Integrating Research into the Curriculum for a 4-Year UG Program in Chemistry

Dr. S. D. Shirke
Department of Chemistry,
Vivekanand College Kolhapur
(Empowered Autonomous)

Abstract:

The National Education Policy (NEP) 2020 provides an opportunity for undergraduate students to engage in research projects. One of its key features is the introduction of a 4-year UG degree (Honours with Research), which allows students to pursue research in their final year. According to the policy, students who achieve 75% marks or an equivalent grade during the first three years (or six semesters) and wish to explore research can opt for a research stream in their fourth year. Given this, it is essential to incorporate research components into the undergraduate curriculum right from the start. This article aims to outline a year by year approach to curriculum design that will help students transition smoothly into research culture. By using a practical example addressing a real world problem related to safe drinking water we illustrate how students can engage in progressive tasks over the course of their program, culminating in a need-based research project in the fourth year. These guidelines can also serve as a framework for tackling other societal challenges and designing curricula for 4 year UG degree programs (Honours with Research).

1. Introduction

The UGC guidelines support National Education Policy (NEP) 2020's vision by promoting the development of research skills among students through structured academic programs. This aims to transform higher education by emphasizing research and practical problem-solving at the undergraduate level. One of its notable provisions is the introduction of a 4-year undergraduate degree with an option for Honours with Research, which allows students to undertake research projects on real-world problems. This policy is complemented by the guidelines set forth by the University Grants Commission (UGC), which advocate for a research-oriented curriculum and encourage educational institutions to integrate research into undergraduate programs. According to the policy, students who achieve 75% marks or an equivalent grade during the first three years (or six semesters) and wish to explore research can opt for a research stream in their fourth year. While introducing research aspect among the undergraduate students, addressing societal issues in this process should not be ignored. This approach not only enhances students' research capabilities but also prepares them to contribute effectively to societal advancement. Many times students do not appreciate importance of research and most of them fail to link the research with the local issues being faced by society. Consider the most common issue, which has prime importance in the day to day life of our society, which is availability of safe drinking water.

Access to safe drinking water is a critical global challenge, impacting public health and quality of life. Contaminants such as heavy metals, pesticides, and pathogens in water sources pose severe health risks and contribute to widespread diseases. Despite advancements in technology, many communities continue to face significant barriers to obtaining clean, potable water. Addressing these issues requires innovative solutions and effective strategies.

According to the World Health Organization (WHO), more than 2 billion people globally use drinking water sources contaminated with feces, leading to widespread waterborne diseases such as diarrhea, cholera, and typhoid. In addition to microbial contaminants, chemical pollutants like heavy metals (lead, arsenic, mercury), insecticides, pesticides, nitrates, sulphates, phosphates and fluoride further exacerbate water quality issues, particularly in developing countries and rural areas.

Water contamination originates from both natural and man-made sources. Industrial waste discharge, agricultural runoff, and improper disposal of chemical pollutants are major contributors to unsafe water supplies. Additionally, natural contamination, such as arsenic leaching from soil into groundwater, poses severe risks in regions like South Asia. Prolonged exposure to these contaminants can lead to serious health problems, including cancer, neurological disorders, and developmental issues in children.

Ensuring safe drinking water is not only a public health priority but also crucial for economic and social development. Contaminated water directly impacts human well-being, reduces productivity, and increases healthcare costs. With climate change and rapid urbanization intensifying water scarcity and contamination issues, it is essential to develop effective, affordable, and sustainable water purification methods.

This article explores how to design an undergraduate curriculum that aligns with NEP 2020 and UGC guidelines by focusing on the challenge of safe drinking water. It outlines a year-by-year strategy to build students' research skills progressively, from acquiring foundational knowledge to executing hands-on research projects. By integrating these elements into the curriculum, educational institutions can foster innovation and equip students with the tools to address pressing global issues, ultimately contributing to public health and sustainable development. Under the NEP 2020, students have the opportunity to conduct research projects in their fourth year, focusing on specific challenges like water contamination. This allows students to:

Develop Practical Solutions: By addressing local water quality issues, students can engage in hands-on research that has immediate societal benefits. For example, projects could focus on creating low-cost filtration systems for rural areas, identifying contaminants in local water sources, or developing chemical treatments for safe water.

Apply Interdisciplinary Knowledge: The policy encourages interdisciplinary approaches, allowing students to combine their knowledge of chemistry, biology, environmental science, and engineering to address the complexities of water purification.

Promote Innovation and Critical Thinking: NEP 2020 fosters critical thinking and innovation by emphasizing problem-solving skills. Tackling the issue of safe drinking water will challenge students to innovate, experiment with new materials (like biochar or nanomaterials), and use advanced analytical tools to test water quality and effectiveness of treatments.

Address Real-World Problems: The NEP encourages research that has direct societal relevance. Water contamination is a problem that affects millions, and students working on these projects will have the opportunity to make a tangible difference in public health, environmental sustainability, and economic well-being.

Thus, NEP 2020 not only nurtures academic growth but also encourages students to take part in nation-building by solving critical challenges like ensuring safe drinking water for all. Through a combination of theoretical knowledge and hands-on research, students are empowered to contribute to sustainable development, public health, and social progress.

2. Importance and Literature Review

There are several important aspects, which attract the need of intervention in the field of safe drinking water. Some of them are as below:

Public Health Implications: Contaminated water is a leading cause of morbidity and mortality, particularly in low-income regions. Diarrheal diseases caused by unsafe water and inadequate sanitation kill approximately 485,000 people annually, with children being the most vulnerable. Addressing this issue would prevent millions of deaths and reduce the burden on healthcare systems.

Environmental Sustainability: Water contamination also threatens aquatic ecosystems, impacting biodiversity and causing long-term environmental damage. Sustainable water treatment methods that reduce chemical usage and energy consumption can protect both human health and the environment.

Social and Economic Impact: Access to safe drinking water is crucial for breaking the cycle of poverty. Communities without reliable water supplies spend a disproportionate amount of time and resources on collecting water, which affects education, productivity, and economic growth. Ensuring safe water access fosters economic development and improves the quality of life.

Technological and Scientific Innovation: The challenge of water purification has spurred significant research and technological advancements in chemistry. From the development of new filtration materials to innovative chemical treatments, science plays a pivotal role in creating solutions that are scalable, cost-effective, and accessible to even the most resource-constrained communities.

Given the far-reaching consequences of unsafe drinking water, there is an urgent need for interdisciplinary research focused on sustainable water purification technologies. Chemistry, with its capacity to understand and manipulate molecular structures, holds the key to developing new and improved methods for detecting, analysing, and removing contaminants from water.

The issue of ensuring safe drinking water has been a global concern for decades, with water contamination posing a significant risk to public health. Contaminants such as heavy metals (lead, arsenic, mercury), nitrates, pathogens, and organic pollutants are frequently found in water sources, particularly in developing countries. Several approaches, including chemical treatments, filtration, adsorption, and membrane technologies, have been extensively studied and implemented to mitigate these contaminants. A common method in developing regions is the use of chemical coagulants like alum for sedimentation, though newer studies have explored more sustainable alternatives such as natural adsorbents and nanomaterials. Recent advances in water

purification technologies focus on novel materials like biochar, graphene, and nanoparticles, which provide higher efficiency and lower cost, making them suitable for widespread use. Moreover, electrochemical methods and solar-driven disinfection systems are emerging areas of interest, given their potential for scalability and effectiveness in remote areas.
Studies have demonstrated the importance of chemistry in understanding the behaviour of contaminants in water and in developing effective remediation techniques. The use of advanced analytical chemistry tools such as atomic absorption spectroscopy (AAS) and inductively coupled plasma mass spectrometry (ICP-MS) has revolutionized water quality monitoring by allowing the detection of contaminants at trace levels. At the same time, green chemistry solutions are being sought to reduce the environmental impact of water treatment processes. Research indicates that the application of natural materials and low-energy filtration systems could bridge the gap between technological advancement and accessibility in resource-limited settings.

Ali and Gupta, V. K. (2007) explores adsorption techniques using activated carbon and natural materials for water purification. WHO/UNICEF (2021) provides an overview of global water quality issues and progress toward sustainable development goals. Zhang, X. et al. (2016) reviews modern technologies like nano filtration and electrochemical methods for water purification. Mohan and Pittman (2007) provide a comprehensive review of arsenic removal techniques, focusing on chemical and adsorptive methods. Bhattacharya et al. (2002) discuss arsenic contamination in Bangladesh and chemical methods for its removal. A review of coagulation methods used in water treatment for removing organic contaminants s given by Sillanpaa et al. (2018). Gupta and Babu (2009) investigate low-cost adsorbents like sawdust for removing heavy metals from water. Sharma and Sanghi (2012) discuss water treatment and pollution prevention.
In the following section we provide year wise details taking up a study of safe drinking water problem in the teaching, learning and research process. By considering these details design of curriculum can be undertaken.

3. Year wise activities

First Year: Building Foundational Knowledge in Chemistry and Water Issues

Objective: To introduce basic chemistry concepts and raise awareness about the significance of water quality, focusing on essential laboratory techniques and real-world water problems.

i. Subjects to Cover:
General Chemistry: Students will learn fundamental principles such as the structure of atoms, periodic trends, physical and chemical properties, molecular bonding, chemical reactions, and the laws of thermodynamics. These concepts are essential for understanding the behaviour of different components in water.

Organic and Inorganic Chemistry: Students are introduced to organic compounds, solvents such as alcohols, benzene and acids, bases, phenols and inorganic ions like nitrates , sulphates, phosphates and heavy metals, many of which are common water pollutants.

Introduction to Environmental Chemistry: The chemistry of water and basic concepts like behaviour water as a solvent, its polarity, and its ability to dissolve solids, liquids, gases, salts, and organic compounds are crucial. This also includes an introduction to pH, alkalinity, hardness, conductivity, dissolved oxygen etc.

ii. Practical Exposure:

Lab Techniques: Students will learn basic lab skills such as solution preparation, titration, filtration, and measurements using pH meters. These skills are fundamental for future water quality experiments.

Water Quality Testing: Basic experiments can include testing local water samples for pH, conductivity, and hardness. Students will start to recognize the variability in water quality due to natural and human-made factors.

Fieldwork: Encourage students to collect water samples from different sources-tap water, ponds, lakes, bottled water, bore water and analyse them in the lab to get practical experience.

iii. Introduction to Water-Related Problems:

Class Discussions: Explore simple but important topics such as water pollution, global water scarcity, and waterborne diseases like cholera and dysentery.

Case Studies: Introduce famous water contamination cases, such as the Flint water crisis in the USA or arsenic contamination in Bangladesh. These discussions help connect theoretical learning to real-world challenges.

Second Year: Analytical Techniques and Problem Identification

Objective: To introduce students to analytical chemistry techniques, which they can use to measure and identify contaminants in water samples. This year focuses on identifying water-related problems and beginning to think about how to address them.

i. Subjects to Cover:

a. Analytical Chemistry: This course provides a deeper understanding of the techniques used to detect contaminants in water. Topics covered may include:

i. Spectroscopy: UV-Visible, atomic absorption spectroscopy (AAS), and flame emission spectroscopy to identify and quantify metal ions (e.g., lead, arsenic).

ii. Chromatography: Techniques like ion-exchange chromatography for separating water-soluble ions.

iii. Gravimetric Analysis: To measure the total dissolved solids (TDS) and pollutants in water.

b. Advanced Water Chemistry: Dive deeper into water contaminants (like heavy metals, nitrates, and fluorides) and their sources, chemical behaviour, and interactions with other substances in water.

ii. Practical Exposure:

a. Water Quality Analysis: Students will learn to apply the analytical techniques discussed in class to assess water contamination levels, such as the presence of heavy metals (e.g., lead, arsenic) and organic pollutants.

b. Laboratory Experiments: Examples include:

i. Measuring chlorine levels in drinking water to assess its disinfection status.

ii. Quantifying levels of fluoride and nitrate, phosphates, sulphates and sulphonates, carbonates in water using spectrophotometric methods.

c. Hands-on Workshops: Introduce students to practical issues, such as how rural communities test water quality and what steps are needed for water treatment.

iii. Problem-Based Learning:

a. Case Study Projects: Students can be given specific water-related problems to research and present solutions, such as arsenic poisoning in groundwater or nitrate pollution in agricultural regions.

b. Fieldwork: Students can visit local water treatment facilities to see how analytical chemistry is applied in real-life scenarios. They might even start collecting their own water samples from local sources for analysis.

Third Year: Research Methodology and Project Proposal Development

Objective: To train students in the principles of research methodology, encouraging them to frame their research questions, develop hypotheses, and design a research proposal on safe drinking water.

i. Subjects to Cover:

a. Research Methodology: Teach students the fundamentals of designing a research project, including:

i. How to formulate a hypothesis.

ii. Experimental design (control vs. experimental groups).

iii. Data collection techniques, statistical analysis, and error analysis.

iv. Scientific writing and reporting.

b. Advanced Water Chemistry and Treatment: Topics might include:

i. Kinetics and thermodynamics of chemical reactions in water treatment.

ii. Different water purification techniques: coagulation, sedimentation, filtration, adsorption, and ion exchange.

iii. Emerging technologies such as Nano filtration, reverse osmosis, and biosorption.

ii. Practical Exposure:

a. Water Purification Experiments: Students can conduct experiments to test the effectiveness of different water purification methods. For instance, they can compare activated charcoal with synthetic resins for removing specific contaminants.

b. Design Experiments: Students are given more freedom to design their experiments, such as investigating the effects of various pH levels on metal ion precipitation or testing natural filtration materials like sand or activated carbon.

iii. Project Proposal Development:

a. Research Focus: Students are encouraged to choose a specific water-related problem to investigate. For example, they could explore ways to remove lead contamination from drinking water using inexpensive adsorbents.

b. Proposal Writing: By the end of the year, students should submit a detailed research proposal that includes:
i. Research objectives.
ii. Methodology (sampling, testing, purification techniques).
iii. Anticipated outcomes and their societal impact.

c. Mentorship: Faculty members guide students through the proposal writing process and provide feedback on their proposed research design.

iv. Collaborations:

a. Field Visits: Students can start collaborating with local organizations, research labs, or NGOs working in water quality management.

b. Workshops and Seminars: Organize guest lectures from professionals in environmental science and water treatment, invite engineers or researchers to inspire students and help refine their project ideas.

Fourth Year: Honors with Research – Execution of Research Project

Objective: To guide students in carrying out their independent research project, providing them with an opportunity to apply their theoretical and practical knowledge to solve real-world problems in water quality.

i. Research Project Execution:

a. Project-Based Research: Students will spend the year conducting their research based on the proposal they developed in Year 3. For instance, they could investigate:
i. Natural Adsorbents: Testing the efficacy of materials like activated carbon, clay, or biochar in removing heavy metals from water.
ii. New Materials for Filtration: Developing and testing new synthetic materials, such as nanomaterials, for more effective filtration of contaminants.
iii. Water Purification in Rural Areas: Designing low-cost purification systems for communities lacking access to safe drinking water.

b. Experimental Work: This will include sample collection, lab experiments, data analysis, and troubleshooting, under the guidance of a faculty supervisor.

c. Field Application: In some cases, students could apply their research by conducting pilot tests in collaboration with local water treatment plants or NGOs.

ii. Scientific Writing and Communication:

a. Thesis Writing: Students will compile their research into a detailed thesis or report, including an introduction, literature review, experimental results, and discussion of findings.

b. Publication: Encourage students to submit their work to undergraduate research journals or present it at academic conferences.

iii. Presentation and Defense:

a. Oral Defense: Students will present their research findings to a panel of faculty members, followed by a question-and-answer session.

b. Poster Presentations: Students can also participate in departmental or national research symposiums where they can showcase their work.

iv. Collaboration with Industry and Research Institutions:

a. Students may have opportunities to work with water quality institutions or collaborate with researchers on real-world projects, which could lead to internships, further studies, or job opportunities in environmental chemistry and water management.

By the end of this year, students will:

- Have a deep understanding of water chemistry, its contamination, and purification methods.
- Be capable of designing, executing, and analysing complex experiments related to water treatment.
- Have contributed meaningful research toward solving real-world problems related to safe drinking water.
- Be prepared for future careers or higher education in environmental science, analytical chemistry, or public health.

This progressive, year-wise approach ensures that chemistry students not only acquire academic knowledge but also develop practical skills, scientific thinking, and a passion for research aimed at solving one of the world's most pressing issues: access to clean and safe drinking water.

4. Conclusion:

The National Education Policy (NEP) 2020 represents a significant shift in the Indian higher education system by introducing opportunities for students to enhance their research capabilities. Previously, such provisions were lacking, and integrating research into the curriculum is now essential for effectively implementing this policy. To achieve this, it is crucial to design curricula that incorporate research elements and encourage students to tackle societal issues through scientific investigation.

Undergraduate students majoring in Chemistry, in particular, have the potential to make substantial contributions to public welfare by addressing pressing challenges such as safe drinking water. By organizing brainstorming sessions and fostering an environment where students can identify and explore real-world problems, educators can inspire and guide students in their research endeavours.

This article aims to outline how such a curriculum can be developed, using the issue of safe drinking water as a case study to illustrate the process. However, this approach can be applied to various other societal problems, demonstrating the broad applicability of this strategy. It is imperative that educators across all disciplines focus on providing students with meaningful research opportunities. This not only enhances their research skills but also enables them to address critical societal issues, thereby contributing to the betterment of society as a whole.

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