Acta Pedagogia Asiana

Review
Volume 4(2), 2025, 86–100
https://doi.org/10.53623/apga.v4i2.651

Blended Learning for Stoichiometry and Mass Balance in Environmental Chemistry

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SUBMITTED: 3 April 2025; REVISED: 1 May 2025; ACCEPTED: 5 May 2025

ABSTRACT: Teaching environmental chemistry today involves both conventional and digital learning modes. Traditional approaches such as lectures, problem-solving, and laboratory exercises, offer content that is more or less structured with direct interaction, but not active engagement, interactivity, and enough resources are often found wanting. To better learn the subject, blended learning has been introduced, including some important digital tools like online facilities, simulations, and virtual labs. These ensure access and increase participation but the major con that students show low motivation because of the unequal access to the tools, the challenge that teachers face using the new tools, low student motivation, and problems in assessment. Its use has grown, but the effectiveness of blended learning, especially in stoichiometry and mass balance, which are considered to be rather complex, is not well documented. This review aimed to answer how traditional, digital, and blended learning approaches work in environmental chemistry education and what the benefits and challenges of each are. While traditional methods are more inclined to encourage the interaction of the instructor, which already appears to be passive and sometimes disconnected from the real situation outside the classroom, the blended learning method will put forward greater interactivity and personalization, though much will now depend on the individual student and the access to technology. A balanced approach will be evidenced by blended learning, with the strong points imbibed from both the modes, but, however, much intelligence is required to apply it to steer clear of further weaknesses. For improvement in the teaching of Environmental Chemistry, it is essential to invest in the digital infrastructure, faculty training, strategies of student engagement, and innovative models of assessment. If applied strategically, then blended learning can bridge effectively between theory and practice, making the teaching of Environmental Chemistry more engaging, inclusive, and outcome-based.

KEYWORDS: Blended learning; stoichiometry and mass balance; assessment model; digital approach

1. Introduction

The scope of environmental chemistry in engineering includes studying chemical reactions, mass transfer, and the behavior of pollutants in natural and engineered systems. Issues related to water quality and the augean stable processes of water and wastewater as well as air pollution and solid waste management are considered. Applications evolved to include stoichiometry and mass balance principles as part of the analysis of chemical processes and prediction of transformations of pollutants as well as for designing effective environmental solutions. Numerical applications are developed for the design of problems such as mass transfer and chemical kinetics in air pollution control and mass transport in the design of a wastewater treatment plant and many others. Hence, suitable computer modules need to be developed and applied [1, 2].

Due to their perceived difficulty by students, stoichiometry and mass balance have typically not received much attention in the curriculum. Very few students can practically apply the stoichiometric equations and concepts of mass balance to visible applications; thus, there is a gap in knowledge retention when it comes to problem-solving. As a consequence of not being able to observe what is being taught practically, the students do not develop a feeling for the subject matter, and thus, they cannot think critically; the mode of learning is passive. It is very difficult to visualize such interactions in the absence of tools. Blended learning is an innovative pedagogical approach that is meant to help alleviate those challenges. It involves learning through a combination of online student-centered activities, whereby learning may be at different times or places with respect to the instructor, and onsite learning, where there is real-time, synchronous interaction with the instructor. The online component may comprise virtual simulations, as well as online interactive problem-solving scenarios and group discussions [3, 4].

Digital resources help students understand concepts by visualizing them, with the aid of real-world case studies and computational modeling exercises to concretize the sometimes-abstract concepts. These are aspects that current literature confirms regarding student engagement and improvement of learning outcomes in environmental chemistry through blended learning. The package will help in the visualization of chemical reactions based on mass balance in environmental systems. For example, online tools for carrying out degradation of pollutants can be accessed, modeling water treatment; thus, it demonstrates kinetics and stoichiometry in a very applied scenario. Learning activities are made fun, like quizzes and problem-solving games that help ensure involvement and restate the main ideas. These aids support regular lessons by giving pupils extra time to work on hard math and apply the theory they learn [3, 5].

Blended learning accommodates different learning styles. Some of the students might be comfortable with viewing and listening to interactive supplementary materials while others may thrive with paper-based workbooks delivered with some degree of interactivity. These include a variety of resources, such as video tutorials, e-books, discussion forums, and step-by-step breakdowns of problems. Students can learn better at their own pace and go back to the recorded lessons whenever they want. However, the primary concern of blended learning is the prerequisite of resources. Even when the digital infrastructure is in place, it may not be equally accessible in times and spaces for all human beings. It is assumed that the hardware at the students' disposal for working at home is not accessible to all students. Only personal computers or mobile devices are available for some, causing inequalities. Trainers also have to be trained to use those tools effectively and to create interactive content. Resources like time and skills are required for that [3, 5]. However, the use of blended learning at the university level can cover up this drawback related to the teaching of environmental chemistry [6, 7].

Universities are investing in online learning platforms, virtual labs, and adaptive learning technologies as part of the substantial growth in student engagement improvement AI tutoring systems, under such conditions, shall be assumed to avail individual feedback so that the learners can address their weaknesses in stoichiometry and mass balance calculations. Collaborative platforms can support peer-to-peer learning in the discussion that leads to problem-solving [8, 9]. The study aimed to explore the contribution of blended learning in teaching stoichiometry and mass balance in environmental chemistry, advantages, limitations, and best procedures for application in environmental engineering education.

2. The Significance of Stoichiometry and Mass Balance in the Subject

Stoichiometry and mass balance are the two basic concepts that play a fundamental role in the analysis of chemical processes and the prediction of pollutant degradation to come up with successful engineering solutions for the environment. They are further expounded upon with the advancement of the subject for modeling air pollution and the management of hazardous wastes. The table then demonstrates their importance in environmental chemistry as applied to provide a responsible and sustainable state when working on the environment in the presence of such disastrous impurities in the numerous ecosystems and on human health. The importance of stoichiometry and mass balance in environmental chemistry is shown in Table 1.

Table 1. Importance of stoichiometry and mass balance in environmental chemistry subject.

Aspect	Description	Example of Learning Topics	Reference
Fundamental for Understanding Reaction Mechanisms	Stoichiometry helps in quantifying reactants and products in chemical reactions, ensuring efficiency in processes like wastewater treatment and air pollution control. It is crucial for chemical dosing and understanding pollutant degradation.	- Chemical dosing in water treatment - Biochemical Oxygen Demand (BOD) calculations - Neutralization of acidic/basic wastewater	[11–13]
Essential for Tracking Substances in Environmental Systems	The principle of mass conservation is used to track pollutants in air, water, and soil. Mass balance calculations help model pollution transport, optimize wastewater treatment operations, and design remediation strategies for contaminated sites.	- Mass balance in wastewater treatment plants - Pollutant dispersion modeling in air quality studies - Contaminant fate and transport in soil and groundwater	[14–16]
Applications in Environmental Engineering	Stoichiometry and mass balance principles are applied in water treatment, air pollution modeling, and hazardous waste management.	- Coagulation and flocculation processes - Air pollution modeling (ozone formation, NOx-VOC reactions) - Hazardous waste incineration and landfill leachate tracking	[16–18]

2.1. Stoichiometry: fundamental for understanding reaction mechanisms.

The accurate stoichiometric application ensures reactions to be carried out efficiently and effectively in such engineered systems like wastewater treatment plants and air pollution control devices. One major stoichiometry application in environmental chemistry is chemical dosing for water and wastewater treatment. For example, the chlorination drinking water treatment process expresses the relevance of stoichiometry in determining the right amount of chlorine to be applied in disinfecting water and concomitantly reducing the formation of disinfection byproducts such as trihalomethanes (THMs). Similarly, stoichiometry balance in the neutralization of acidic or basic wastewater streams should be as accurate to leave no excess component to prevent secondary pollution. Stoichiometry helps predict the degradation pathway of organic pollutants and the pathway must be understood. Stoichiometric relationships also control the oxidation of contamination, for instance, the breakdown of organic material by oxygen in aerobic biological treatment systems. An instance is the assay of BOD founded on the stoichiometric rules and applied actually on a broad scale for judging the degree of organic waste in water. Right comprehension of these links helps technologists maximize treatment processes and lower amounts of waste to safe levels [11–13].

2.2. Mass balance: essential for tracking substances in environmental systems.

The mass balance or conservation principle of mass asserts that no creation or destruction of matter is made within the system. It falls in the area of environmental chemistry concerned with keeping track of different substances- modeling pollution transport and later designing appropriate treatment technologies. It is this principle that gives scientists and engineers the mandate for studying and predicting a long-term environmental impact concerning movement of pollutants into the air, water, and soil. Mass balance of other individual components within the system can equally be accounted for over various sections. Mass balance calculations are used to account for pollutants in the different sections of a wastewater treatment plant. Such mass balances, for example, are involved in the assessment of process performance and optimization in studies related to air pollution. These balances are theoretical in steady-state conditions, and the actual operating conditions might be such that they are deviated from the conditions assumed. This forms the scientific basis of achieving regulatory air quality. It also forms the basis for environmental cleanup and hazardous waste management. Such a balance, therefore, becomes applicable both in the design of pump-and-treat or in situ bioremediation systems and in the actual performance reporting based on actual performance to state how remediation should be carried out to reduce mass either in the soil or groundwater and be ultimately able to reduce mass balance within the contaminant [14–16].

2.3. Applications in environmental engineering.

The real-world applications of stoichiometry and mass balance are in water and wastewater treatment, air pollution control, and hazardous waste management. Concepts of stoichiometry and mass balance are heavily used because through these concepts, engineering treatment processes can be designed complying with the standards from regulatory authorities directed to protect public health and the environment. Engineering knowledge for the removal of contaminants from water sources relies very strongly on stoichiometry and mass balance. For example, in the treatment of drinking water, coagulants must be added. These are the salts of metals; for example, aluminum sulfate, $Al_2(SO_4)_3$; will react with the impurities, etc., and then the precipitate formed can settle down, a process that can then be separated by filtration. All these must be determined stoichiometrically to optimize treatment and keep chemical waste to a minimum. Stoichiometry and mass balance are equally valid for predictive model formulation on the behavior of pollutants in the atmosphere. Stoichiometric relationships of nitrogen oxides and volatile organic compounds can be applied to predict the formation of secondary pollutants, such surface O3 in photochemical smog. The mass balance model extrapolates emission sources from point sources, traffic sources, and natural sources; it is an essential model for air quality management and policy development. Management and disposal of hazardous wastes require an approach based on stoichiometry and mass balance for acumen toward safety and compliance with environmental regulations. For example, destruction abatement systems for hazardous organic compounds should normally consider stoichiometry related to the combustion reaction for the exact required quantity of the supplied oxygen for the complete oxidation and emerging formation of hazardous byproducts as well as to keep them from being formed in unburned or off-gas phase [17–19].

3. Traditional and Digital Learning Methods

The evolution of learning approaches has considerably impacted on the teaching and learning of environmental chemistry. Traditional approaches, characterized by lectures, chalk-and-board problem-solving, and textbook exercises, have long been the foundation of education. However, the advent of digital technologies has introduced new paradigms, challenging the efficacy of conventional methods [8]. Table 2 shows comparison between traditional and digital learning methods.

Table 2. Comparison between traditional and digital learning methods.

Aspect	Traditional Learning Methods	Digital Learning Methods	References
Content Delivery	Lectures, chalk-and-board explanations, and textbook exercises provide structured knowledge transfer.	Online platforms, video tutorials, and AI-based tutoring systems offer interactive and self-paced learning.	[8, 21]
Engagement Level	Often passive learning, requiring student initiative to engage beyond lectures.	High engagement through interactive simulations, virtual labs, and gamified learning.	[22–24]
Visualization of Complex Concepts	Chalkboard illustrations and textbook diagrams may not fully capture dynamic environmental processes.	Augmented reality, simulation software, and virtual labs provide 3D visualizations of reaction mechanisms and pollutant dispersion.	[21, 23]
Real-World Application	Focuses heavily on theory, with limited hands-on problem-solving outside laboratories.	Simulation software (MATLAB, Aspen Plus) allows real-world modeling of chemical reactions and environmental systems.	[25, 26]
Practical Training	Physical laboratory experiments provide hands-on experience but may be limited by resources.	Virtual laboratories offer cost-effective, scalable alternatives for conducting chemical analyses in a risk-free environment.	[23–25]
Assessment & Feedback	Manual grading and face-to-face feedback, which may delay response times.	AI-based assessments provide real-time feedback and adaptive learning paths.	[21, 27, 28]
Flexibility & Accessibility	Fixed class schedules and location-dependent learning.	Online platforms enable remote learning and self-paced study options.	[8, 29, 30]
Challenges	Limited engagement, passive learning, and resource constraints in lab sessions.	Requires digital literacy, internet access, and investment in technology.	[7, 22]

3.1. Traditional Approaches

3.1.1. Lectures.

Lectures are used as the primary mechanism for content delivery, whereby a lecturer imparts information to students in a structured manner. It is within the purview of this methodology that theoretical and fundamental bases be best explained and understood with regard to environmental chemistry. While it is true that more often than not lectures place students in rather passive sponges of knowledge, it is in the same way very engaging to the critical capacities of students. Studies have shown that passive learning environments may not develop the problem-solving skills required for scientific inquiry [8, 22].

3.1.2. Chalk-and-board problem-solving.

Utilizing chalkboards for problem-solving exercises allows instructors to demonstrate analytical techniques and step-by-step solutions. This method provides a visual representation of problem-solving processes, aiding in the comprehension of complex chemical equations and reactions. Despite its benefits, this approach may not cater to diverse learning styles, potentially leaving some students struggling to grasp intricate concepts [8, 25].

3.1.3. Textbook exercises.

Assigning problems from textbooks reinforces lecture material and offers students opportunities to apply theoretical knowledge. Regular practice through these exercises can enhance proficiency in environmental chemistry principles. However, reliance on textbook exercises may not adequately address real-world applications, limiting students' ability to connect theory with practice [21, 23].

3.1.4. Face-to-face interaction with instructors and peers.

Direct interaction fosters immediate feedback, clarification of doubts, and collaborative learning. Engaging with instructors and peers in person can enhance understanding and retention of complex topics. Nevertheless, the effectiveness of these interactions depends on the quality of communication and the willingness of students to actively participate [21, 27].

3.1.5. Laboratory experiments for practical applications.

Hands-on laboratory sessions are integral to environmental chemistry education, allowing students to observe chemical phenomena firsthand and develop essential experimental skills. These experiences bridge the gap between theory and practice, fostering a deeper understanding of scientific concepts. However, traditional laboratory settings may face challenges such as limited resources, safety concerns, and time constraints, which can impede the learning process [7, 23, 24].

3.1.6. Challenges of traditional methods.

While the role of the lecture as the primary didactic approach has deep historical roots in education and is still very much foundational, it is not benign, and several common challenges may adversely affect the degree of involvement and hence the learning outcomes of students. Typically, the traditional lecture is more inclined to be passive, thus imposing conditions where students merely have to receive what is being given; such situations often lead students to disengage, and indeed, critical thinking and problem-solving skills in environmental chemistry have to be developed [22-24]. Such traditional methods are very much impervious to varied learning preferences. Without which, students would lose motivation and a reason to stick to the presentation—hence, poor academic performance. The lecture is very weak in action when it comes to teaching the very abstruse and complicated concepts common in the environmental chemistry course; that alone clearly shows that textbook diagrams are not adequate. Molecular interactions and reaction mechanisms cannot be justifiably demonstrated through the use of traditional methods; however, the linkage is not usually well balanced with the real-life situation. This gap sometimes makes it difficult for learners to understand how important applied chemistry is in dealing with issues pertaining to the environment. Setting up the labs requires quite a lot of resources in terms of equipment, chemicals, and safety measures. Even when resources are available, colleges may have restrictions that limit how often and to what level practical classes can be held, diminishing the students' hands-on time and skills [22, 25, 26]. In order to overcome these challenges, teachers have tried several new ways to improve the old teaching methods, like active learning, technology use, making a curriculum, and making programs for teachers (Figure 1). More use of active learning ways, such as group talks, case studies, and problem-based learning, can help raise student participation as well as make the understanding much deeper; the methods give students responsibility for their learning processes and therefore develop critical and collaborative measures in learning [8, 21, 25, 26].

Figure 1. Several approaches to improve traditional teaching techniques.

3.2. Digital approaches in environmental chemistry education.

The use of digital strategies in teaching environmental chemistry has changed the way challenging chemical issues are addressed among students. Advanced learning technologies have recently come into existence, including online educational resources, simulation programs, virtual labs, and AI-based tutoring systems. These tools make the learning process more interactive, make it possible to bridge the gap between theoretical concepts and their practical applications, make the learning process more adaptive and also reduce the degree of student isolation associated with distance learning [21, 23, 25, 26].

3.2.1. Online learning platforms.

Online learning platforms, such as Moodle, Blackboard, and Canvas, are to put it simply, the future of modern education! Some of the features that these platforms offer include video tutorials, quizzes, discussion forums, and tools for submitting assignments. Video tutorials are the main source material that students are able to use for going over complex issues on an individual basis. Most independent learning can take place through interactive discussion where the students are able to post to a thread, respond to the posts of others, and quizzes that check understanding and give immediate feedback. Yet, these forums advance collaborative learning by inviting students to "speak" in an academic thread, share ideas, and clear up any muddy points with the instructor. Online quizzes and automated assessments serve as a reinforcement of key concepts with immediate feedback. Some of these systems can support the blended learning approach that would help an instructor combine a face-to-face lesson in a traditional classroom with an online component designed to increase student interaction and learning [8, 21, 29, 30].

3.2.2. Simulation software.

Simulation software, such as MATLAB, Aspen Plus, and ChemCAD were used. This played a major role in changing how the balance of mass and kinetics of reaction is understood by students taking environmental chemistry. The same tools can be used to model chemical reactions, optimize process parameters, and analyze environmental systems. MATLAB, for example, can be used by the student in modeling chemical reactions taking place in the environment, both in the air and in waters, thus helping him to understand about environmental modeling. Aspen Plus and ChemCAD also provide practical process simulators for the treatment of wastewater, control of air pollution, and management of hazardous wastes. These software applications help the student to interact with the variables as well as to test the different scenarios and have also visualization of effects of mass balance principles in real-time. It is through this interactive simulation tool that the gap between theoretical knowledge and hands-on environmental problems is bridged, hence preparing a student for professional applications [21, 23, 25, 26].

3.2.3. Virtual labs and augmented reality.

Immersive and interactive learnings are shared by virtual laboratories and AR applications. Concepts are carefully understood by students who may be finally allowed to run chemical analyses, view reaction mechanisms, and interpret outcomes and results. Augiated reality acts by placing relevant digital information on real scenes, thus allowing scholars to keenly observe molecular structures, chemical reactions, and the spread of pollutants. AR applications in environmental chemistry have been proven to significantly enhance spatial conceptualization and problem-solving abilities since they provide a platform through which students can fully engage with 3D models and dynamic simulations. The combination of virtual laboratories, AR, and chemistry creates hands-on learning, making vague concepts more solid and understandable [22–25].

3.2.4. AI-Based tutoring systems

Artificial intelligence has personalized and adaptive learning through AI-based tutoring. The tutoring learns from a variety of machine algorithms on student performance and generates recommendations for individual students' learning needs. Such AI-driven tutoring would be able to offer real-time feedback to a student while navigating a complex problem-solving process on stoichiometry and mass balance calculations. The AI-based system would also be able to make an intelligent assessment by adapting the difficulty level of questions based on the response provided by the students, hence ensuring customized learning that meets individual requirements. Some AI-based systems further incorporate natural language processing that allows a chat-based learning environment where learners can ask questions conversationally and get responses in real-time [21, 27, 28].

4. Benefits of Blended Learning for Stoichiometry and Mass Balance

Blended learning offers significant advantages in teaching stoichiometry and mass balance in environmental chemistry. An old-age problem with static diagrams, equations in the textbook, and theory is that the real dynamic nature of complex chemical interactions and mass transfer processes cannot be well-illustrated [8, 21]. With blended learning, students will have visualization tools, simulations, and virtual experiments for observing dynamic reaction mechanisms. For example, software simulation packages may be used to help students model chemical reactions, degradation of pollutants, and material flow in environmental systems. These digital resources drive home abstract concepts with feedback in real-time, thus helping to close the gap between knowing the theory and applying it in practice [21, 23, 24].

Another great benefit of blended learning is flexibility and access. Better than conventional lecture-based teaching, which has fixed hours, blended learning lets students move at their own pace. For example, Moodle, Blackboard, and Canvas may let students replay the lecture, take the tutorial at the speed they want, and review problem-solving exercises; these can be viewed as and when required. This will remove the lag which weaker students have because they do not get the right answer instantly. For instance, most of the content can be viewed on mobiles enabling very easy access. Different learning speeds and preferences can then be matched with the appropriate way individualized learning sets the study's pace, and the mobile access will be a bonus for those anatomically seated in one place [31, 32].

Blended learning teaches student engagement and motivation with interactive exercises and game elements. In a passive classroom environment, where rote methods exact memorization, the use of interactive quizzes, virtual labs, and real-world problem-solving challenges will make the learning process more active. For example, gamified activities offered in earning points for quizzes or engaging in knowledge-based battles will set an environment of challenge, individual recognition, and status identification.More information is remembered and retained for problem-solving application when information is couched in an active, relevant, and timely learning approach. Therefore, Blended Learning has evolved as a didactically powerful, motivational, and effective treatment condition that fully engaged students in the learning process and invested them in the coursework to be completed [22, 24].

One major advantage of blended learning is its linkage of theoretical knowledge and practical application. Conventional learning is such that the theory is always separated from the mode of practical application. Digital simulations support laboratory experiments which are to be carried out, and application is strengthened through parallelism with the real world [25, 26]. Blended learning also provides a personalized learning experience through adaptive technologies. AI-driven tutoring systems analyze student performance, identify weaknesses, and recommend tailored exercises to address specific learning gaps. These adaptive learning tools ensure that students receive targeted support, increasing their chances of mastering stoichiometry and mass balance concepts efficiently [21, 27, 28].

5. Challenges and Limitations of Blended Learning

Blended learning combines new and traditional teaching methodologies in the teaching of environmental chemistry. The approach that is of the digital nature to the teaching of environmental chemistry is riddled with challenges and limitations (Table 3) despite having very many benefits. The greatest of these drawbacks is the fact that not all students have equal access to the technology that underlines reliable internet connections and advanced software as well as personal devices; this may sharply create disparities in their opportunities for learning [33]. Most simulations and virtual labs require high-speed internet and compatible hardware to run effectively; students will therefore not gain much from these tasks. This leaves students in regions where the technology infrastructure is not that good with challenges to access the materials required for the course, for example, engaging in online discussions and completing assignments that require specialized software. Such technological barriers would work to further increase the disparities between the more resourceful digital-wise students and the less fortunate ones, hence eventually affecting the general learning outcome [31, 32].

Table 3. Challenge and solution for blended learning.

Challenge	Description	Impact on Learning	Possible Solutions
Technological Accessibility	Unequal access to reliable internet, software, and devices. Some students may struggle with running simulations and virtual labs due to infrastructure limitations.	Creates disparities in learning opportunities and may hinder access to essential course materials.	Investment in institutional tools assets, offline learning options, and approachability improvements.
Instructor Training & Readiness	Traditional educators may face difficulties adapting to digital tools and interactive teaching methods. Some may resist technology due to confidence issues.	This can lead to ineffective course delivery and a lack of engagement in digital components.	Faculty training programs, technical support, and gradual combination of digital tools.
Student Engagement & Motivation	Online components need self-discipline, and some students may struggle with time controlling.	Decreased involvement in discussions, incomplete assignments, and weaker theoretical understanding.	Interactive content, scheduled live sessions, and personalized response to sustain accountability.
Assessment & Evaluation	Online assessments may not correctly evaluate student understanding. Academic integrity concerns occur due to access to external sources.	Challenges in evaluating true competency in environmental chemistry topics.	Innovative assessment methods such as project-based evaluations, virtual lab reports, and adaptive testing.

Another major challenge is the matter of instructor training and readiness. Conventional teachers who have been used to the physical classroom setting may find it difficult to learn the online system and make proper integration with their curriculum. The hybrid mode of learning would require the faculty to be acquainted with several online tools, learning management systems, and interactive teaching methodologies. Moving from one to another would take time and effort that instructors need to be provided with professional development programs that can help them create interesting and interactive digital content. Some of the teachers may not want to use the technology; they will not be confident about using the technology or they may feel that the technology does not put better measures to keep student attention. The implementation of the hybrid learning method without proper support and training would lead to ineffective course delivery and disjointed learning [7, 34].

The major limitations of blended learning are compromised, first and foremost, by students' low engagement in the online activities. Just like traditional learning, the success of blended learning requires that the students be motivated intrinsically to watch the lectures and participate in discussions. However, an online blended module is riskier because students do not have direct supervision, which also causes problems with engagement. Problems with engagement, coupled with procrastination and lack of study planning, lead to disengagement and subsequently weaker conceptual understanding due to incomplete coursework. The major limitations, in this case, would be the problems of most students who are used to group learning and consider individual activities in e-learning to be more engaging, regarding group discussions and group projects as isolated activities. One way to address the reduced engagement is creating a feeling of dependence through interactive activities, individual feedback, and scheduled live sessions [5, 35].

Assessment and evaluation in a blended learning environment can prove rather challenging. Traditional exams and quizzes might not exhibit full measure of understanding on the part of the students when the greater proportion of the coursework is conducted in a digital environment. Online assessments raise equitable concerns since the students can use external resources or even collaborate to find answers. There is the need to come up with a creative assessment that gives a true measurement of the student's performance in stoichiometry and mass balance. This may involve projects based on virtual lab reports and adaptive testing. The other concern is that instructors have to balance formative and summative assessments at all times to give the students proper feedback on their progress on the course [36, 37].

6. Best Practices for Implementing Blended Learning in Environmental Chemistry

Applying blended learning to the teaching of environmental chemistry requires a strategic plan that integrates the use of technology into traditional teaching methodologies. One of the best models is the flipped home classroom, wherein traditional lectures are eliminated and replaced by recorded video lessons. The videos can be viewed by the students at leisure so that all theoretical aspects, for example, stoichiometry and mass balance, can be prepared outside the class time, which is then used for face-to-face interactions. Thus, the class hours can involve problem-solving through interactions and discussions related to the application of the concept. This type of model supports active learning since students come having already prepared, therefore being able to engage in the discussion and application part of the teaching and reinforcing their understanding through interaction and guidance by the instructor [21, 22 37].

Instructors should use case studies and real problems as part of their in-service training to make stoichiometry and mass balance more relevant to the real environmental problems students will encounter after graduating. Wastewater treatment, air pollution modeling, and hazardous waste management are some of the environmental engineering applications that could provide such a setting. The real environmental case studies, including but not limited to actual mass balance calculations for events such as industrial pollution or remediation projects, promise comparison of actual chemical processes into which mass balance rules enter at critical points. This can help foster critical thinking, problem-solving ability, and a more in-depth understanding of the role chemistry plays in environmental issues [1, 2, 25, 26].

A properly balanced mix of both physical and virtual labs would add to the practical experience of the students. While the use of traditional laboratories is very important for hands-on learning, the virtual labs and simulations can fulfill the same requirements by facilitating the students to work on an available digital setup. The simulation software allows students to design mass balance scenarios and reaction kinetics that are difficult or hazardous for the real laboratory. This will help the students provide a complete overview in the environmental chemistry concept and provide support for the improved technical skill on computational modeling, both physical and digital [31, 32].

Regular feedback and lively discussions are the nuts and bolts in successful blended learning. Online chat rooms, peer-to-peer sites, and projects serve as avenues wherein students can interact with both their classmates and teachers outside the physical classroom. Inviting the students to participate in the discussion, ask questions, and work on projects creates a sense of community and deepens the understanding of challenging topics. The regular feedback of the instructors, be it in the digital platform or through personal mentoring, helps the students keep track of their performance and deal with learning challenges [38, 39].

7. Conclusion

Blended learning provides an approach to teaching stoichiometry and mass balance in environmental chemistry that is quite transformational. It combines supplemental digital tools with traditional teaching. The approach helps students view the concepts through the use of visualization tools, simulations, and interactive exercises. Abstract chemical processes may be perceived as rather challenging. The online resources are not only informative but also highly flexible for use as a tool for learning, thereby permitting a student to address difficult subject areas at his pace. More difficult topics can be made even more engaging through the use of gamification and case-based teaching. While Blended learning has all the advantages, there are numerous obstacles that stand in the way, such as the level of technology of the student which can be a limiting factor; the instructor must also be trained to incorporate the required teaching tools. Online activity often results in inconsistent student participation, thereby needing student-centered strategies to ensure discipline and participation. In addition, appropriate and fair assessment methods should be implemented to assess student learning within a blended setting. To enable the implementation of best practices in blended learning, the following are purposed: the flipped classroom model, online quizzes, gamified learning, and the integration of physical and virtual labs. Collaboration in discussions using real-world case studies further engages students more deeply. With a promise from all the challenges and the best practices approached, blended learning will enhance the teaching and learning of environmental chemistry as it will impart the students the requisite analytical and problem-solving skills for improving the environment. As technology continues to advance, blended learning remains one of the pivotal methods of advancement in teaching environmental engineering.

Acknowledgment

The authors would like to express their gratitude to Curtin University Malaysia, Universitas Pendidikan Indonesia, and Universiti Tun Hussein Onn Malaysia for their support in facilitating this research. We also acknowledge any funding bodies, institutions, or individuals who contributed to the success of this study.

Author Contributions:

Tony Hadibarata: Conceptualization, methodology, supervision, data analysis, manuscript writing, and review; Topik Hidayat: Investigation, data collection, formal analysis, and editing. Mohd Hairul Bin Khamidun: data analysis.

Competing Interest

The authors declare no competing interests.

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