

Iztok Devetak *Editor*



University Chemistry Teaching in the 21. Century

University of *Ljubljana*
Faculty of *Education*



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Preface

This peer-reviewed monograph entitled “*University Chemistry Teaching in the 21. Century*” includes five chapters presenting different approaches to university chemistry teaching and learning. The chapters have their basis in EUROVARIETY 2021 conference presentations organised by University of Ljubljana, Faculty of Education, Slovenian Chemical Society and European Chemical Society in July 2021.

The importance of effective chemistry teaching and learning at university level is addressed in this book. We often think that chemistry teaching at university level is not so important as teaching this abstract subject at lower and upper secondary level, but we all know that also students at tertiary level struggle to learn chemistry. For that reason, researching and applying new teaching and learning strategies in tertiary chemistry lecture rooms and laboratories is as important as doing this for lower educational levels.

Authors come from 6 countries and presenting their views on tertiary chemistry education, from teaching chemistry to engineering students, using modern technology in analytical chemistry, using models in organic chemistry course, and how COVID-19 influences on first year university students’ chemistry learning. The book ends with the chapter dealing with continuous professional development of STEM lecturer at the university level.

Gabriel Pinto and Isabel López-Hernández in the first chapter entitled “*Context and inquiry-based chemistry teaching and learning for engineering students*” show some applications carried out in recent years with first-year Industrial and Chemical Engineering students who study Chemistry. The aim of these kinds of experiences is that students solve, as a team, a series of problems and cases contextualized in their day-to-day life. To do that, they must understand a given problem, search for the underlying data set, analyse different information sources (in Spanish and English) for the data search, discriminate between the contents of the subject (and others) that they must apply, carry out experiments (in some cases), proceed according to an accurate data processing, make approximations, analyse the results (whose outcome is open) and propose future inquiries and applications. In detail, the cases included in this publication, chosen among dozens of others that have been adopted and implemented, are an experimental study of the ice melting rate in various liquids, calculations, and analysis of the relationships between vehicle fuel consumption and carbon dioxide emissions, discussion about self-heating beverage containers, chemical and thermodynamic fundamentals of domestic condensing boilers, and critical analysis of pseudoscientific deceptive information. These examples, suitable for other studies and stages of education, show that students are more interested in the subject and they acquire skills in a more appropriate way than with the use of more traditional problems, which are of a closed nature regarding the baseline data and with unique findings. Therefore, there is a clear contribution to the education of more responsible citizens with better knowledge of some products and technologies that they use in their daily

lives. On the other hand, these experiences and other similar ones, have been made available for secondary teacher training courses to promote its use in pre-college educational stages.

In the second chapter's entitled "*Smartphone-based analytical procedure in the teaching lab: a proposal for undergraduate students*" by Roberto Sáez Hernández, Agustín Pastor, Ángel Morales-Rubio, and María Luisa Cervera main objective is to serve as a guide for chemistry instructors willing to implement the use of the smartphone in the undergraduate laboratory. Different samples have been studied and the laboratory protocol described, in order to ease the adaptation to the preferences of each reader. Additionally, the obtained results are shown and the theoretical concepts discussed. In this chapter, a proposal to get the students involved in the analysis process is made using the smartphone as an analytical detector. To it, a simple setup was built from locally acquired materials, and phosphate was analyzed based on color parameters extracted from the image. As an analyte, phosphate has been chosen due to its wide appearance in diverse matrices and its importance in the industry. Based on the RGB color space, phosphate can be easily analyzed in water, washing powders, eyedrops and blood matrices. Overall, with this lab practice students can use their own smartphone to carry out the analysis, and optimize the image conditions that best suit their device. Additionally, Green Analytical Chemistry principles are implemented in the approach to ensure that students can identify them.

The third chapter by the group of authors Sean Gao, Taylor C. Outlaw, Jason G. Liang-Lin, Alina Feng, Jennifer L. Roizen, Colton Melnick lead by Charles T. Cox Jr. entitled "*Students' Identification and Application of Models to Rationalize Organic Acid-Base Trends*" discuss that acid-base chemistry is an essential component of the undergraduate chemistry curriculum. Acid-base concepts are introduced in general chemistry and expanded on in organic chemistry, biochemistry, and other advanced chemistry courses. Through a mixed approach of surveys and think-aloud interviews, the proficiency of second-semester organic students in acid-base chemistry was measured. Students were given two questions, both requiring them to rank the acidity of three compounds and justify the ranking. The first question focused on substituted carboxylic acids, and the second question focused on substituted aromatic structures. Although most students were able to correctly rank both sets of molecules, the correctness of their justifications was structure-dependent. Students did better at justifying the acidity of the aromatic structures, but while they were more successful at ranking the acidity of the substituted carboxylic acid structures, students were largely unsuccessful at justifying the trend. Students often relied on memorization, attributing acidity to the presence of specific functional groups or substituents. Specific alternative conceptions observed in both surveys and interviews include the idea that resonance structures are always central in justifying properties for molecules that have π bonds, and that alkenes and alkynes have differing numbers of resonance structures given they have different bond orders. Finally, students had difficulty with identifying the most acidic proton and often selected sites based on content that could be memorized from lectures. Students were also asked to report their confidence in their answers on a 6-point Likert scale from 0–5, and statistically significant differences were observed between students who ranked compounds correctly versus incorrectly for both questions in the study. However, when comparing the correctness of the justifications, a statistical difference between reported confidence was only observed with the aromatic structures question. The substituted carboxylic acids question required the application of models and ideas that extended beyond memorization.

The fourth chapter with the title “*A Whole Team Approach to Integration of Student Feedback into Continuous Assessment Activities for First-Year Students Transitioning to University Chemistry Education during the COVID-19 Pandemic*” by Frances Heaney, Denise Rooney, Orla Fenelon, Tobias Krämer, Eithne Dempsey, Stephen Barrett, Caytlin Boylan, Kyle Doherty, Luke Marchetti, Joseph Curran, Lisa O’Regan, and Trinidad Velasco-Torrijos” reports on a team-led, discipline specific solution to the problem of gathering, analysing and responding to student feedback on teaching and learning in a timely manner and in a way that supports transition to university for the in-situ group. We demonstrate the pedagogical value of integrating student feedback into mainstream, on-going teaching and learning activities as a vehicle to increase engagement and improve representation. The cohort was a large and diverse first year chemistry class (350 students) transitioning from second to third level teaching and learning methods in an Irish University during the COVID-19 pandemic where the bulk of activities were delivered either remotely or in a blended fashion. We show that a continuous assessment framework can be piggy-backed to gather student feedback and enact informed improvements in a manner which is both immediate and noticeable. We believe our approach is an excellent fit for chemistry programmes that could readily and be incorporated into other programmes in cognate subjects and could be easily adapted for second and higher year students.

The last chapter by Nataša Zupancic Brouwer, Ștefania Grecea, Johanna Kärkkäinen, Iwona Maciejowska, Matti Niemälä, and Lotte Schreuders entitled “*Roadmap for continuous professional development of STEM lecturers*” presents the Erasmus+ project STEM-CPD@EUni. Despite the ongoing systematic integration under the Bologna Agreement, higher education systems in Europe are still different in different countries and have different focus areas in the professional development of lecturers. At many European universities, professional development is often organised from a pedagogical point of view and the lecturers are left alone to apply the acquired pedagogical knowledge in their own teaching practice. In the Erasmus+ project STEM-CPD@EUni, five European universities and the European Chemistry Thematic Network (ECTN) are collaborating to enable continuous professional development (CPD) in a local university STEM teaching practice. A new concept in CPD is introduced, the CPD ambassador. Three dimensions characterize the activities of the CPD ambassadors in their local context: (1) STEM educational competences, (2) teaching attitudes, and (3) CPD activities. To define the needs for the CPD in these dimensions, a survey was developed with 66 statements evaluated from two different perspectives: their general importance for the quality of teaching and learning and their use in teaching practice. 420 lecturers from 80 universities from 26 countries and 46 education managers from 31 universities from 11 countries in Europe completed the survey from the end of November 2020 to the end of January 2021. The results show similarities and also some differences between the European countries and indicate in which directions the CPD is needed. The survey also showed that the priority list of needs for CPD should not be blindly followed but used in an evidence-based way. It is recommended to repeat the survey after some time. Based on the results of this research, a roadmap for STEM-CPD with guidelines and recommendations was developed in the STEM-CPD@EUni project.

It can be concluded that chapters in this book can influence modernising chemistry teaching at university level and for that reason they can be recommended to novice and expert tertiary education lecturers.

Editor and Contributors

About the Editor

Dr. Iztok Devetak is Professor of Chemical Education at University of Ljubljana, Faculty of Education, Slovenia. His research focuses on how students, from elementary school to university, learn chemistry at macro-, submicro- and symbolic level, how chemistry in context and active learning approaches stimulate learning, using eye-tracking technology in explaining science learning, aspects of environmental chemistry education, developing teachers' health-managing competences etc. He has been involved in research projects in the field of science education and he was the national coordinator of PROFILES project (7th Framework Program) for 4.5 years. He co-edited a Springer monograph about active learning approaches in chemistry. He (co)authored chapters in international books (published by Springer, American Chemical Society, Routledge, Nova Science...) and published papers in respected journals (altogether about 400 different publications). He was a Fulbright scholar in 2009. He is a member of ESERA (European Science Education Research Association) and EuChemS (European Association for Chemical and Molecular Sciences) Division of Chemical Education and he is also a Vice-chair for Eastern Europe of EuChemS DivChemEd. He is a Chair of Chemical Education Division in Slovenian Chemical Society and president of the national Subject Testing Committee for chemistry in lower secondary school. Dr. Devetak is Editor-in-Chief of SCOPUS indexed CEPS Journal, publishing papers from different educational fields and editorial board member of respected journals, such as Chemistry Education Research and Practice, Eurasian Journal of Physics and Chemistry Education.

About the Contributors

Dr. Charlie Cox is an associate professor of the practice and director of undergraduate studies at Duke University. Charlie got a Ph.D. under the guidance of Melanie Cooper in 2006. Charlie worked as a lecturer for 10 years prior to joining Duke in 2020. Charlie's research interests focus upon students' longitudinal progression across the chemistry curriculum with a specific interest in acid base chemistry, kinetics, and thermodynamics.

Dr. Gabriel Pinto received an MSc degree in chemistry in 1985 and a PhD in physical chemistry in 1990, both from the Complutense University of Madrid. He has, since 1986, been Professor (since 2010 as Full Professor) in the Technical University of Madrid, where he teaches chemistry and communication of science for engineering students, and science education for future teachers. His research has concentrated on characterization of polymers and polymer composites, on the teaching of chemistry and STEAM at different educative levels, and on history of science. He has published over 200 papers in national and international journals. He is an active member of scientific societies and he has received about 20 awards at his University and at national level, for his tasks developed in educational innovation and outreach of science.

Dr. Isabel López Hernández holds a Ph.D. in English Literature from Universidad Complutense (Spain, 2005). She is an Associate Professor at the Technical University of Madrid (UPM) where she teaches English for Professional and Academic Communication. He has also taught a diverse variety of Cultural Studies, Applied Linguistics, and Literature courses. Her research specialization is the study of new teaching methodologies. She has published in journals of national and international reputation in the field of Language Learning Strategies and English for Specific Purposes.

Sean Gao is a senior undergraduate chemistry major at Duke University and has been member of the Dr. Cox's' research group since 2020.

Taylor Outlaw is a third-year graduate chemistry Ph.D. student. Taylor received a Bonk Fellowship, which provides funding for a one-year research experience in a chemical education group.

Alina Feng is a senior undergraduate student at Duke University. Alina joined the Cox's' research group as one of the first members.

Colton Melnick is senior undergraduate student at Duke University.

Dr. Jennifer Roizen has a Ph.D. in organic chemistry from California Institute of Technology, and she completed a postdoc at Stanford University.

Dr. Nataša Brouwer is a senior consultant STEM higher education working at Teaching and Learning Centre Science, University of Amsterdam. She has a PhD in chemistry. Her expertise is the professional development of academic STEM educators in teaching and learning and the use of digital technology in higher education. She was involved in many national and international education innovation projects and in the European Chemistry Thematic Network (ECTN) Working groups. She has published more than thirty publications in the field of higher STEM education.

Dr. Ștefania Grecea is Associated Professor at the Faculty of Science of the University of Amsterdam where she leads the Functional Materials research group. She is chair of the Quality Standards in Teaching Standing Committee of the European Chemistry Thematic Network. She is also teaching at both BSc and MSc levels and coordinates the MSc Chemistry tracks Science for Energy and Sustainability and Molecular Sciences. Dr. Grecea is project leader of the Erasmus+ STEM-CPD@EUni at the University of Amsterdam and together with a team of lecturers and educational developers focuses on the development of activities for the continuous development of chemistry lecturers.

Dr. Johanna Kärkkäinen is university lecturer at the Research Unit of Sustainable Chemistry, University of Oulu. She has taught organic chemistry in all study levels. Her research focus on lignocellulosic biomasses, their chemical conversion and modification. She has published over 25 papers in the international scientific journals. In addition to supervising Bachelor, Master and PhD theses, she has worked as Erasmus coordinator in the field of chemistry.

Dr. Iwona Maciejowska is the chairman of the Jagiellonian University Ars Docendi Council, professor at the Department of Chemistry Education JU, co-editor of the journal Chemistry Teacher International (De Gruyter, CCE IUPAC). Activities related to increasing the teaching competences of academic staff, including conducting workshops for lecturers and doctoral students, are of particular importance to her. Author and / or scientific editor of several books and monographs, including: A Guidebook of Good Practice for Pre-Service Training of Chemistry Teachers (2015). Maciejowska I., & Byers B. (ed.), and over 100 articles in the field of natural sciences and higher education.

Dr. Matti Niemelä is University lecturer at the Research Unit of Sustainable Chemistry, University of Oulu. He teaches inorganic and analytical chemistry at all study levels. He is also the leader of the chemistry degree programme at the University of Oulu. His research interests include fundamentals and applications of sample pre-treatment and atomic spectrometric techniques. He has published over 40 papers in the international scientific journals.

Lotte Schreuders MSc after studying chemistry and working as a lecturer within the MSc Chemistry, track Analytical Sciences (Faculty of Science), Lotte Schreuders is now working as an educational researcher at the Teaching and Learning Centre of the University of Amsterdam. The project is a collaboration between the University of Amsterdam Teaching and Learning Centre and the research group Educational Sciences (Department of Child Development and Education, University of Amsterdam) where we investigate educational innovation and professional development in higher education.

Dr. Frances Heaney holds a BSc and a PhD from Queen's University Belfast, after postdoctoral research at Trinity College Dublin she began her academic career at Galway University before taking up a post at Maynooth University where she has been teaching all levels of undergraduate students and supervising PhD and MSc students since 1999. Current interests include the synthesis of new antimicrobial agents and chemistry laboratory education.

Dr. Denise Rooney obtained both her BSc and a PhD from Queen's University Belfast. She held a postdoctoral position at the University of York in the UK and then was appointed as a lecturer at Maynooth University in 1994. Her research interests are in organometallic and materials chemistry, and she is currently investigating metal-based compounds which can act as antimicrobial agents. She is leading an Irish inter-institutional project on using educational technologies to enhance chemistry laboratory education.

Orla Fenelon holds a Hdip and a BSc from Maynooth University and a MSc from Trinity College Dublin. She spent 18 years as a chemistry technical officer in Maynooth University and was involved in teaching practical chemistry to undergraduate students. She has a keen interest in science outreach and was involved in many activities promoting chemistry to all ages. She currently works as a chemist in the State Laboratory.

Dr. Tobias Krämer studied Chemistry at the Universities of Bonn and Hamburg in Germany, and after receiving a MSc he completed a Dphil at the University of Oxford. Following postdoctoral positions in Germany and Scotland, he was appointed as an Assistant Professor at Maynooth University in 2017. He is strongly involved in lecturing within the undergraduate curriculum and the supervision of PhD and project students. His research interests centre around the electronic structure of inorganic systems, encompassing transition metal and main group compounds. Besides research, Tobias has a broad interest in the pedagogy relating to learning in laboratories, research skills and best practices in lecturing.

Dr. Eithne Dempsey received a PhD in Electroanalytical Chemistry from Dublin City University followed by postdoctoral research at St. Vincent's Hospital, Dublin. She then took up a position as Lecturer in Chemistry at Technological University Dublin – Tallaght Campus where she managed the Centre for Research in Electroanalytical Technologies. She was appointed visiting Professor of Chemistry at University of the Western Cape, Capetown, South Africa in 2012 and in 2017 joined Maynooth University, currently as Associate Professor (since 2020) in Dept. Chemistry. Her research objective is to address electroanalytical challenges using bespoke (nano)materials integrated with chemo/biosensing systems suitable for onsite deployment in multiple application scenarios.

Dr. Stephen Barrett holds a BSc in Chemistry and PhD from Maynooth University. After completion of his doctoral thesis Stephen took up a 1 year post as a lecturer in Maynooth University. He has extensive experience in teaching undergraduate Chemistry labs and lectures. Stephen is currently an Irish Research Council awardee and is carrying out post-doctoral research at Royal College of Surgeons Ireland in the area of bioorthogonal Chemistry and Platinum based anti-cancer therapies. His current interests are synthesis of novel and selective Platinum and copper based anti-cancer complexes, bioorthogonal Chemistry and undergraduate education.

Caytlin Boylan obtained a BSc in Pharmaceutical and Biomedical Chemistry from Maynooth University in 2018 and is currently a PhD candidate in Neurochemistry. She has recently taken an assistant lecturer role in physical and analytical chemistry. Her research interests include developing electrochemical biosensors for neurochemical monitoring and she has a strong interest in chemistry teaching and education.

Kyle Doherty graduated from Maynooth University with BSc in Pharmaceutical and Biomedical Chemistry in 2019. He has worked both in the State Laboratories and in Randox Laboratories. Kyle is currently completing a PhD in the field of Synthetic and Carbohydrate Chemistry, where he is preparing new glycoconjugates against opportunistic fungal pathogens.

Dr. Luke Marchetti obtained his BSc in Chemistry from Maynooth University where he continued his studies and completed his PhD in Supramolecular Organic Chemistry in 2022. Luke has recently undertaken a post-doctoral research position in Maynooth University, funded by Science Foundation Ireland and Janssen Pharmaceuticals. His research interests centre around supramolecular host-guest chemistry and its applications in medicinal chemistry.

Dr. Joseph Curran was a Postdoctoral Researcher at the Centre for Teaching and Learning, Maynooth University between 2022 and 2021 where he worked on the “Enhancing Teaching and Learning through Programme and Module Evaluation” Initiative. He is particularly interested in exploring disciplinary-appropriate student feedback methods. He is also an urban historian and is currently an Irish Research Council Government of Ireland Postdoctoral Research Fellow at the Department of History, Trinity College Dublin.

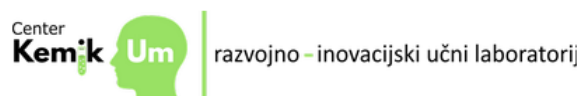
Dr. Lisa O’Regan is Head of the Centre for Teaching and Learning in Maynooth University and Project Manager for the ‘Enhancing Teaching and Learning through Programme and Module Evaluation’ initiative. Lisa holds a BA, Hdip Education and H.D BFIS from University College Cork and a MSc in Education and Training Management from Dublin City University. Lisa has over 15 years’ experience in Higher Education digital learning, educational development and project management and is particularly interested in the area of assessment and feedback.

Dr. Trinidad Velasco-Torrijos obtained her BSc from Universidad Autonoma de Madrid, Spain, where she studied Organic Chemistry. She then completed her PhD in Supramolecular Chemistry from University of Bristol, United Kingdom. After holding postdoctoral positions in Belgium and Ireland, she took up a position as lecturer at Maynooth University in 2007. Her research interests concern the development of carbohydrate-based antiadhesion agents against infection and soft materials. Trinidad is actively involved in Teaching and Learning projects in Chemical Education seeking to enhance the learning experience in the laboratory.

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From the Review



»The results of the contributions presented in the monograph “University Chemistry Teaching in the 21st Century” clearly contribute to enriching the opus research already being conducted in the field of tertiary chemistry education, providing guidelines for further research, and promoting insights into the own teaching and the transfer of research results to other levels of education.«

Dr. Jerneja Pavlin

»The published monograph contains important, high quality and original knowledge from the authors of the articles that will influence the modernization of the way chemistry is taught at the university level. It is crucial that all this knowledge finds its way to students - future chemistry teachers and secondary and primary school chemistry teachers.«

Dr. Miha Slapničar