Perspective

Israel Journal of Chemistry

www.ijc.wiley-vch.de

doi.org/10.1002/ijch.202512004

Mentoring Doctoral Students in the Chemical Sciences

Rosaria Ciriminna,*[a] Cristina Della Pina,[b] Rafael Luque,*[c] and Mario Pagliaro*[a]

Abstract: The relevance of effective mentoring of doctoral students in the chemical sciences is now widely recognized. However, the scholarly literature on the topic is virtually non-existent, and most approaches to faculty education on mentoring are based on "tips" and "guidelines. Following the analysis of current mentorship practices, we suggest a new approach based on evidence resulting from surveys of doctoral students, and on theory derived from studies in social and human sciences.

Keywords: Mentoring · PhD in chemistry · open science · chemical sciences · systems thinking

Introduction

Mentoring doctoral students in chemistry is an old academic practice going back to the early days of chemistry research in Europe in the first half of the 19th century. For example, from the late 1830s Liebig hosted in Giessen, Germany, numerous doctoral students.[1] The word "mentor" comes from the character Mentor, in Homer's *Odyssey* a friend of Odysseus to whom Ulysses asked to advise, teach and protect his son Telemachus.

Education of doctoral students in modern chemistry was international since the beginning. In 1822–1824 Liebig studied in Paris under Gay-Lussac; Berzelius in Stockholm had as students Rose (1819-1821) and Wöhler (1823-1825); whereas Liebig in 13 years will host in Giessen 21 British and 3 American doctoral students.[2] So important was chemistry even in the 19th century amid all disciplines that, for example, with 251 PhDs awarded between 1863 and 1900 American universities awarded more doctorate degrees in chemistry than in any other discipline.[3] In the same period, only the broad category of "languages and literature, general" took more (17.2%) doctorates than chemistry (11%).

The importance of mentorship ("the activity in which professionals engage to help develop the next generation of science, technology, engineering, mathematics, and medicine professionals"[4] is now widely recognized. Mentorship is "mentorship is a skill that can be developed through intentional and reflective practice and cultural responsiveness".[4]

Yet, as put it by Heemstra and Garg, there is a "dearth of formal training or advice that most science faculty receive when it comes to building this skill set".[5]

Such "dearth" does not limit to formal educational programs at universities worldwide concerning effective mentorship, but it extends to research on the scholarship of mentorship. In contrast, for comparison, plentiful chemistry education research gets regularly published.[6]

The need for better graduate and doctoral student mentors is evident from multiple empirical analyses. A recent survey of doctoral students from across all continents showed a substantial decrease - from 71% in 2019 to 62% in 2022 - in student satisfaction with their current doctoral program.[7] Even worse, 50% of respondents in the 2022 survey say that their satisfaction has declined since starting their program.

Today numerous journals such as the *International Journal of Doctoral Studies*, *Research in Higher Education*, *Innovative Higher Education*, and *International Journal of Mentoring and Coaching in Education* regularly report findings of relevance to the effective mentoring of doctoral students in the natural sciences. These journals, however, are generally not read by research chemists. Furthermore, as noted by Ibo completing in 2021 one of the very first doctoral theses on the doctorate in chemistry in the world, scholarly literature on doctoral education in chemistry "is mostly non-existent".[8] For example, in a study of adviser mentoring and doctoral student outcomes extending over 5.5 years published in 2006 in *Research in Higher Education* on a sample of 133 PhD students in chemistry, physics, and engineering at universities in the USA, Paglis and co-workers found clear positive benefits of mentoring for subsequent productivity and self-efficacy of PhD students.[9] Finally, recounting the kindness and helpfulness of Fraser Stoddard as mentor during his 7 years at Northwestern University, Feng in 2024 published a brief advice for new principal investigators recommending them to avoid assigning blame when mentees make mistake, but rather opt to provide constructive feedback.[10]

[a] Istituto per lo Studio dei Materiali Nanostrutturati, Palermo, Italy
[b] Dipartimento di Chimica, Università degli Studi di Milano, Milano, Italy
[c] Universidad ECOTEC, Samborondón, Ecuador

Correspondence: Rosaria Ciriminna and Mario Pagliaro, Istituto per lo Studio dei Materiali Nanostrutturati, CNR, via U. La Malfa 153, 90146 Palermo, Italy.
Email: rosaria.ciriminna@cnr.it and mario.pagliaro@cnr.it

Rafael Luque, Universidad ECOTEC, Km 13.5 Samborondón, Samborondón Samborondón, EC092302, Ecuador.
Email: rluque@ecotec.edu.ec

Israel Journal
of Chemistry

The aims of this study are two-fold. First, we address the reason for which formal education of young chemical science faculty on mentoring doctoral students is now necessary. Hence, we identify suitable ways to provide said education based both on theory concerning graduate student mentoring; as well as on evidence concerning the specific needs of chemistry.

Method

To address the reason for which formal education of young faculty on mentoring doctoral students in chemical sciences is now necessary, we first identify the early studies in which by the end of the 1980s problems with PhD supervisors of doctoral students in chemistry started to emerge. Hence, through a brief historical analysis we identify the global megatrends affecting doctoral studies in chemistry-related disciplines and their effects in the years of the second great globalization following the collapse of Soviet Union in 1991.[11]

Aiming at identifying suitable ways to provide faculty education, we rely on theory concerning graduate student mentoring from studies in the social and human sciences that so far has remained elusive to scholars in the natural sciences. Students are more willing to take the intellectual risks required for creating new knowledge when their mentor is trustworthy.[12] Studying mentors' trustworthiness from the point of view of the mentored doctoral student, Roberts and Ferro-Almeida in 2019 introduced a theory inspired by authoritative parenting and pedagogy that provides answers to the question of which mentor behaviors and characteristics help doctoral student succeed.[13]

Furthermore, we adopt to academic education the systems thinking approach developed by Seddon.[14] According to said approach, the university is considered as a system whose purpose is defined from the perspective of students. Action to improve the mentoring activity of this system becomes effective when informed by knowledge, not opinion. Knowledge is acquired by research and starts from a "Check" of what matters to students. As shown in Figure 1, willing to found effective change on knowledge, and not on opinion, improvement starts from check.

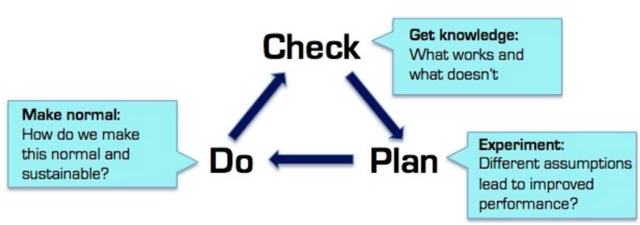


Figure 1. Improvement starts from check. [Adapted from Ref.14, with kind permission].

Check provides valid data and knowledge to inform the solutions found by experimentation for effective mentoring. The aim is to understand how the mentor is performing against the purpose of the doctorate defined by the student: "Provide me with all the resources and help I need to achieve a positive outcome from my time at your university during the doctorate". In this way, action becomes informed by said real knowledge,[15] and not by anecdotes.

Discussion

Why Faculty Education is Required

One of the first alerts concerning problems with PhD supervisors of doctoral students in chemistry was published by Mohrig in 1988. The college chemistry professor collected the response of 46 former students who had enrolled in a PhD program in chemistry at 18 of the main universities in the USA between 1970 and 1985:

"I am concerned about the persistent comments in the responses that some faculty do not appear to be interested in educating graduate students, but onlv in producing research results… Some respondents wrote that they were encouraged by their advisors not to "waste time" by attending departmental seminars. Others were discouraged from doing anything that would take time away from the lab bench."[16]

By the end of the 1980s, indeed, the "publish or perish" pressure, namely the pressure to get publishable results and publish them in a high journal impact factor (JIF) journal was starting to dominate academic work. Ironically, the scholar and entrepreneur who introduced the JIF that eventually led to the "impact factor madness"[17] was a chemist (Eugene Garfield, 1925–2017), founder and owner of the Institute of Scientific Information). Though being the outcome of a highly skewed distribution, the JIF of chemistry journals plays a major role in chemistry scholarship evaluation still today.[18]

Showing evidence of the aforementioned "impact factor madness", at the end of the 1980s an education faculty based in Canada wrote in *Studies in Higher Education*:

"Whether we agree or disagree, getting published appears to be entrenched in the fields of academe. Which leaves prospective authors with two choices. Either they can choose to perish in the trenches, or they can take command and publish their way to professional victory."[19]

The very idea that "professional victory" in the academy equates to a high number of publications (and citations) is one of the main drivers of the ongoing crisis with graduate and doctoral students, many of which (see below) experience bad mentorship due to problems identified by Mohrig in 1988.[18]

In 2020 Margalit, a life scientist at the Hebrew University of Jerusalem, was awarded a "lifetime award for excellence in mentoring" by a scientific journal. Asked why she mentors, she answered "she'd never really thought about it" adding that "it's so much built in me that I think this is one of the main tasks of a principal investigator in the university".[20] Neither

Professor Margulit nor most today's senior or retired faculty in chemistry departments across the world belonging to her generation were ever provided formal training on mentoring graduate students. They typically received their undergraduate and doctoral education in the 1960s and in the 1970s in prestigious universities where a few eminent scholars in chemistry, biology, physics, and mathematics were teaching to a relatively small number of talented students.

In the three decades following the collapse of the USSR (1992-2022), however, this situation dramatically changed. In most world's countries (including Israel) numerous new universities were established. For comparison, a small country such as Italy has now 67 public universities, 20 of which offer undergraduate and graduate studies in Chemistry.[21] An even higher growth has been recorded in the world's most populated countries, namely China and India.

In China, for example, between 2000 and 2017 the number of Chemistry departments rose by 182%, going from 243 to 686, and the number of researchers in chemistry more than tripled.[22] Furthermore, since at least 2008 doctoral students in the chemical sciences face a situation which is similar to that succinctly explained below by Feigenbaum, granted a PhD in Communication studies from Canada's McGill University in 2008:

"Like thousands of other early career scholars, I earned my PhD as the economy collapsed…Since 2008, I have worked at four different universities, in three countries, across two disciplines. During this time I acquired an impressive array of file-totting suitcases and a job application archive large enough to run big data analyses on."[23]

The crisis originated in the USA credit markets in late 2008 had a significant effect on activity in every country and region.[24] Along with the "great financial crisis" started in 2008, the other main driver creating times in which uncertainty about the future dominates society,[25] has been globalization.

In former industrialized countries in western Europe and North America, globalization translated in deindustrialization with plentiful industrial productions, including bulk and fine chemical productions, outsourced to China, India, and Middle East countries. Many world-class industrial research units in Europe and in North America that attracted plentiful PhDs in chemistry were closed. For example, in 2016 DuPont closed its Central Research & Development center in Delaware.[26] Employing at that time a 2,500-employee workforce, this was the experimental station (originally established in the 1920s) where nylon was invented by Carothers, and where Charles Pedersen, the 1987 chemistry Nobel laureate, discovered crown ethers.

Perhaps not surprisingly, in the USA in 2022 the number of PhD graduates in the physical sciences (the classification includes both physics and chemistry) that went on to work in academia reached the lowest level ever, amounting only to 10.7%.[27] For comparison, in 2010 the percentage was 29.1%.

Finally, the other two megatrends directly affecting the work of doctoral students in chemistry-related disciplines are the marketization of the university, and the global environmental crisis. The former sees universities transforming into market players in which the university acts as a competitive entity in a market wherein ranking lists classify universities chiefly based on research productivity and student evaluation of teachings.[28]

Following the 1992 UN "Earth Summit" in Rio de Janeiro, the energy industry burning oil, gas and coal, and the chemical industry largely relying on petroleum, were clearly identified as key contributors to the global pollution of air, land and water. Not by coincidence, the "green chemistry" approach to chemical productions based on pollution prevention (rather than on control) had originated a few years before at chemical companies .[29]

If we compound all these factors with the accelerated innovation made possible by the global uptake of the internet that opened the route to open science,[30] and related technology, environmental and energy megatrends that are reshaping the chemical industry,[31] we get a clear picture of the global socioeconomic context in which today's doctoral students in the chemical sciences study and carry out research since about two decades.

Table 1 summarizes the six main global trends impacting the work of doctoral students also in chemistry-related disciplines in post 2008 years.

Learning from Evidence

"A mentor", wrote Ynalvez and Aviles in *Scientometrics* in 2021, should "engage doctoral students in active learning activities that simultaneously develop leadership, management, collaborative, socialization, and professional interactional skills in addition to technical and scientific skills".[32]

How this should be done for a young faculty in times globally dominated by uncertainty,[25] however, is neither explained nor taught.

Table 1. Global trends affecting today's doctoral studies in chemistry-related disciplines and their effects.

Global trend	Effect
Globalization	Deindustrialization and lack of sufficient industrial job opportunities in Europe and North America
Marketization of the university	Further increase of the "publish or perish" pressure
Financial turmoil	Precarious times with frequent job shift
Newly established universities	Lack of sufficient number of eminent scholars able to provide adequate mentoring
Advent of open science	Lack of education on open science at most world's universities
Environmental crisis, advent of green chemistry	Widespread lack of practically-useful education on green chemistry and sustainability

A search with the query "mentoring doctoral students" was thus conducted on the World Wide Web as of early February 2024. The search returned 17,000 web pages indexed by the search engine.[33] Today, plentiful online resources, such as mentorfirst.org, promote "positive mentoring practices".[5] Manuals "to accelerate the process of learning to be a mentor" are freely available online. In one of them, Handelsman and co-workers highlight that mentoring can be learned, but not taught:

"Good mentors discover their own objectives, methods, and style by mentoring. And mentoring. And mentoring some more. Most faculty learn to mentor by experimenting and analyzing success and failure, and many say that the process of developing an effective method of mentoring takes years".[34]

Such "experimenting and analyzing success and failure" in mentoring, a social behavior, analogous to trial and error in the laboratory.

Clearly, we need theory and knowledge to inspire such "experimenting" and also to replace the anecdotal approach to mentoring that often starts from recounting personal experiences and ends with a list of bullet points listing the "mentoring positive practices" in a presentation slide.

"Check" in Figure 1 starts from surveying doctoral students. A recent investigation in Great Britain based on interviewing four chemistry graduate students every 6 months during their first two years of the PhD showed that participants looking for careers in industry were dissatisfied with their exposure to industry.[35] Three out of the four PhD students expressed an interest in industry, but none of them had direct exposure to industry. Seeing their desire to hear from industrial chemists during seminars and colloquia frustrated, the students explored opportunities to help them gain industrial experiences on their own, by talking to other graduate students with prior industrial experience about job options and by researching job advertising for industrial careers.[35]

Another survey, conducted in 2022 involving 412 PhD graduates in chemistry in the USA, unveiled that even if most (75%) of the respondents were academic chemists (only 17% from industry and 8% from other sectors), chemists complained about insufficient education and attitudes in "securing funding and reputation", "interpersonal skills" and "group/multiple project management".[36]

Results of a survey of graduate students (including 2274 doctoral students) carried out by the American Chemical Society in 2019 found that 26.9% of the respondents "strongly" or "somewhat" agreed with the statement, "My primary research advisor is out of touch with the career issues that graduate students face".[37] Another concerning trend was that, in comparison to the survey carried out by the ACS in 2013, 10% fewer (68% in 2019 *vs.* 78% in 2013) indicated that they would "definitely complete" their degree.[37]

Noting that scholarly literature on doctoral education in the academic discipline of chemistry was "mostly non-existent", Ibo in 2021 published the outcomes of interviewing 31 chemistry PhD supervisors in Australia.[8] Supervisors claimed that graduate employment was considered to be a measure of supervisory success. Yet, 22 out of 31 expressed not having follow-up discussions with their graduates regarding how the PhD had best prepared them for their careers.

Another investigation carried out in 2018 interviewing 19 doctoral students enrolled in Canadian university doctoral programs (of which 5 in natural sciences and engineering) found that a substantial number had "toxic" mentorship (with doctoral students with "toxic" mentors still graduating but at the expense of their well-being).[38] As noted by Mohrig thirty years before,[16] "negative supervisors valued their own interests over those of their students".[38]

One more doctoral experience survey carried out on 248 from three Finnish universities in all disciplines, 52 of which in natural sciences and engineering, found significant negative correlations between experienced exhaustion and cynicism and experiences of supervisory support, researcher community support, and equality in research community support.[39]

In 2013, a study investigating the full-time doctoral student work-life balance at a large southeastern university in the USA found that in order to achieve work-life balance students faced challenges with time management and needed higher wages.[40] Ten years later, doctoral students at an Irish university lamented the same problems: poor time management resulted in work taking up nearly all of student time each day, and the average yearly stipend of 18,500 EUR was found being too low.[41] Finally, plentiful research has identified that there is often insufficient training of supervisors to effectively assist their doctoral students in publishing and disseminating their result.[42]

Table 2 summarizes the main problems identified by scholars investigating the outcomes of doctoral studies in chemistry and the natural sciences.

Table 2. Main problems raised by doctoral students identified by selected studies between 1988 and 2023.

Problem	Authors of study, year, Ref.
Faculty not interested in educating graduate students, but only in producing research results	Mohrig, 1988, [16]; Al Makhamreh and Stockley, 2020, [38]
Mentor out of touch with the career issues that graduate students face	American Chemical Society, 2021, [37]
Lack of interest in industry and poor exposure to industry	Busby and Harshman, 2021, [35]
No follow-up interaction with former PhD students	Ibo, 2021, [8]
Low wages, and lack of time management skills	Martinez et al., 2013, [40]
Low wages and lack of work-life balance due to doctorate consuming whole daily time	Prendergast et al., 2023, [41]
Lack of training on scientific writing and academic publishing	Kamler, 2008, [42]
Poor training on social ("soft") skills	Al Makhamreh, & Stockley, 2020, [38]

Learning from Theory

Following learning about the main problems with doctoral studies in natural science disciplines in several countries, willing to improve the mentorship of doctoral students in chemistry starts with understanding the purpose of doctoral studies. As put it by Roberts writing in 2020 in the *International Journal of Doctoral Studies*:

"The point of doctoral education is to bring about the transformation of the student from a consumer of knowledge to a creator of knowledge. To this end, doctoral students are required to produce original research in their dissertations, the capstone events in most dissertation journeys."[43]

We agree with Handelsman and co-workers that it is the practice of mentoring that will eventually improve this important part of scholarship work.[34] Yet, we emphasize the need for a conceptual approach to effective mentoring based on theory.

According to "tough love" theory, an expanded theory of authoritative pedagogy,[13] mentors driving real growth of *protégés* from students to autonomous, independent scholars, are trustworthy and are benevolent, competent, honest, reliable, and demanding. In brief, said theory states that educators with high levels of benevolence and high levels of demandingness would bring about optimal growth and learning in their *protégés*, by including in the benevolence dimension the qualities that make one trustworthy (benevolence, honesty, competence, and reliability).

This is the key to inform the formal training of mentors praised in this study. The mentor is taught that her/his role involves two primary functions: a psychosocial function (role modeling, empathizing, counseling, etc.) and a professional function including teach mentees how to write well-written research papers.[44]

Accordingly, effective mentoring is progressively tailored to the developmental needs of the doctoral student from basic to ever more advanced level. Seen from this perspective, the education of young faculty on effective mentoring replaces "tips" or "guidelines", with conceptual understanding based on evidence and theory. A successful student mentor nurtures a positive relationship with the student based on the ability to be demanding and trustworthy.

Most empirical studies indeed confirm that doctoral students who enjoyed successful mentorship experiences emphasized the importance to have a confident supervisor "who knows how and where to guide and who knows the tools a student needs", caring about the development of the PhD student own identity without "trying to make her another version of herself".[38]

Having to lead a young researcher for 3 to 4 years during the PhD, the main psychosocial skill of an effective supervisor is the ability to listen to the personal needs of the mentee, and act accordingly leading the student to achieve her/his personal objectives. A certain doctoral student will be interested in pursuing the academic profession, while another to work in industry or in government employment.

Whatever the job sought by the PhD student, she/he should be taught how to effectively write and publish a scientific paper as both an essential part of the research process and of their doctoral education. First published in 1979, Day's book on scientific writing remains an essential resource. It is instructive to review today what Day wrote in 1979:

"Especially, students must learn how to write, because science demands written expression. Erudition is valued in science; unfortunately, it is often equated with long words, rare words, and complex statements. To learn to write, you must learn to read. To learn to write well, you should read good writing. Read your professional journals, yes, but also read some real literature. Many universities now provide courses in scientific writing. Those that do not should be ashamed of themselves.

"What I have said in this book is this: scientific research is not complete until the results have been published. Therefore, a scientific paper is an essential part of the research process. Therefore, the writing of an accurate, understandable paper is just as important as the research itself. Therefore, the words in the paper should be weighed as carefully as the reagents in the laboratory. Therefore, the scientist must know how to use words. Therefore, the education of a scientist is not complete until the ability to publish has been established."[45]

It is enough to ask a PhD student in Europe or North America if he/she ever received training on scientific writing to verify that very few universities across the world listened to Day's plea going back to 45 years ago. Rothenberg, a chemistry professor at the University of Amsterdam, alongside with Lowe gave their first two-day "Write it Right" workshop on writing scientific articles, funding proposals and technical reports back in 2002. Given at hotels, universities, research institutes and research agencies around Europe in two decades the workshop was attended by thousands of doctoral students, postdocs, young faculty and research agency employees.[46] Recent studies suggest how to organize and deliver updated education of doctoral students on scholarly communication in the digital and open science era.[47]

When receiving the reviewer report with comments from the reviewers on her/his first manuscripts, the PhD student will experience the conflicting dynamics of today's academic publishing system. On one side, delayed and succinct peer review reports by which "reviewers sabotage papers that compete with their own"[48] recommending rejection without providing any advice. On the other, true scholarly altruism in which peer review offered by colleagues for free translates into plentiful and purposeful advice:

"Reading the comments from the reviewers, … there were over ten pages of detailed suggestions for revision. For the reviewers, I am just an author whom they have never met. But they devoted so much time and effort to giving me comments on my writing. They contributed their ideas to improving my writing, not thinking there should be anything in return."[49]

Israel Journal of Chemistry

"Effective Mentor" Course

Table 3 lists the topics and learning objectives of the course "Effective Mentor" for PhD student mentors in the chemical sciences. The course has been designed following the analysis of current doctoral mentorship practices coupled to insight into theory concerning doctoral student mentoring in Table 2.

Given by a chemistry scholar having not only a track of successful mentoring work, but also knowledge of the aforementioned pedagogical theory and evidence emerging from doctoral education studies, the course is organized by combining five modules that work together toward the desired learning outcomes, each lasting one day

The first module deals with learning how to develop the PhD student interpersonal abilities. This primarily requires to develop the ability to listen fostering empathic understanding. Effective and more meaningful communication requires said empathic listening. Mentors are taught to avoid forming judgment prematurely when formulating the response, but rather to establish deeper connections based on said enhanced empathy. A good listener herself, a good mentor will show her students also nonverbally that she is accurately understanding what the speaker is saying, avoiding distractions. Miller's slim book contains plentiful concepts and opportunities to learn the practice to strengthen this essential interpersonal skill.[50]

The second module ("Time management") teaches the mentor how to achieve a state "characterized by a sense of control, focus and well-being relying on the method for enhancing personal productivity and reducing the stress caused by information overload" developed by Allen.[51] This is in sharp contrast to confusion, anxiety and procrastination that characterize much of today's academic work. The mentor teaches her doctoral student how, by simply taking notes, ideas are safely stored and not quickly lost as it happens due to the limited capacity of only about 4 items of the short-term memory temporarily holding the items we keep in mind while we are thinking.[52]

The simple act of writing things to be done on paper clears the mind because it places thoughts about those tasks outside of the student mind. Reflection on each thing to get done suggests how to actually do it. Reviewing the list of items being done and to do, for example at the end of each week, allows to reflect on what remains to be done further clearing the mind. Student's time progressively becomes freed from non-productive work and activities making room for purposeful, productive activities both at work and in personal life.

The third module of the course ("Open science") teaches mentors how to improve reproducibility and impact of research in chemistry resting on open scientific data and procedures, and open scholarly communication. The latter relies on making research articles openly available immediately after research completion in preprint form, followed by self-archiving the refereed articles on institutional repositories or personal academic websites.[53]

In this course module mentors are taught how and why self-archived open access articles systematically achieve citation rates higher or comparable to those of paywalled publications, even when published in journals with lower h-index values, and far higher levels of engagement on social media.[54]

The fourth module ("Scholarly communication") teaches mentors how to transfer the principles and methods of good scientific writing. Along with the current edition of Day's book published in 2022,[55] numerous recent studies on scientific publishing in the open science era may further inform education on this key topic of the mentorship work. In one of them, the editor of *The Canadian Journal of Chemical Engineering* identified the reason for which many researchers find that writing articles is a laborious and thankless task: "Most authors feel like this because they have been conditioned by the large number of ineptly written and often dreary articles they were compelled to read (and mimic in their own writings) during their graduate studies and professional lives".[56]

Students should also be taught how to produce also impactful illustrative graphics and use videos to illustrate their findings. For example, Ananikov, a chemistry professor at Moscow's Russian Academy of the Sciences and the PhD students co-authors of the work, inserted in the Supporting Information of the article "Rapid 'mix-and-stir' preparation of well-defined palladium on carbon catalysts for efficient practical use" published by ChemCatChem a link to a video showing the straightforward and quick catalyst preparation.

The video shows that less than 4 min are needed to make the catalyst, including filtration and washing, starting from a commercially available palladium complex and nanoglobular carbon powder.[57] Besides improving the reproducibility of the published research, the video substantially improves the research impact. For instance, in the subsequent 8 years (mid 2017-February 2025) the video has been viewed 5,673 times.

The fifth module ("Career") teaches mentors the relevance of today's chemical industry and the need to involve industry's practitioners in the education of PhD students, alongside the need to foster the doctoral student oral (and visual) presentation skills using multimedia digital resources. Whatever their

Table 3. Topics and learning objectives of the "Effective Mentor" course for mentoring students in the chemical sciences.

Entry	Topic	Learning objective
1	Personal growth	Learning to develop interpersonal abilities
2	Time management	Mastering the getting things done approach to time management
3	Open science	Learning the principles and tools of open science in conducting research and communicating its outcomes
4	Scholarly communication	Learning how to develop good scientific writing
5	Career	Involving chemical industry practitioners in the education of PhD students, and develop good oral (and visual) presentation skills

Israel Journal of Chemistry

profession, PhD graduates will be required to effectively present the results of their work to an audience in short time but clearly and accurately. Besides effective use of multimedia presentation digital tools, this requires the ability to speak clearly at a deliberate unhurried and carefully considered pace, but in a relaxed, conversational manner so as to be heard and understood by all members of the audience.

Conclusions

In summary, this study suggests a new evidence-based approach merged with theory to mentoring doctoral students in the chemical sciences. After providing arguments for which formal training of young faculty on effective mentoring of doctoral students is a necessity driven by global megatrends, we define the topics and learning objectives of a course for PhD student mentors in the chemical sciences designed following the aforementioned approach.

Besides filling a gap in the literature,[8] this study replaces approaches to chemistry faculty education on mentoring based on anecdotes and "guidelines".

Like any other study, this study has its own limitations. The study for example suggests that the 5-day "Effective Mentor" course will be conveniently given by a research chemist educated in the scholarship of mentorship. Mentoring, however, is an intrinsically cross-disciplinary aspect of academic work. Hence, a suitable alternative overcoming the common tendency of responding to academic problems "through silo structures confined to faculties and departments or specialized professional services",[58] would see the involvement as teachers of psychologists, chemical industry's managers, scientific journal editors, and researchers proficient in the practice of open science. Furthermore, besides the tough love theory, other purposeful student mentoring theories and models exist that might be taken as foundation of effective mentoring work.

Acknowledgements

This study is dedicated to the memory of Professor Michele Rossi (1939-2023), great student mentor for over forty years of work first at Bari's University and then at the University of Milan. We thank all our past and current doctoral students: years of purposeful interaction led us to deepen our studies in mentoring theory and young faculty education.

References

[1] C. R. Jackson, *Notes Rec.* **2008**, *62*, 31. https://doi.org/10.1098/rsnr.2007.0032.

[2] P. R. Jones, The Training in Germany of English-Speaking Chemists in the Nineteenth Century and its Profound Influence in America and Britain. In: *World Views and Scientific Discipline Formation. Boston Studies in the Philosophy of Scienc*e, W. R. Woodward, R. S. Cohen (Ed s, vol.134, Springer, Dordrecht: **1991**. https://doi.org/10.1007/978-94-011-3164-3 27.

[3] A. Thackray, J. L. Sturchio, P. T. Carroll, R. Bud, Chemistry in America 1876–1976, Springer Netherlands, Dordrecht: **1988**; pp.148–149.

[4] M.L Dahlberg, A. Byars-Winston (Ed s *The Science of Effective Mentorship in STEMM*, National Academies Press, Washington DC: **2019**. https://doi.org/10.17226/25568.

[5] J. M. Heemstra, N. K. Garg, *Nat. Chem. Rev.* **2022**, *6*, 757. https://doi.org/10.1038/s41570-022-00430-5.

[6] M. M. Cooper, R. L. Stowe, *Chem. Rev.* **2018**, *118*, 6053, https://doi.org/10.1021/acs.chemrev.8b00020.

[7] C. Woolston, *Nature* **2022**, *610*, 805. https://doi.org/10.1038/d41586-022-03394-0.

[8] R. Ibo, *Chemistry PhD Supervisors in Australia: A Study of the Relationship between their Conceptions of Doctoral Purpose and their Reported Educational Practices*, PhD Thesis, The Australian National University, College of Arts and Social Sciences, Canberra: **2021**. https://doi.org/10.25911/M6BK-8Q87.

[9] L. L. Paglis, S. G. Green, T. N. Bauer, *Res. High. Educ.* **2006**, *47*, 451. https://doi.org/10.1007/s11162-005-9003-2.

[10] Y. Feng, *Trend Chem.* **2024**, *6*, 342. https://doi.org/10.1016/J.TRECHM.2024.04.0082.

[11] K. Shibayama, The Second Globalization, the Second Tragedy?. In: *Beyond Global Capitalism*, S. Fujii (Ed.), Springer, Tokyo: **2015**. https://doi.org/10.1007/978-4-431-55181-2 4.

[12] R. D. Goddard, M. Tschannen-Moran, W. K. Hoy, *Elem. Sch. J.* **2001**, *102*, 3. https://doi.org/10.1086/499690.

[13] L. R. Roberts, S. C. Ferro-Almeida, *Int. J. Dr. Stud.* **2019**, *14*, 613. https://doi.org/10.28945/4419.

[14] J. Dunnion, B. O'Donovan, *Syst. Pract. Action Res.* **2012**, *27*, 23. https://doi.org/10.1007/s11213-012-9258-4.

[15] J. Gibson, B. O'Donovan, Introduction to the Vanguard Method in People Centred Services. Vanguard Consulting, Buckingham (Great Britain): **2008**. https://slideplayer.com/slide/12156468/ (accessed April 22, 2025).

[16] J. R. Mohrig, *J. Chem. Educ.* **1988**, *65*, 588. https://doi.org/10.1021/ed065p588.2.

[17] S. Berlin, *EMBO Rep.* **2023**, *24*, e58127. https://doi.org/10.15252/embr.202358127.

[18] R. Ciriminna, M. Pagliaro, *Chimia* **2023**, *77*, 62. https://doi.org/10.2533/chimia.2023.62.

[19] K. A. Noble, *Stud. High. Ed.* **1989**, *14*, 97–102. https://doi.org/10.1080/03075078912331377642.

[20] Prof. H. Margalit, cit. in: J. Gould, Why science needs strong mentors, nature.com, 8 September 2021. https://www.nature.com/articles/d41586-021-02440-7 (accessed April 22, 2025).

[21] Censis, Quali sono le migliori università in Italia dove studiare Chimica nel 2023?, Rome: **2024**. https://www.joinrs.com/it/migliori-universita-chimica-2022/ (accessed April 22, 2025).

[22] S. Qiu, C. Steinwender, P. Azoulay, *CESifo Working Paper* **2023**, *10127*, http://hdl.handle.net/10419/271861.

[23] A. Feigenbaum, *Three-D* **2013**, *21*, 9–10. https://www.meccsa.org.uk/nl/three-d-issue-21-personal-academic-websites-in-precarious-times/ (accessed April 22, 2025).

[24] M. Edey, *Econ. Pap.* **2009**, *28*, 186–195. https://doi.org/10.1111/j.1759-3441.2009.00032.

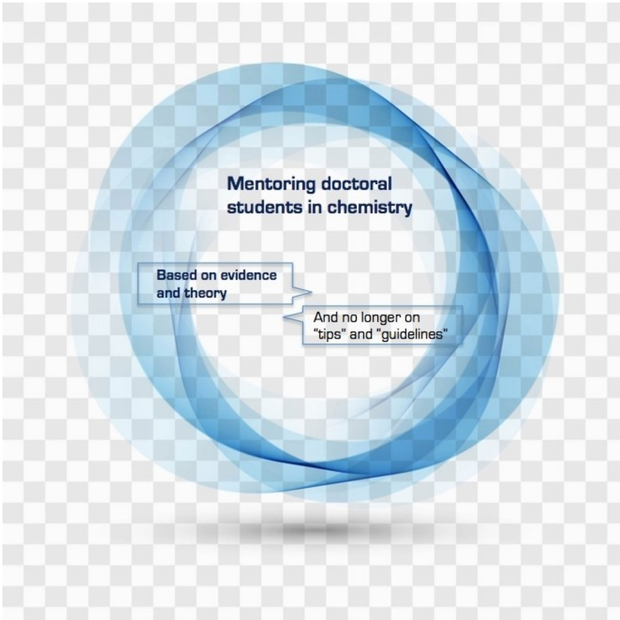
[25] G. DeMartino, I. Grabel, *World Dev.* **2024**, *173*, 106426. https://doi.org/10.1016/j.worlddev.2023.106426.

[26] F. Esposito, DuPont cutting jobs, closing Central Research unit. Plastic News, 29 December 2015. https://www.plasticsnews.com/article/20151229/NEWS/151229900/dupont-cutting-jobs-closing-central-research-unit (accessed April 22, 2025).

[27] U. S. National Science Foundation, Survey of Earned Doctorates, Alexandria, VA: **2023**. https://ncses.nsf.gov/pubs/nsf24300/report/postgraduation-trends#first-postgraduate-employment (accessed April 22, 2025).
[28] L. Wedlin, University marketization: the process and its limits. In: *The University in the Market*, L. Engwall, D. Weaire (Ed s, Portland Press, London: **2008**; pp.143–153.
[29] J. A. Linthorst, *Research between Science, Society and Politics: The History and Scientific Development of Green Chemistry*, Eburon, Utrecht: **2023**.
[30] S. Bartling, S. Friesike, *Opening Science*, Springer, Cham: **2014**. https://doi.org/10.1007/978-3-319-00026-8.
[31] M. Pagliaro, *Angew. Chem. Int. Ed.* **2019**, *58*, 11154. https://doi.org/10.1002/anie.201905032.
[32] M. A. Ynalvez, J. L. Aviles, *Scientometrics* **2021**, *126*, 6323–6347. https://doi.org/10.1007/s11192-021-04031-9.
[33] Search carried out at google.com with the query "mentoring doctoral students" on February 6, 2024.
[34] J. Handelsman, C. Pfund, S. Miller Lauffer, C. Maidl Pribbenow, *Entering Mentoring*, Board of Regents of the University of Wisconsin System, Madison WI: **2005**. https://undergradresearch.illinois.edu/assets/docs/OUR Faculty Mentoring.pdf (accessed April 22, 2025).
[35] B. D. Busby, J. Harshman, *Chem. Educ. Res. Pract.* **2021**, *22*, 347–363. https://doi.org/10.1039/d0rp00200c.
[36] Q. Cui, J. Harshman, *JACS Au* **2023**, *3*, 409–418. https://doi.org/10.1021/jacsau.2c00561.
[37] American Chemical Society, *2019 ACS Graduate Student Survey Report*, Washington, DC: **2021**. https://www.acs.org/education/resources/graduate.html (accessed April 22, 2025).
[38] M. Al Makhamreh, D. Stockley, *D. Int. J. Mentor. Coach. Educ.* **2020**, *9*, 1–20. https://doi.org/10.1108/ijmce-02-2019-0013.
[39] S. Cornér, E. Löfström, K. Pyhältö, *Int. J. Dr. Stud.* **2017**, *12*, 91–106. https://doi.org/10.28945/3754.
[40] E. Martinez, C. Ordu, M. R. Della Sala, A. McFarlane, *Int. J. Dr. Stud.* **2013**, *8*, 39. https://doi.org/10.28945/1765.
[41] A. Prendergast, R. Usher, E. Hunt, *Educ. Sci.* **2023**, *13*, 916. https://doi.org/10.3390/educsci13090916.
[42] B. Kamler, *Stud. High. Educ.* **2008**, *33*, 283. https://doi.org/10.1080/03075070802049236.
[43] L. Roberts, *Int. J. Dr. Stud.* **2020**, *15*, 29–56. https://doi.org/10.28945/4475.
[44] R. T. Brown, B. P. Daly, F. T. L. Leong, *Prof. Psychol. Res. Pract.* **2009**, *40*, 306–313. https://doi.org/10.1037/a0011996.
[45] R. A. Day, *How to Write and Publish a Scientific Paper*, ISI Press, Philadelphia (PA): 1979; p.158.
[46] Dr. C. Lowe, cit. In: S. Houlton, The Educated Chemist: publish or be damned, *ChemistryWorld*, 30 July 2008. https://www.chemistryworld.com/careers/the-educated-chemist-publish-or-be-damned/3006936.article (accessed April 22, 2025).
[47] J. Marson, K. Ferris, *Encyclopedia* **2023**, *3*, 1358–1372. https://doi.org/10.3390/encyclopedia3040097.
[48] A. McCook, *The Scientist* **2006**, *20* (2), 26. https://www.the-scientist.com/is-peer-review-broken-47872 (accessed April 22, 2025).
[49] Y. Huang, *High. Educ. Res. Dev.* **2021**, *40*, 753–766. https://doi.org/10.1080/07294360.2020.1789073.
[50] W. R. Miller, *Listening well*, Wipf & Stock, Eugene (OR): **2018**.
[51] The Main Idea, *The Main Idea, Getting Things Done: The Art of Stress-Free Productivity, By David Allen (Penguin Books, 2nd Edition 2015)*, **2017**. https://saanys.org/wp-content/uploads/2020/10/The-Main-Idea-Getting-Things-Done-August-2017.pdf (accessed April 22, 2025).
[52] N. Cowan, *Behav. Brain Sci.* **2001**, *24*, 87–114. https://doi.org/10.1017/S0140525X01003922.
[53] R. Ciriminna, G. Li Petri, G. Angellotti, R. Luque, M. Pagliaro, *Front. Res. Metr. Anal.* **2025**, *10*, 1544965. https://doi.org/10.3389/frma.2025.1544965.
[54] K. W. Walker, D. L. Gilstrap, V. F. Scalfani, E. Walker, *J. Acad. Librariansh.* **2025**, *51*, 102984. https://doi.org/10.1016/j.acalib.2024.102984.
[55] B. Gastel, R. A. Day, *How to Write and Publish a Scientific Paper*, Greenwood, Santa Barbara (CA): **2022**.
[56] J. B. P. Soares, *Can. J. Chem. Eng.* **2022**, *100*, 2718. https://doi.org/10.1002/cjce.24428.
[57] V. Ananikov, Rapid 'mix-and-stir' preparation of supported Pd/C catalysts. YouTube, 25 June 2017. https://www.youtube.com/watch?v=ZIme3liGVeo (accessed April 22, 2025).
[58] A.-R. Hofer, G. Kaffka, HEInnovate: facilitating change in higher education. In: *Entrepreneurial Universities*, J. J. Ferreira, A. Fayolle, V. Ratten, M. Raposo (Ed s, Edward Elgar Publishing, Cheltenahm (Great Britain): **2018**; pp.135–152.

Version of record online: ■■, ■■

PERSPECTIVE



R. Ciriminna, C. Della Pina, R. Luque*, M. Pagliaro**

1 – 9

Mentoring Doctoral Students in the Chemical Sciences

The relevance of effective mentoring of doctoral students in the chemical sciences is now widely recognized. However, the scholarly literature on the topic is virtually non-existent, and most approaches to faculty education on mentoring are based on "tips" and "guidelines". Following the analysis of current mentorship practices, we suggest a new approach based on evidence resulting from surveys of doctoral students, and on theory derived from studies in social and human sciences.