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DIGITAL RESOURCES IN CHEMISTRY: A PATHWAY TO INNOVATION AND SUSTAINABLE DEVELOPMENT

BY

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Abstract

Digital resources in chemistry have revolutionized research, education, and industrial applications, offering pathways for innovation and sustainable development. This abstract explores the transformative impact of digital tools on the field of chemistry, emphasizing their role in enhancing efficiency, accessibility, and collaboration. In research, digital resources such as databases, simulations, and computational modeling enable accelerated discovery and optimization of chemical processes and materials. These tools facilitate data-driven approaches, predictive analytics, and machine learning algorithms, thereby advancing precision in molecular design and synthesis. Education benefits significantly from digital resources, providing interactive learning platforms, virtual laboratories, and multimedia simulations that enhance student engagement and comprehension. Accessible globally, these resources democratize knowledge and skills in chemistry, fostering a new generation of scientists equipped to tackle complex challenges. Moreover, digitalization promotes sustainable development by optimizing resource utilization, reducing experimental waste, and supporting green chemistry initiatives through predictive modeling and simulation. This approach minimizes environmental impact while maximizing efficiency and innovation in chemical industries. Collaboration across disciplines and geographical boundaries is enhanced through digital platforms, fostering partnerships that drive interdisciplinary research and innovation. Open access to data and tools promotes transparency and accelerates the pace of discovery, contributing to the global advancement of chemistry and sustainable development goals. In conclusion, digital resources are indispensable in shaping the future of chemistry, offering transformative opportunities for innovation, education, and sustainable development on a global scale.

Keywords: digital resources, chemistry, innovation, sustainable development.

Introduction

The term “digital resources” refers to information resources that can be accessed through the Internet-connected devices. Electronic journals, electronic books, online databases, locally loaded databases, websites, CD-ROM, electronic text, e-news, e-images, and electronic music are all examples of DR. Digital resources has been hailed as one of the most essential sources of information for students (Ternenge & Kashimana, 2019), as it offers them current and relevant information on a variety of topics. Digital resources are handier than print resources because it enables access to materials that might otherwise be denied to consumers owing to geographic location, economics, or other constraints (Anunobi & Okoye, 2008; Lo et al., 2017). Digital resources provide students with new opportunities that earlier generations did not have. DR can be used to encourage students to learn actively and independently while also collaborating with others. According to Adeniran (2013), DR has the potential to increase students’ academic performance by providing them with appropriate and up-to-date information items. Digital resources are powerful tools to support learning. Main contributing factors include their technological characteristics, namely their capacity to record, manage, represent, and communicate data and information. However, the essential contribution of digital resource technologies to the learning process comes, indirectly, through their pedagogical exploitation. As Dalgarno & Lee state, “technologies themselves do not directly cause learning to occur but can afford certain tasks that themselves may result in learning” (Dalgarno & Lee, 2010).

Digital resource technologies have been used in education since the 1950s, at all educational levels, from primary to higher and adult education and in all disciplines, from science to humanities and social sciences, in various ways. A substantial contribution of digital technologies in teaching and learning processes, especially in science education, is that they create meaningful digital educational environments that in turn contribute to the creation of mental models and provide incentives for learner engagement. The prevailing approach to the pedagogical use of digital technologies, regardless of the technology used, is that of cognitive tools, based on the constructivist theories of knowledge (Jonassen, 2000 and Mikropoulos & Bellou, 2010). Until the early 1990s, computer technology was used in Chemistry Education mainly to support teachers in delivering recurring educational activities and as a means of transferring "traditional" teaching and learning activities onto the computer. In the early 1990s, although a behavioristic approach was still evident and digital learning technologies were mainly used to provide tutorials and "drill and practice" environments, new approaches would later surface, such as "Computer-Assisted Instruction," "virtual experiments," or "modeling-based learning" (Tsaparlis, 1991).

O'Haver (1999) states that digital learning technologies are mainly used in secondary Chemistry Education and concludes that the real value of using digital technologies in teaching and learning is to tackle impossible or extremely difficult issues in a different way, as opposed to paper or laboratory work. He also identifies the pedagogical value of digital technologies in the active participation of students through interactive and dynamic models, simulations, and analytical tools. In the 2000s, web applications would emerge and the behavioristic approach would gradually transform to a constructivist approach promoting open-ended digital learning activities. In the early 2000s, a report on science education and the role of digital learning technologies from Futurelab acknowledges the potential of digital technologies in teaching and learning (Osborne & Hennessy, 2003). The report, however, notes that it is not enough to integrate digital technologies into the teaching process, but emphasizes the role of the teacher in creating the right conditions by selecting appropriate technologies and designing learning activities.

The introduction of digital resource has provided students with much-needed comfort, ease, and timely information for learning, completing academic projects, and conducting research (Mawere & Sai, 2017). As a result, DR are now important resources in every university library, demonstrating a commitment to bringing information closer to users in a more trustworthy and easy manner. Research in chemistry teaching with the support of digital resource is particularly important to identify trends in theoretical approaches as well as in technologies used at the educational practice level. Despite the importance of digital learning resource technologies in Chemistry Education, there seems to be a lack of reviews on the literature regarding digital learning resource in primary, secondary and tertiary Chemistry Education. Such reviews outline and organize the existing literature, highlight the technologies used, and the pedagogical approaches followed in Chemistry Education. Therefore, they can provide valuable insights into the current state of art in the field to help researchers identify research topics of continuing importance.

Theoretical Framework

This study's theoretical framework is based on Rogers' diffusion of innovation theory, which he proposed in 1962. This theory is concerned with the transition from creation to the usage of new tools/technologies, approaches, ideas, and so on. The diffusion of innovation theory describes how an idea or product acquires traction over time and diffuses (or spreads) through a population or social system before being adopted. Five primary characteristics drive innovation adoption, according to Rogers. These are, as follows:

1. **Relative advantage:** The extent to which an invention is thought to be superior to the idea, program, or product it is intended to replace.

2. **Compatibility:** How well does the innovation align with the potential adopters' values, experiences, and needs.

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3. **Complexity:** This is the degree to which new technology is thought to be difficult to comprehend and use. Simpler-to-understand ideas are adopted more quickly than advances that need the adopter to acquire new skills and knowledge.

4. **Triability:** The extent to which an idea can be tried or experimented with before deciding to adopt it.

5. **Observability:** The degree to which the innovation has a measurable impact.

As a result, for an innovation like DR to achieve acceptance and be used by university students, it must appear to them to be more valuable and superior than printed resources. It should be perceived as being in line with the beliefs and needs of university students, as well as being very user-friendly. In other words, students' perceptions of an innovation's utility and simplicity of use, such as DR, may inspire them to use them, thereby enhancing their academic performance.

The Role of Chemistry for Education on Sustainability

There is no doubt that the field of chemistry and the industries related to it are in the economic heart of every highly developed industrial society (Bradley, 2012). Industry provides the basic materials necessary for every other type of business. It also defines the basis of energy supply, modern agriculture, and innovative technologies. Unfortunately, many chemical industries around the world have not always been careful in the past. Quite often, they neither concerned themselves with the preservation of natural resources, nor did they give much thought to protecting the environment. Accidents both large and small have significantly contributed to the negative public image of industrial undertakings and chemistry as a science (Hartings & Fahy, 2011) However, a change in attitude has slowly taken place, at least in Western societies. This change goes hand in hand with a growing public awareness of both the finite nature of natural resources and the existence of limits which regulate and determine feasible rates of growth (Meadows, et al., 2005). Both being careful with our resources and avoiding damage to our ecology and health has aided in promoting a better image of chemistry in the past decades. Ever since the 1990s, sustainability and sustainable development have emerged as the core issues of today's chemical industry, its actions and its public image. The report by the European Communities Chemistry Council entitled *Chemistry for a Clean World* set the stage in 1993.

In the USA, the works of Anastas and Warner (1998) presenting their concept of green chemistry began to expand and gain recognition in the mid-1990s. In the early years, a struggle to find a proper name for the concept occurred (Hutzinger, 1999). In Anastas and Warner, (Anastas & Warner (1998) the idea of a more environmentally friendly and resource-preserving synthesis in chemistry was expanded to include twelve fundamental principles. These principles became the generally accepted guidelines for the contemporary understanding of green, sustainable chemistry, which has been implemented by both research and industry worldwide. Limited resources and a constantly growing consciousness of the value of environmental protection were both among the driving forces of this movement. But, increasingly stringent legal restrictions for the handling of chemicals and the search for a better self-image for industrial chemistry in Western society also contributed to this development. Today, worldwide initiatives are focusing on a more environmentally responsible form of chemistry. Examples of this include the ACS Green Chemistry Institute (ACS-GCI) and the European Technology Platform for Sustainable Chemistry (SUSCHEM). The core role of chemistry and chemical industry for sustainable development in modern societies suggests a central role for chemistry education in ESD (Bradley, 2012).

Basic Models of Approaching Sustainability Issues in Chemistry Education

Adding sustainable development issues to the chemistry curriculum is not a new idea by any stretch of the imagination. For the last two to three decades, many pupils around the world have been faced in chemistry education with issues such as keeping water resources clean, dealing with the effects of acid rain, coping with the hole in the ozone layer, and searching for both renewable sources of energy and raw materials. These topics and others have been widely implemented as content in many chemistry curricula worldwide (Bader & Blume, 1997). In any case, the question of how to deal with issues of sustainable development can take on different appearances and can follow different models. Although they partially overlap and can be integrated in different ways, four different basic models are presented by Burmeister and colleagues when it comes to implementing issues of sustainable development into formal chemistry education (Burmeister et al., 2012).

Model 1: Adopting Green Chemistry Principles to the Practice of School Lab Work

The first model applies the philosophy of green chemistry to the handling of chemicals and laboratory work procedures in chemistry classes. Student experiments can be shifted from the macro- to the micro-scale, dangerous substances can be replaced by less poisonous alternatives, and catalysts can be used to stimulate reactions (Schwarz et al., 2012). The potential of ESD—at least when it deals with learning about chemistry's contribution to sustainable development—can be expanded if students are able to recognize, compare and reflect upon the altered strategies. Students can learn how chemistry research and chemical industry attempt to minimize the use of resources, maximize the effects, and protect the environment. Karpudewan*et al.*, (2009) have already demonstrated that this strategy has the potential to change the attitudes and knowledge of student teachers. The strength of this approach is that chemistry education truly contributes to sustainability by reducing the amounts of chemicals used and by producing less waste. The weakness of the approach concerning ESD is that it is often less embedded into continuous self-reflection upon how society handles debates around changing technologies. In this case, students will not develop skills for contributing to society's decision-making on new or alternative technologies. Additionally, students will barely touch upon the controversial nature of developments in society and the real interplay between science, technology and society. In this case, the holistic approach of ESD will hardly be achieved in the manner outlined above.

Model 2: Adding Sustainability Strategies as Content in Chemistry Education

This model takes the strategies and efforts used to contribute to sustainability development into account when deciding which content to include in chemistry education. In this approach, the basic chemical principles behind sustainable and green chemistry and their industrial applications appear as topics within chemistry curricula (Luhken & Bader, 2003). Practical examples of this include the development of efficient processes in industrial chemistry in the fields of energy and raw materials conservation, research into the structure, properties and application of innovative catalysts, and the chemical considerations behind the production of fuels stemming from renewable materials (Bader & Blume, 1997). Learning about green chemistry and chemical research's contributions to sustainable development can also offer a basis for better understanding of various developments in wide-ranging fields. The strength of this approach is that it highlights the learning of the chemical principles disguised behind everyday processes and end products, thus making them more meaningful to students (Pilot & Bulte, 2006). At any rate, a thorough understanding of the interplay between science, technology and society—ESD terms the 'interplay of economic, ecological and societal impacts'—will never take place if learners' concentration is primarily focused on (or even restricted to) the learning of chemical content behind its technological application. In such a scenario, the general skills necessary for participating in societal debates on socio-scientific issues will hardly have a chance to emerge. Making sustainability issues part of chemically based content in the proper context can provide the initial step which offers learners access to sustainability issues as they exist in modern chemistry.

Model 3: Using Controversial Sustainability Issues for Socio-Scientific Issues Which Drive Chemistry Education

The third model integrates the chemistry learning using socio-scientific issues (SSI) having the tension of current societal debate behind them (Marks & Eilks, 2009). SSI teaching does not primarily focus the learning of chemistry as a subject or sustainability issues *per se*. Instead, lessons tend to mould sustainable development education by developing general educational skills in the area of an individual's actions as a responsible member of society. This model's approach varies from that of the second model in that it includes both the chemical basis of knowledge and reflecting society's debate about its practical application in technology as factors to be learned. Model 3 focuses primarily on learning exactly how developments in chemistry can be and actually are evaluated and discussed within society using all of the sustainability dimensions (Burmeister & Eilks, 2012.). This approach not only constitutes the explicit learning *of* chemistry, but also includes the learning *about* chemistry as it is dealt with in society. Examples with respect to sustainable chemistry include the ongoing controversy about the use of biofuels, the application of specific compounds and alternatives to them in everyday products, and the evaluation of innovative products from chemistry using a multidimensional approach (Eilks, 2002). The aspects of understanding societal debates and developing appropriate skills to actively participate in them are systematically built into the lesson focus. Students learn how to take part in societal decision-making in order to contribute to shaping a sustainable future. The strength of this approach is that it is skill-oriented with a sharp focus on ESD. It closely mirrors the differentiation defined by Holbrook, who has demanded more education through science instead of science through education. However, some socio-scientific issues of controversial nature have limited potential in the areas of individual and local action. Often, debate about new technologies is extremely complex and occurs primarily in expert committees at the political level. In such an arena, the influence of the individual is very limited. But in a truly democratic society, no individual is hindered from entering the political scene if he or she wishes to. The type of teaching in this third model attempts to prepare students for this very eventuality.

Model 4 Chemistry Education as a Part of Education for Sustainable Development (ESD)

This model integrates chemistry education as part of ESD-driven school development. Such an approach demands opening chemistry classrooms even further (Breiting et al., 2005 & Haan, 2006). This model suggests that school life and teaching should become part of ESD. Educating children to become active citizens who have the ability to achieve sustainable lifestyles requires entire school process models. Such models include development, self-evaluation and reflection (Shallcross, et al., 2006). All shareholders in the school system are required to explore future challenges, to clarify values, and to reflect on both learning and actively taking part in society in the light of ESD. If we understand school development as changing schools to become learning organizations offering new experience, reflections, innovations, we necessarily need to change both the way people lead discussions and act (Breiting et al., 2005). Chemistry education should help contribute to such an altered teaching culture. Many opportunities exist for opening chemistry teaching to reflect how this domain influences us in the here and now, including our current lives inside and outside of school or other educational institutions. Chemistry teaching can actively contribute to saving resources (energy, clean water, *etc*.) in local environments, including school. It can also offer suggestions for treating waste in an efficient fashion suitable for later recycling. Chemistry education no longer needs to stop at the point where teaching is limited to describing the chemical theories and knowledge behind sustainability issues and potential avenues of action. Chemistry lessons and school life morph into an action-based pattern of living and learning. Students gain first-hand experience of how taking action can fundamentally change their lives. This experience includes pupils seeing how their personal contributions to in-school decision-making processes factor into both changed behaviour on their part and alterations in the learning process in which chemistry is an integral part. In teaching practice, all four of the above-mentioned models may overlap or even combine in order to place a stronger focus on sustainability issues connected to chemistry education.

Conclusion

Integrating technology with the learning process for creating sustainable development has many benefits. Such blending can lead to a trans-disciplinary approach to address societal challenges. It will also equip students and teachers to shift their focus from what of thinking to how. Today, different departments/ schools in academic institutions are working in silos and there is no common language for communication. It is emerging as the biggest stumbling block in our efforts to achieve SDGs. In the context of sustainable development, learning is equivalent to addressing issues of how to sustainably shape the future in concrete fields of action, *i.e.*, chemistry and chemistry education. This includes observation, analysis, assessment and design of a given context in creative and cooperative processes. What is addressed and called for specifically are a critical assessment of knowledge in the light of the present-day information overload, the development of self-worth, self-determination and self-reliance, as well as social competencies such as the ability to participate (Rauch, 2008). Chemistry dramatically influences everything from the life of the individual to society as a whole. Chemistry curricula and chemistry teacher education should more thoroughly reflect not only the importance of education and sustainable development but support the development of human identity which is interrelated with the environment, both individually and collectively the goal being to allow students to actively learn how to shape society in a positive, sustainable fashion.

Suggestions

The following suggestions are made for the study;

- The use of digital resources in chemistry should be encouraged in schools.
- Government, schools, educational managers and stakeholders should ensure provision of digital resources in chemistry in schools.
- Teachers and students should be trained on the best use of digital resources in chemistry.

References

Adeniran, P. (2013). Usage of electronic resources by undergraduates at the Redeemer's University, Nigeria.*International Journal of Library and Information Science, 5*(10), 319-324.

Anastas P.T. and Warner J. C., (1998).*Green Chemistry Theory and Practice*, Oxford University, New York.

Anunobi, C. V., &Okoye, I. B. (2008). The role of academic libraries in universal access to print and electronic resources in developing countries.*Library Philosophy and Practice*, 189.

Bader H. J, and R. Blume, (1997). *Environmental chemistry in classroom experiments*, IUPA C, Delhi, 1997.

Bradley, J, D, (2012). Chemistry Education for Development.*Chem. Educ. Int.*, 2005, 6, Retrieved from the World Wide Web, December 30, at http://old.iupac.org/publications/cei/vol6/index.html.

Breiting, M., Mayer and F. Mogensen, (2005). *Quality criteria for ESD-schools*, ENSI, Vienna.

Burmeister M and I. Eilks, (2012). An example of learning about plastics and their evaluation as a contribution to Education for Sustainable Development in secondary school chemistry teaching.*Chem. Educ. Res. Pract*, 13, 93–102.

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, *41*(1), 10–32.

De Haan, G (2006). The BLK '21' programme in Germany: a 'Gestaltungskompetenz'- based model for education for sustainable development. *Environ.Educ. Res.*, 2006, 12, 19–32.

Eilks, I, (2002). Teaching 'Biodiesel': A sociocritical and problem-oriented approach to chemistry teaching, and students' first views on it.*Chem. Educ. Res. Pract.*, 2002, 3, 67–75.

Hartings M. R, and D. Fahy, (2011). Communicating chemistry for public engagement.*Nat. Chem.*, 3, 674–677.

Hutzinger, O, (1999). The greening of chemistry – Is it sustainable? *Environ. Sci. Pollut. Res.*, 6, 123.

Jonassen, D. H. (2000). *Computers as mindtools for schools*. Upper Saddle River: Prentice Hall.

Karpudewan, Z. H. Ismail and M. Norita, (2009). The integration of Green Chemistry experiments with sustainable development concepts in pre-service teachers' curriculum: experiences from Malaysia. *Int. J. Sustainable High. Educ.*, 2009, 10, 118–135.

Luhken, A and H. J. Bader, (2003). Energy input from microwaves and ultra sound – examples of new approaches to Green Chemistry, In *Green Chemistry*, ed. Royal Society of Chemistry, Royal Chemical Society, Cambridge(2003), http://www.rsc.org/Education/Teachers/Resources/green/docs/microwaves.pdf.

Marks R, and I. Eilks, (2009). Promoting scientific literacy using a socio-critical and problem-oriented approach to chemistry teaching: concept, examples, experiences. *Int. J. Sci. Environ. Educ.*, 2009, 4, 231–245.

Meadows, D. H. Meadows and J. Randers, (2005). *Limits of Growth.The 30 Year Update*, Earthscan, Milton Park.

Mikropoulos, T. A., &Bellou, I. (2010). *Senáriadidaskalías me ypologistí (Educational scenarios with ICT)*. Athens: Kleidarithmos.

O'Haver, T. C. (1991). Applications of computers and computer software in teaching analytical chemistry. *Analytical Chemistry*, *63*(9), 521–534.

Osborne, J., & Hennessy, S. (2003). *Report 6: Literature review in science education and the role of ICT: Promise, problems and future directions*. Bristol: Futurelab Series.

Pilot A and A. M. W. Bulte, (2006). Special issue: Context based chemistry education. *Int. J. Sci. Educ.*, 2006, 28, 953–1112.

Rauch, F, (2008). Bildung fur NachhaltigeEntwicklungalseinelernendegesellschaftspolitischeStrategie, in *DemokratieLernenHeute*, ed. G. Gruber and K. Stainer-Hammerle, Bohlau, Wien, 2008, pp. 173–188.

Schwarz, M. Hugerat and M. Livneh, (2006). *Microscale chemistry experimentation for all ages*, Arab Academic College for Education in Israel, Haifa.

Shallcross, J. Robinson and P. Pace, (2006). *Creating Sustainable Environments in Our Schools*, ed. Trendham Books, Staffordshire, 2006.

Ternenge, T. S., &Kashimana, F. (2019). Availability, accessibility, and use of electronic information resources for research by students in Francis SulemanuIdachaba Library University of Agriculture, Makurdi.*Library Philosophy and Practice*, 2352.

Tsaparlis, G. (1991). *ThémataDidaktikísPhisikískaiKhimíasstiMésiEkpaídefsi (Topics in Physics and Chemistry didactics in secondary education)*. Athens: M. P. Grigori.