589–616.

Emden, M., Weber, K. and Sumfleth, E. (2018) Evaluating a learning progression on 'Transformation of Matter' on the lower secondary level. *Chemistry Education Research and Practice*, **19**(4), 1096–1119.

Faraday, M. (1861) (ed. Crookes, W.) *Course of Six Lectures on the Chemical History of a Candle: to which is added a Lecture on Platinum. Delivered Before a Juvenile Auditory at the Royal Institution of Great Britain during the Christmas Holidays of 1860–1*. London: Griffin, Bohn, and Company. Facsimile available at: https://archive.org/details/acoursesixlectu00faragoog.

James, F. A. J. L. ed. (2007) *Christmas at the Royal Institution: An Anthology of Lectures*. Hackensack, NJ: World Scientific.

James, F. A. J. L. ed. (2011) *Michael Faraday: The Chemical History of a Candle. Sesquicentenary Edition With a Facsimile Reproduction of Faraday's Manuscript Lecture Notes From Royal Institution MS F4 J21*. Oxford: Oxford University Press.

National Research Council (2011) *A Framework for K–12 Science Education. Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: National Academies Press.

Roth, W.-M. (2015) *Enracinement* or the Earth, the originary ark, does not move: on the phenomenological (historical and ontogenetic) origin of common and scientific sense and the genetic method of teaching (for) understanding. *Cultural Studies of Science Education*, **10**(2), 469–494.

The Royal Institution (n.d.) *Complete List of Christmas Lectures*. Available at: www.rigb.org/docs/christmas_lecturers_18252015_0.pdf.

Seeger, R. J. (1967) Michael Faraday: his scientific insight and philosophical outlook. *The Physics Teacher*, **5**(3), 104–111.

Wagenschein, M. (1956/1999) Teaching to understand: on the concept of the exemplary in teaching. In *Teaching As A Reflective Practice: The German Didaktik Tradition*, ed. Westbury, I., Hopmann, S. and Riquarts, K. pp. 161–175. New York: Routledge (original paper published 1956).

Wagenschein, M. (1976/2008) *Save the Phenomena: The Primacy of Unmediated Experience*. (Trans. Salted, J. K. and Holdrege, C. 2008). Available at: www.natureinstitute.org/article/martin-wagenschein/save-the-phenomena-the-primacy-of-unmediated-experience.

Wildhirt, S. (2008) *Lehrstückunterricht gestalten*. Bern: hep verlag.

Williams, L. P. (1960) Michael Faraday's education in science. *Isis*, **51**(4), 515–530.

Markus Emden is a professor of science education at Zurich University of Teacher Education, Zurich, Switzerland. Email: markus.emden@phzh.ch. **Mario Gerwig** is a mathematics and science teacher at Gymnasium Leonhard, Basel, Switzerland. **Michael Jänichen** is a lecturer at Lucerne University of Teacher Education, Lucerne, Switzerland. **Susanne Wildhirt** is a professor of secondary education at Lucerne University of Teacher Education, Lucerne, Switzerland.