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| **The Coversheet** | |
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| Student Number  (as shown on student ID card): | 240217811 |
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| I have read and understood the [Academic Misconduct statement.](https://blog.yorksj.ac.uk/assessment/coversheet-statements/) | Tick to confirm ☒ |
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| I am satisfied that I have met the Learning Outcomes of this assignment (please check the Assignment Brief if you are unsure) | Met ☒ |

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| **Self-Assessment** – If there are particular aspects of your assignment on which you would like feedback, please indicate below.  Optional for students |
| ***Suggested prompt questions-***  *How have you developed or progressed your learning in this work? What do you feel is the strongest part of this submission?*  *What feedback would you give yourself?*  *What part(s) of this assignment are you still unsure about?* |
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| **Assessor’s Feedback** (may be delivered in line with the submission) | |
| Were the learning outcomes met? | Yes ☐ If not, what was not met: |
| Assessor’s response to the student’s submission, request for feedback and / or self- assessment (feedback): | |
| What specific actions should the student undertake to progress their learning? (feedforward): | |
| Please take this and other feedback to your next academic tutorial to plan your future  work. | |

**INTELLIGENT TUTORING SYSTEM FOR CHEMICAL**

**Abstract**

This report outlines the development of an Intelligent Tutoring System (ITS) designed to teach high school chemical equations balancing skills. To formulate an objective representation the system utilizes an ontology built using Protege in which chemical relationships between elements, molecules, coefficients, reactants, and products are defined. The system incorporates a Natural Language Processing tool in Python along with RDFLib to engage with the ontology to help student solve equations and give them feedback on their steps. The ITS prototype allows students to practice equations by moving coefficients around, and assessing the solutions made. It provides suggestions and feedback in case of mistakes made, hence encouraging an effective learning process. The project also points out the fact that issues regarding the organization of the knowledge representation and comprehensible interface remain vital in the creation of educational tools. They also detail the improvements made during the development of the report, the issues encountered, and the recommendations for future modifications, such as extending the ontology, designing a more intuitive interface, and integrating machine learning for personalization.

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# Introduction

Teaching and learning of chemistry and the balancing of chemical equations are core component of high school chemistry syllabi. Achieving a state of equilibrium in chemical reactions teaches students about principles of conservation of mass and chemical reactions which are very vital in the understanding of the several science phenomenon. When students progress through their learning curve, the formula balancing is critical for further learning of chemistry, which has future influences on areas such as biochemistry, environment, and pharmacy. But, with this skill, it has been difficult for many students to master it and that needs an educational system that not just teaches the learner but offers practice sessions along with feedback sessions.

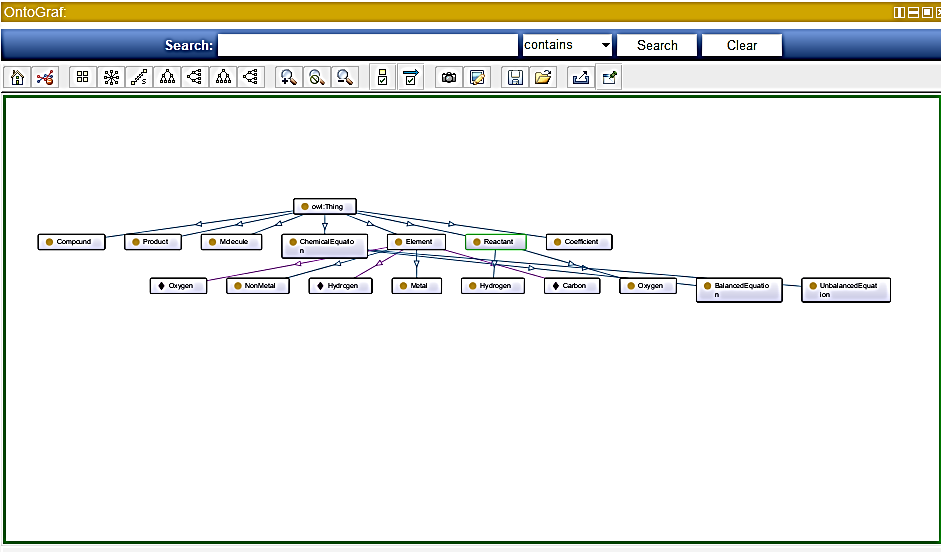
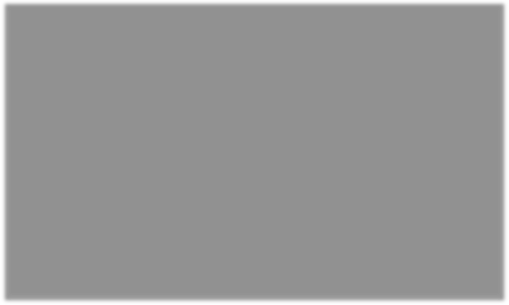
Intelligent Tutoring Systems (ITS) are a major innovation in the cognitive technology paradigm that provides individualized instruction. An ITS can elicit an input from a learner and give feedback based on the input, as well as provide explanation, and further practice according to the learner’s rate of learning. Also, unlike other conventional learning systems where the learner is tuned to a certain sort of learning style, ITSs are flexible enough to adapt the level of difficulty and contents according to the particularity of the learner. This makes ITS useful in areas such as chemistry as it can assist students with challenges of compromising equations. Using the approach of a tutor’s assistant, the ITS can perform the function of guiding students from their perceived knowledge level to the intended learning objectives.

The ITS constructed for this project focuses on high school students who need help in solving chemical equations. The actual purpose of the system is to facilitate how learners can come up with a way of solving problems involving the balance of chemical equations through an approach that offers feedback in real time. This kind of approach enables the students to move at their own pace and thus a reinforcement of chemical reactions.

To this end, a number of technologies were adopted with the major focus on the integration of ontologies for knowledge representation. The part of the ontology which has been developed in the Web Ontology Language (OWL) is aimed at presenting with the relations between chemical elements, molecules, and coefficients encountered in the chemical equations. The described ontology gives a structure and dynamism necessary to perform a query on a student’s knowledge. Also, the Turtle (TTL) format was employed to serialize the created ontology for usability and information exchange. Analyses were conducted using Python programming, and this was used in implementing the system’s tasks like parsing of the developed ontology,

querying function and user’s interface. Such integration of sophisticated technologies allows the ITS to present user-friendly, engaging, and extensible learning environment for student use.

# Project Plan



### Figure 1: Onto Graph Overview

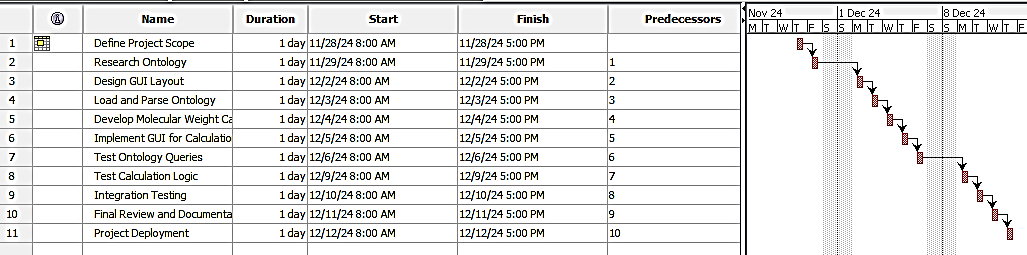
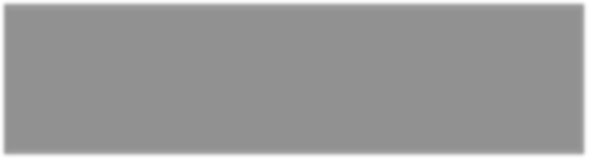
(Source: Obtain from Protege)

The organization and management of this project involve clear task allocation and timely completion of key milestones, ensuring that the development of the Intelligent Tutoring System (ITS) progresses smoothly.

## Team Roles and Responsibilities

However, the project is a personal one, but in a team environment, the roles will be assigned according to specialization and interests. Initially, one team member would work on the **ontology development**: defining the domain and creating the OWL-based ontology to represent the specifics of the chemistry concepts involved in chemical equations (Kochmar et al. 2022). This entails placing concepts such as elements, molecules, and coefficients into the structure of the ontology so that it meets the learning goals of ITS. Another member would be in charge of the **Python programming** while another would handle the specific logic behind the ITS which would involve mining the ontology using RDFLib and Duffy et al’s (2006) Model, querying the mined data in the ontology to determine the progress of the students and the level of feedback at each level of the model. Furthermore, there would be someone employed to assume the role of designing the **user interface** (UI) (Jakobsche et al. 2023). The

functionality of this position includes design of a simple, clear graphic interface that will enable the students to communicate with the program, input answers and get instructions.

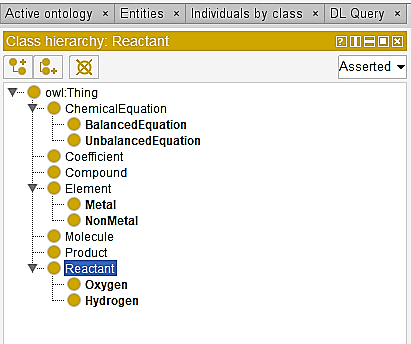
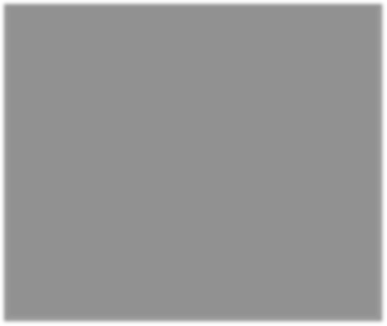


### Figure 2: Gantt Chart Overview

(Source: Obtain from Project Libre)

## Milestones

The project timeline is divided into several major stages. The first phase involves **defining the domain and ontology** where all the chemical concepts and relations are described. This stage is important as it serves as the base on which the rest of the system will be built (Uriarte-Portillo et al. 2021). The second one is **developing the ITS prototype**, which should be achieved by applying Protege for the ontology and Python for the system programming. This encompasses the inclusion of the developed ITS ontology into the existing ITS framework as well as coding the basic operations. The third achievement that requires attention is the **testing the prototype with sample users** to assess the functionality of the system and its ability to provide effective learning (Mousavinasab et al. 2021). In this phase, feedback from the test users will be incorporated to fine and enhance the product. The last step is **writing the report** that will describe the steps taken in the design, implementation, testing, and evaluation phases as well as brief conclusions.



### Figure 3: Onto Classes Overview

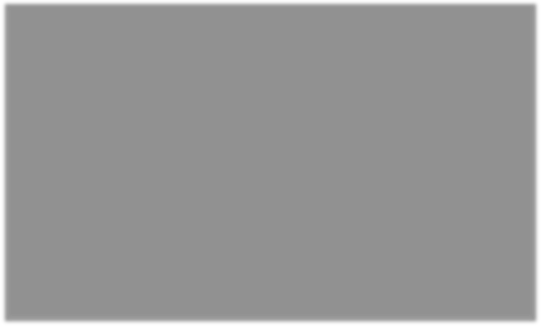
(Source: Obtain from Protege)

**Resources Required:** To achieve the final goal several tools, software and libraries are required for the said project are listed below: **Protege** is the tool for the creation and storage of new ontologies, thus, it serves as the environment for the chemical ontology definition and visualization. To conceptualize the information, ontology is stored in Turtle (TTL) format, and for parsing and querying of the ontology, **RDFLib**, a Python library is employed (Ateş, 2024). **Python** is at the base of the ITS, and codes their interactions, as well as the integration of the ontology. These resources are vital for effective realization and deployment of the ITS in the transport system.

# Literature Review

## State of the Art

Intelligent Tutoring Systems (ITS) have been used implemented in education contexts, due to their capability to offer individualized learning environments for learners. Such systems are intended to replicate a face-to-face tutoring setting, provide feedback, support the learner through the content material, and adjust for learning rates (King et al. 2022). In different fields especially in STEM (Science, Technology, Engineering, and Mathematics), ITS can help in promoting a better learning environment because it caters the needs of each learner. In various learning environments, ITS frameworks have developed into intelligent systems that use AI, machine learning, and big data to analyze and address students’ interactions.



### Figure 4: OWL File Overview

(Source: Obtain from Protege)

More precisely, in chemistry ITS has been used to teach easy material containing chemical reactions, equations’ balance and molecules structures. Most of these systems employ question answering models, whereby students are presented with questions, which they solve individually with immediate feedback in the form of hints or explanations (Gunawan et al. 2021). This shows how ITS has advantages over traditional learning processes since it can also test the knowledge of the students and adapt content as necessary.

## Mechanism

**ITS Frameworks and Technologies:** ITS has several frameworks and technologies, through which it operates. Ontologies especially within the context of knowledge representation have become one of the proliferated tools in these systems (Gobert et al. 2023). Ontologies give a way of structuring and relating explicit information that is conducive to ITS’s design, explaining the complex information and organizing the relations between them in an easily interpretable manner (Borchers et al. 2024). In chemistry, ontologies can semantically describe such elements as elements, compounds, reactions, and other concepts inherent in chemical equations.

Ontologies also help in supporting adaptive learning. Moreover, ITS allows the student input to be evaluated directly and in real-time so as to adjust the difficulty levels, provide hints based on the learning progression or even take the student through complete steps of solving the

problem. The other strength of ITS is that it is flexible in that it can adjust to different levels of students so that the students are not overloaded in their lessons or lack challenge in their learning activities. Also, techniques like natural language processing and semantic web enable ITS to engage with students at a human platform, hence enhancing engagement and efficiency in learning.

**Existing Chemical Equation Balancing Systems:** There are several ITS that have been designed for the purpose of teaching students on how to balance chemical equations. Such systems tend to offer directions, examples, examples as well as quick responses to assist the students in comprehending the rules and procedures in balancing equations properly whereby (Guo et al. 2021). For example, some ITS are designed in a question-answer manner where students are given equations and are supposed to complete equations by inputting correct coefficients.

Although these systems can potentially provide a great amount of learning aid, their efficiency is usually determined by how realistic the approach to problem solving is and how accurate the feedback which is provided is. Some systems give tips or enable the learners to try several solutions before being offered help, whereas in other systems the answers are more straightforward (Leon and Vidhani, 2023). However, the utilisation of these tools may, at times, have some constraints when it comes to the variation in students’ knowledge and ways of their thinking and learning. Besides, most of the current systems are not equipped with real-time and interactive feedback features that can involve students actively in the learning process.

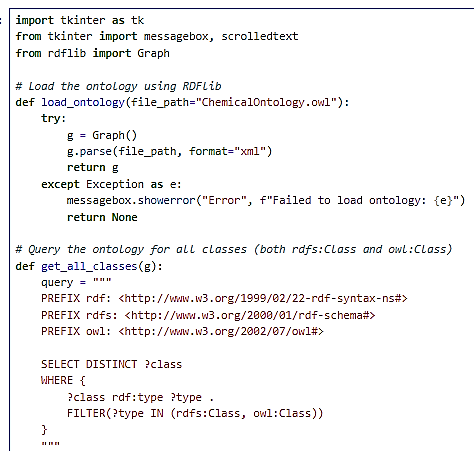
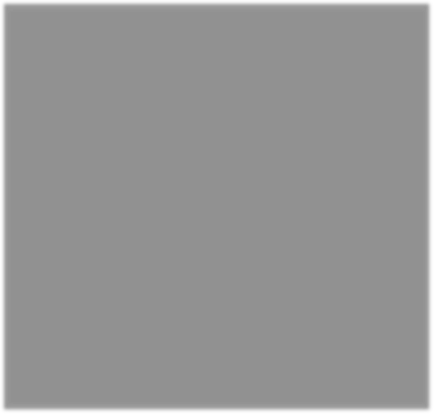
**Critique of Existing Solutions:** ITS for chemistry and especially for chemical equation balancing reveals various advantages and limitations. One of the main advantages is that they can send back feedback quickly (Kurniawan et al. 2023). Affordance of this feature enables students to identify mistake and correct them while doing exercises which enhances learning. Moreover, ITS is individual and can be directed on certain aspects which a student has problems with, and thus provide her or him target exercises pertinent to individual conditions.

However, certain drawbacks are definable in these systems. Some ITS are poorly designed; thus, they have poor user interface that makes learning more exhaustive compared to the normal practices (Beier and Rau, 2022). An overly complicated interface that is difficult to navigate can frustrate the students and eventually hinder learning. Moreover, these systems might not be very interesting to keep on catching the students’ attention continuously. In some cases,

there is no engagement component or game-based aspect to ITS which implies that students may easily get bored every time they use the system.

Although ITS can take the students’ responses and give feedback, feedback giving systems are often difficult to provide highly individualized. For example, when a student confuses about any topic, the system might not be able to give an adequate amount of explanation or different ways of approaching that topic (Gunawan et al., 2020). Flexible learning capacity could enhance the **learning efficiency** of many ITS because, at present, these systems are unable to handle the variability of approaches that students take to complete their tasks.

# Development of the Intelligent Tutoring System



### Figure 5: Python code Overview

(Source: Obtain from Jupyter Notebook)

## Domain Description

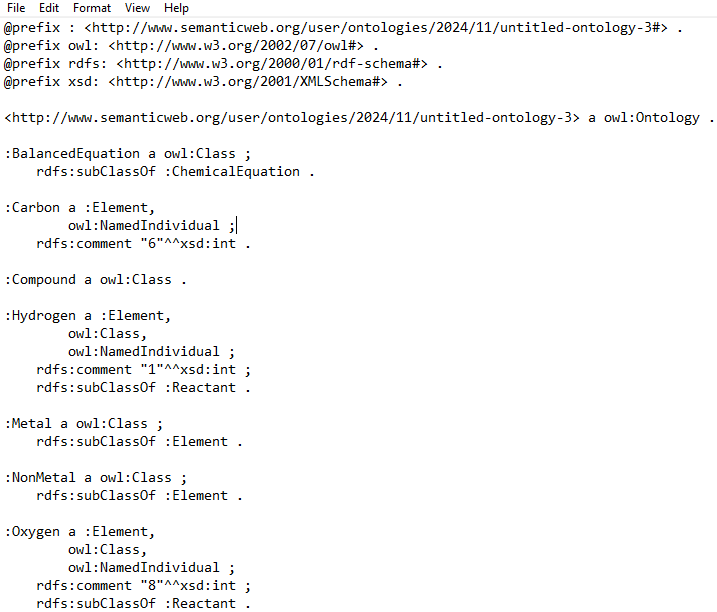
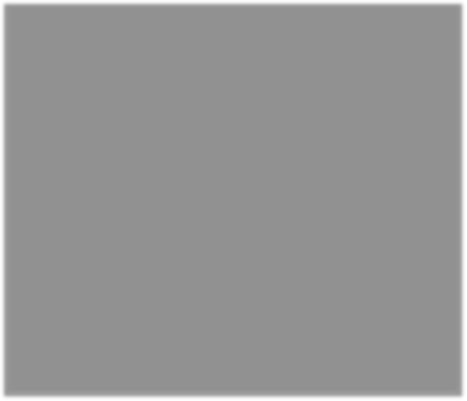
The domain of chemical equations is an important one to learn in chemistry, for the law of conservation of mass is respected by the equations. Balancing equations is one of the first concepts taught to learners in high school chemistry in order for them to understand chemical reactions (Chiu, 2021). It involves changing the coefficients in a chemical equation with the

aim of balancing the number of atoms of one element with that of the other. This idea is significant because it will build up the basis for learning other advanced chemical reactions and ratios.

Achieving an understanding of how to balance chemical equations is a core component of every chemistry program. It connects the theory with the practice whereby the students can watch how different substances combine during a chemical reaction (Matayoshi, Uzun & Cosyn, 2020). An ITS that helps teach this concept provides interactivity and adaptability to the learning process; this concept has gained popularity since it helps the students to master the knowledge. The establishment of such a system employs several technological enablers, such as ontology-based knowledge representation, which can facilitate content in a more orderly and interactive way.

## Ontology Development

The development of the ontology helped to define the necessary knowledge for explaining to students how to balance chemical equations. This prototype of the ontology was developed with the help of Protege, which is a widely used tool for developing OWL ontologies (Jun Wang et al. 2023). The main concept was intended to capture the dependencies of elements, molecules, reactants, products and coefficients in equations.



### Figure 6: TTL File Overview

(Source: Obtain from Protege) The ontology was designed to have several core components:

* + - **Classes:** The ontology splits distinct classes which display the elements and the molecules content in the chemical reactions. The main classes are Element, Molecule, Reactant, Product, Coefficient, and ChemicalEquation (Eitemüller et al. 2023). Every class represents an object related to the domain of use of the application. For instance, Element has various elements which are Carbon, Oxygen, Hydrogen while Molecule is a substance which is made of these elements.
    - **Object Properties:** These properties mark out characteristics that an individual or a class can be directly assigned. For example, the hasAtomicNumber property connects an Element to an integer value, which defines an atomic number. In the same way, the hasCoefficientValue method connects the Coefficient class to an integer that represents the coefficient in a chemical equation.
    - **Datatype Properties:** These properties mark out characteristics that an individual or a class can be directly assigned. For example, the hasAtomicNumber property connects an Element to an integer value, which defines an atomic number. HasCoefficientValue connects the Coefficient class to an integer value that represents the coefficient of the chemical equation.
    - **Individuals:** The ontology also contains individual ontologies which are the concrete members of the classes. For instance, Carbon, Hydrogen, and Oxygen are individuals of the Element class (Ramadhan, Warnars, and Razak, 2024). These individuals are important because they reflect real chemical substances in the proposed system.

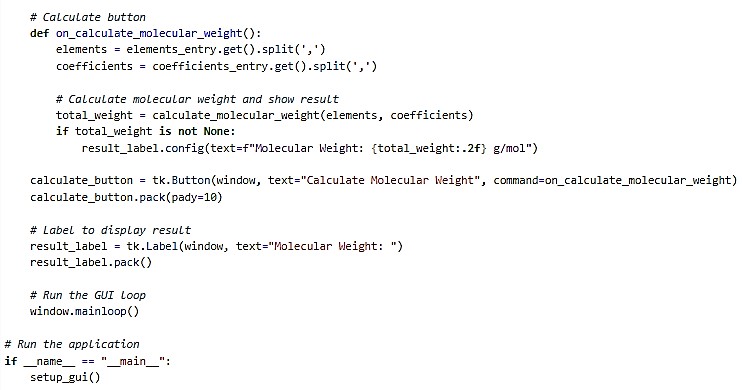
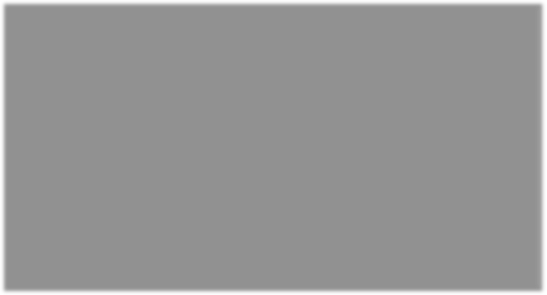
In this manner, the system can represent chemical reactions and balance equations by means of manipulating with coefficients and satisfying the law of mass conservation.

## Develop

**Data Representation:** The conversion of chemical equations is crucial in the ITS because it allows the system to model chemical reactions and also give out problems for students to solve. The data is arranged in categories using RDF (Resource Description Framework) and OWL

(Web Ontology Language) to represent the classes, relations and attributes of the specified ontology.

In the ITS, chemical equations are written by interconnecting the reactants and the products with the proportional number of coefficients. For instance, a chemical equation such as 2H2 + O2 → 2H2O can be represented by defining two instances of the class Molecule for the reactants H2 and O2 and only one for the product H2O (Bernard et al., 2020). In all these structures, a Coefficient individual is nearby each of these molecules where the stoichiometric coefficient in the chemical equation is identified. This means that we are to make sure that the number of atoms of every element is equal before and after the reaction, as it is the case with a balanced chemical equation.



### Figure 7: Calculation Section Code

(Source: Obtain from Jupyter Notebook)

RDF and OWL are especially effective in structuring this knowledge because they offer a semi- flexible and semantic approach to the relation between objects. This kind of structure (RDF triple) helps the system to depict the chemical equation as a number of relations between different objects. For instance, the triple <H2, hasCoefficient, 2> means that there are two H2 molecules of hydrogen gas are taking part in the reaction. Likewise we have the triple <O2, hasCoefficient, 1> which means one molecule of oxygen required is stated.

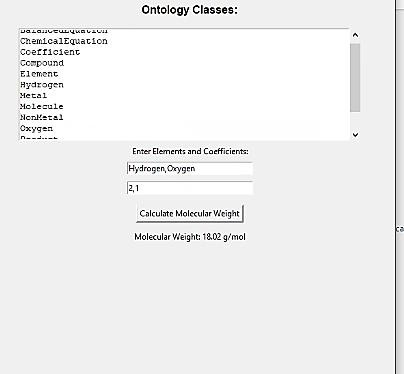
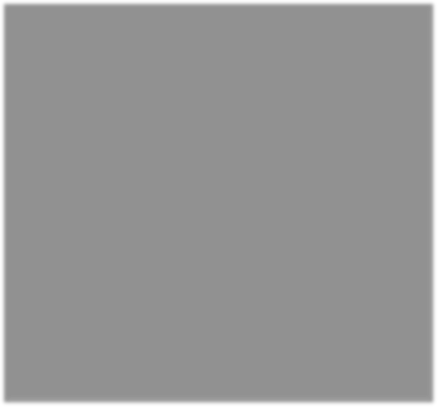
## Programming the User Interface

Python was used to code the graphical user interface, as well as to linking the ontology in the ITS with the backend logic. The OWL ontology file was parsed as stated using RDFLib, a Python library The OWL ontology file was then converted into Turtle (TTL) for easier querying since it is a format designed for this kind of use (Chrysafiadi et al. 2022). User interface of the system makes it easier and more convenient to assist students in balancing chemical equations.

Through the user interface, the students can input their coefficients and the system replies back. In case a student enters an unbalanced equation, the system carries out a validation check from the ontology in order to establish whether the entered equation is balanced or not (Iyamuremye et al. 2024). Should the equation be inaccurate then the system gives the learner suggestions as well as tips on how to correct the coefficients.

The conversion of the OWL ontology to the TTL format using RDFLib is a significant step because it allows the system to query the ontology dynamically. Python code asks the ontology for the classes and relations that describe all chemical elements and chemical compounds in the equation (Alfakihuddin, Surahman and Haryani, 2022). These classes are presented as a structured query system, enabling the user to consider them and adjust coefficients if needed.

Furthermore, the ontology follows a certain structure with logical operations being carried out through Python. For example, it verifies if the atom count of each element has been retained on both sides of the equation, which is important when balancing the equation.



### Figure 8: GUI Overview

(Source: Obtain from Jupyter Notebook)

**Prototype Development:** The process of developing the ITS prototype included the following steps, namely defining the ITS ontology and implementing the user interface. It was the basic and intuitive since its primary aim was to assist the students in achieving balance of chemical equations.

The idea of the given prototype is to proceed step by step starting with an equation that is not balanced. The students are then asked to enter coefficients for the reactants and products. Whenever the student types in a new coefficient, the program automatically balances the equation and shows the result. If the equation is wrong, the system tips the user on which coefficients to change and why the balance is not achieved.

During the development of the prototype, effort was made to address the issue of the ability of the system to produce solutions for chemical equations ranging from simple to complex. In the system, there were multiple reactants and products that had to be indicated; besides, the coefficients also differed. The feedback mechanism also had to be informative without flooding the students with information as this is counterproductive.

The implemented approach was based on a stepwise manner, which would allow students to modify coefficients ‘step by step’ and get more specific feedback after each step. It enabled the system to follow the speed at which the students studied and, deliver individual support where necessary.

**Limitations:** However, there are issues that have not yet been solved in the ITS prototype designed for balance support: One of the major drawbacks that have been identified includes High **complexity of the user interface**. Although this is implemented in a simple manner, for complex chemical equation, it may need more input mechanism which is beyond this prototype.

Another drawback is the **scope of the domain** in question. The current system is to determine the coefficients so that the total coefficients in the reactants and products will be equal to each other, though it has no other aspects like reaction mechanisms, stoichiometric coefficients or thermodynamics of reactions. Using the system for more subjects would increase its potential educational impact, though at the developmental cost.

The **adaptive capabilities** of the system may be further enhanced. Although the system does offer feedback, there are ways the level of personalization can be further increased for example hints can be given according to the students’ particular errors or choices.

# Conclusion

**Summary of the Solution:** Specifically, the Intelligent Tutoring System (ITS) designed in this project aimed at helping high school students understand balanced chemical equations. This system filled this requirement by allowing the students to have a step-by-step guide on how to balance equations, in addition to giving them a prompt feedback on their work. One of the components of the ITS is an ontology built using the Protege tool that captures the relationships between elements, molecules, coefficients, reactants, and products. This ontology further enables the system to organize knowledge in a scalable and flexible manner within the field of chemistry. The functionalities incorporated into the model of the ITS include the capability of entering chemical equations, variation coefficients and identifying the balance of the equation. If wrong, the system suggests ways to get to the solution and in the process, the student gains more knowledge of the concept in question.

**Lessons Learned:** Some important lessons were learnt while developing the ITS. Another common defining lesson was that it is always important to possess a precise and hierarchical structure of an ontology of knowledge. The nature of relationships between the chemical entities was defined through an ontology and thus the system was able to give the students logical sound feedback. The second lesson I was able to take away from this is the need for an easy to navigate interface. The basic idea of the prototype was to make it as easy to use as possible, but it became apparent in the process of creating tutorial materials that more attention should be paid to improving the usability and interactivity, especially when working with more complicated formulas. Though the prototype was useful, it was realized that a more refined interface would be more helpful towards the learning of the content.

Some of the problems encountered during the development of the program include the ability of the designed system to support different equations for the chemical reactions and ability to give feedback to the students. One of the major accomplishments is the development of the query system, which further engaged the ontological elements by querying them to get information to the student. Nevertheless, the problem of maintaining high content density while still keeping the interface as clean as possible did not disappear. The feedback system while

being fully functional may be improved to provide more targeted feedback which would in turn improve learning outcomes.

**Future Directions:** However, based on the current discussion, there are several opportunities for enhancing the ITS prototype that is otherwise conceived of as being strong. The potential for further development involves adding more details to the model regarding various features of a chemical reaction such as the reaction mechanism and stoichiometry. This would enhance the size of the system and make it convenient for the students to have a wider learning resource. Also, there is a lack of interaction or engagement UI design improvement where some features can be added like molecular pictures to represent chemical reactions or balances.

One area for improvement is to leverage next-generation artificial intelligence (AI) capabilities to make learning delivery more individualized. AI could be applied to modify the feedback according to the progress of a particular student; more detailed instructions or explanations could be provided. Moreover, with the use of AI technology student feedback should be capable of identifying patterns of misconceptions and devise ways to overcome them to enhance the learning process and make it more effective.

In summary, the current prototype described here is recommended as an effective means of teaching stoichiometry, even though a great deal of enhancement can still be made. The tool is effective in teaching students about balancing equations and is useful in this sense, yet with certain improvements, it could become a more comprehensive source of learning. The improvements could be the enhancement of topics covered by the application to encompass more chemistry areas, improvement of the interactive interface and use of more enhanced AI applications. When thus implemented, the intelligent tutoring system (ITS) may develop into a potent tool in chemistry education. Apart from just confirming that the equations on both sides are equals it would offer extended aid in enhancing understanding of basic chemical concepts as well as making learning more lively and effective.

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