OpenOChem: An LMS Agnostic Chemistry Quizzing Platform

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Abstract

OpenOChem is a freely available online homework system and interactive classroom tool under active development. Like most commercially available electronic homework systems, this program enables instructors to ask questions that students answer by drawing structures (2D/3D), reaction mechanisms and more. Unlike commercially available systems, instructors can write their own questions/feedback and access a shared library of questions from other instructors. Furthermore, OpenOChem is Open-Access so it is cost effective for students. The OpenOChem system uses Learning Tools Integration (LTI), enabling faculty members and their students access through their learning management systems (e.g., Moodle and Canvas) used on their individual campuses. We discuss the general functionality of OpenOChem and its use in organic chemistry instruction.

Introduction

Active learning and prompt feedback are two key principles for good practice in undergraduate education. (Chickering and Gamson) Active learning requires students to engage with the materials and put it in a context connected to prior knowledge. Prompt feedback allows for students to quickly assess what they understand and do not, and determine their level of competence.

Online homework systems are able to combine these two principles and several studies have indicated the benefits of online homework systems for learning organic chemistry. They can be used to encourage students to engage with the material and to put in study time in a regulated manner through weekly online homework deadlines. Students are more likely to complete homework if it’s online, and they completed the online homework more consistently (Richards-Babb, 2011). Feedback is immediate as responses can be automatically evaluated and specific prompts can be provided for both correct answers and common misconceptions. Parker and Loudon (2013) found that students studying problems in the textbook was no better preparation for exams than online homework. They had hypothesized that even though book problems were more complex it was the immediate feedback that more effectively reinforced the material. Finally, online homework correlates with student performance. Richards-Babb (2015) found a direct correlation between online homework and final course grade, suggesting that online homework is an important aspect in student learning. Malik et. al
(2014) found that students who used online homework earned approximately 15 percentile higher scores on ACS exams than those used used only paper based homework. Some students in the Malik study indicated that feedback was a primary advantage of the online homework system, further supporting Parker and Loudon's hypothesis.

History of OpenOChem

In 2012 the organic chemistry instructor/programmer (CL) became interested in developing interactive online teaching and assessment tools for organic chemistry. At that time his university was using the Moodle learning management system (LMS) and since Moodle is open source and had a well-documented API it was very amenable to developing plugins. This work culminated in the EasyOChem plugin series for the Moodle LMS which was presented at the 2014 BCCE (LeBlond 2014). Concurrently, JM was developing the Reaction Zoo, an interactive web-based application with an online database of over 1200 organic reactions. (Muzyka and Williams, 2016) Over the next few years Moodle underwent numerous revisions, so the EasyOChem Plugins required continual updates to keep pace. While Moodle LMS was the original platform for this tool, as interest increased, several organic chemistry faculty members who learned about EasyOChem were disappointed that it would not work with other learning management systems used on their campuses. EB was an early user of EasyOChem questions in Moodle, but as his institution was updating the LMS, those questions were no longer available. He was working on a system for optical recognition of hand drawn structures and other cheminformatics projects, and contacted CL to make suggestions for improvement of the interface, use of line notation in answers, and system tags for sharing information.

Chemistry drawing and input in early versions of the EasyOChem question types for Moodle were based ChemAxon’s Marvin JAVA Applet. These JAVA applets often required users to install a java runtime environment (JRE), were slow to load and cumbersome for users. However, security flaws and malware issues associated with these Java based plugins spurred the development Javascript based drawing apps (MarvinJS, JSME, ChemDoodle, Kekule). The EasyOChem Question types evolved to use MarvinJS, simplifying the user experience. OpenOChem currently uses ChemDoodle, Kekule and JSmol javascript libraries for entering molecular structures and mechanisms.

OpenOChem’s agnosticity can be attributed to the Tsugi Framework (https://www.tsugi.org/). Tsugi was developed by Dr. Charles Severance of the University of Michigan and it provides the low-level implementation of IMS Global’s Learning Tools Interoperability (LTI). The IMS LTI standard provides a framework for integrating a variety of learning tools, making them each compatible with any LMS. Instead of each individual LMS system hosting a resource, LTI allows for gaining access to externally-hosted learning tools. This approach allows the learning tool provider to focus on maintaining and developing the tool, the administrator and faculty to use tools
that best fit their courses, and students to have a seamless integration of a learning tool that would normally be hosted in another environment. Finally, since the tool is an external application, it is portable by definition and agnostic of the LMS used.

Why OpenOChem?
Commercial systems available today include OWLv2, Sapling, and MasteringChemistry which require students and faculty to use additional resources outside their campus LMS and require additional monetary cost to the student. These “do all” homework systems were designed to be very general and applicable to numerous subjects. OpenOChem is designed to be specifically for Organic Chemistry. The goal was to develop question types that are ubiquitous in the organic subdiscipline, but not necessarily found in other areas.

Problems with commercial systems are also that students and faculty are required to maintain accounts on many systems- their home institutional LMS as well as an external site. Additionally use of other vulnerable technologies such as Adobe Flash (Sapling, Mastering, OWLv2) and Java (Mastering) make these commercially available homework systems less attractive. As pointed out by Steve Jobs, Flash has issues with “reliability, security, and performance.”

Another issue is that many institutions tend to switch from one LMS to another as cost and delivery and support structures change. For example, at one of our institutions (CL) the LMS has switched from Moodle, Blackboard and D2L in the past few years. At another (EB), hosting switched from on-site, to vendor contracted. Problematically, as our institutions’ LMS offerings changed, our questions and content could be lost in the transitions. Furthermore, the ability to share questions across multiple LMS was limited to very simple questions types such as MultiChoice or using SCORM format. OpenOChem solves these issues as it is independent of a specific LMS. Thus, developed questions are hosted on one system rather than many. One of the advantages of this is that it lends itself to a system where faculty can act as a community of users to build shared questions, activities and content. This approach is a strength of OpenOChem, as our combined efforts enable us to develop a larger library rather than duplicating content in individual LMSs.

OpenOChem is designed as an Open Access system. While the tool is hosted by the developers and is currently proprietary, the content on the system is intended to be shared and adapted by any users of the system. As such, OpenOChem has adopted the Creative Commons Attribution-NonCommercial 4.0 (CC BY-NC 4.0) copyright license for questions developed in the system. Therefore, when a user creates a question, other users of the system are allowed to copy and adapt the question for use in their courses. CC BY-NC 4.0 is a non-commercial attribution, such that OpenOChem, or users of the system cannot monetize the questions generated by the users. Ideally, users will generate questions, and let others take advantage of the novel ways that each faculty member teaches their course. Some of the questions also take time to
build, and by sharing the questions, you are helping other faculty members to use their time developing additional interesting questions that will be shared with you.

Finally, OpenOChem allows faculty members to have more control and freedom, while students currently have no cost. By designing a system from the ground up, the developers and users can have increased freedom to build and design the learning tool that best suits their needs. This project allows for collaboration, and is intended to push the boundaries of what can be done within an organic chemistry grading tool without the need to meet profit goals or cut corners.

Functionality

After a faculty member completes a request on the OpenOChem website, an LTI encrypted key and secret pair is provided. A link between the faculty member’s LMS and OpenOChem is accomplished in Moodle via an “External Tool.” In Canvas, faculty users can insert either a Module or Assignment to create the link to OpenOChem.

Workflow

Once the key and secret have been installed, using OpenOChem is rather easy. OpenOChem’s design allows several possible workflows. One general workflow appropriate for developing and using content is described below.

1. **Access the link.** Clicking on the link as an instructor takes you to the OpenOChem Instructor Dashboard. Students do not see this Dashboard upon accessing the link; instead, they see the Activity you assign from your Dashboard. Alternatively, you could hide this link from your students and use it as an entry point to OpenOChem for authoring questions and activities. If a student accesses a link in which no activity was assigned, a warning message will be displayed.
Figure 1. Screenshot of OpenChem Dashboard in Moodle.
2. **Assign an Activity.** Under the Activities menu item an instructor can access “My Activities” or the “Activity Bank”. From the My Activities page, an Activity is assigned by simply clicking the assign checkbox for the activity. Activities can be easily copied from the Activity Bank, and then be assigned as well.
Figure 3. Instructor’s “My Activities” page show all your activities you’ve created.

3. **Author New Questions and Activities (Optional).** You can author new questions/activities from any link into OpenOChem as long as you have an Instructor role in your LMS. In step 3 above you could also create a new activity and assign it.

**Activities**

Questions are arranged into activities. There are currently three kinds of activities available on OpenOChem. They were designed to address different pedagogical situations where instructors want to ask questions of students.

A primary design goal of OpenOChem is to make quiz creation and editing very efficient and intuitive. With this in mind the search for questions and insertion into activities is done on the same page and makes use of drag-and-drop technology when possible. While the question searching capabilities are constant across all activity types, the method in which you assemble or arrange your questions differs depending on whether you are preparing a Quiz, Adaptive quiz, or SlideDeck.

**Quiz Functionality**

The quiz activity was designed for use in formative assessment (homework and quizzes). Quizzes are highly configurable, with options for controlling the navigation (sequential or Free navigation), the # of allowed attempts, timing and grading. Instructors can also easily control whether the students see if their responses were correct, the correct answers, and/or their grades. There is also a “Builds On Last” (BOL) mode which shows students their own previous responses upon which they can build. The BOL mode is ideal for homework. Questions are organized into activities through a drag and drop interface.
Adaptive Quiz Functionality

With an Adaptive Quiz, the student’s response or correctness determines their next question. Due to the adaptive nature of these assignments, there are fewer options for the instructor as they set up these quizzes. The instructor can control whether students see their correctness, the correct answers and/or grades. In an adaptive quiz the questions are arranged into a “Question Flow” diagram by dragging and dropping “Question Operators” onto the flowchart. The questions are then linked together to control the flow. You can easily create branching, loops and other adaptive questioning with this activity.

SlideDeck Functionality

SlideDecks are HTML based presentations with questions. SlideDecks are based on the Reveal.js presentation framework and are like PowerPoint presentations but with interactive questions! Students self-check their understanding by answering questions and getting feedback as they move through your content! SlideDecks are ideal for delivering lectures or lessons in a flipped classroom environment, with students proceeding at their own pace. There is also a “Live” mode option in which SlideDecks behave like a Student Response System (SRS), in which the instructor can pose...
questions and get responses in real-time from students. Other response systems offer a similar ability to present a series of slides with the opportunity for students to answer a variety of question types (multiple choice, free response, and drawing). OpenOChem’s SlideDecks allow instructors to pose chemistry questions that students answer by drawing structures (2D/3D) and mechanisms.

**Question Types**

A variety of question types are available on OpenOChem. This section provides an introduction to the organic chemistry specific question types. Standard question types such as multichoice, T/F, MultiAnswer, Short Answer and Formula question types are also available but will not be presented.
All question types except for MCQ, T/F, Formula and MultiAnswer allow incorrect/correct answers and specific feedback for each answer. All question types also allow both positive and negative general feedback as well. Question editors employ a tabbed interface for easy editing of the question settings, answers and feedback. All questions must be given a title, question text, at least one tag and at least one answer. The title is not seen by the student and is used for the question bank description. The Question Text is what the student sees and must answer during an attempt. You can easily insert images, embed videos and 2D/3D interactive structures into the question text as well. We have implemented two methods for inserting 2D or
3D structures into a question’s text or answer feedback. These are accessed by clicking one of the two buttons. These tools use Kekule.JS (2D or 3D) and ChemDoodle (2D only). The Kekule tool inserts a javascript object into the page that can be edited. The ChemDoodle based tool uploads an image to the server and creates a html link to it. The ChemDoodle image can not be edited, only deleted.

![Question editing interface](image)

Figure 7. Question editing interface

We have designed a very powerful tagging system for OpenOChem. The tags are utilized for searching questions from the question bank and for specifying random questions. There are tags for every functional group, mechanism type and most every organic chemistry concept. Users can easily request new tags be added to the system. A question can have many tags. For example suppose you create a question in which you expect students to draw the product of the electrophilic addition of H-Br to propene. You could assign three tags to this question; 1) Alkenes--Reactions of, 2) Alkyl Halides--Formation of and 3) Mechanisms--Electrophilic Addition. You can also assign your own user defined tags as well. Searching the database for Alkenes--Reactions of would yield this question as well as any other questions that have this tag.
Instructors can also classify their questions into different categories. Categories are for personal use only. You can only define one category per question and the categories are not visible in the “Question Bank,” only the instructors “My Questions”.

You can easily share your questions, making them available in the Question Bank for other instructors to use. Selecting the Share checkbox when editing a question will submit your question to the “Sharing Queue.” A reviewer will check that the question works, is chemically correct and has appropriate tags. After your question is approved, it will appear immediately in the Question Bank. If it is not approved you will receive comments describing what needs to be remedied. Any questions you develop are licensed by you under a Creative Commons Attribution-NonCommercial-ShareAlike license.

One of the benefits that we see from use of the OpenOChem platform is that questions are peer reviewed, and an argument could be made that your work is making a greater contribution beyond your institution. Questions used in the system can be tracked for how many students answered the question, and how many faculty used the question. We foresee faculty members seeking promotion or tenure might request analysis from OpenOChem on how many different institutions or faculty members are using their contributions to the system.
ChemDoodle - 2D Structures and Mechanisms

Currently, 2D structural and mechanism questions in OpenOChem utilize the open-source ChemDoodle Web Components. The instructor and the student use the ChemDoodle sketcher to author and answer questions respectively. There are four question subtypes that can be specified, and they are set from the “Question Specific Options” tab. Table 1 outlines the different types of questions you can ask. While ChemDoodle is our primary interface, we are also using the Kekule.js for other structural input in some question interfaces. Each method has its benefits, but we do recognize that standardization on one will decrease development time and minimizes duplication of efforts.

Table 1
2D Structure and Mechanism Question Types Examples

<table>
<thead>
<tr>
<th>Question Sub-Type</th>
<th>Example Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural – Students respond by drawing 2D structure(s).</td>
<td>Draw (R)-butan-2-ol in the sketcher below? Draw the electrophile formed by the following reagents/conditions below.</td>
</tr>
<tr>
<td>Lewis Structure – Students provide electrons or charges on a molecular template to satisfy valence rules.</td>
<td>Provide any charges need in the following electrophilic aromatic substitution intermediate?</td>
</tr>
</tbody>
</table>
Below are the Lewis structures for the two resonance structures of ethenylamine. Provide any lone pairs that are missing?

| Mechanism (Arrows On Template) – Students provide curved arrows on reaction/resonance templates. | Provide curved arrows on the following structures showing how the acylium ion can be converted between its two resonance forms. |
| Provide curved arrows on the following template for electrophilic addition of a t-butyl cation to benzene to form a cyclohexadienyl cation. |
Mechanism Full
– Students must draw complete reaction mechanism with all intermediates and electron flow arrows

Provide the complete mechanisms for the acid catalyzed dehydration of 2-propanol.

Provide curved arrows showing how you would interconvert the following resonance structures?

Animation 1. Mechanism (Arrows On Template) question type example.
Draw the mechanism for electrophilic addition of a t-butyl cation to benzene forming a cyclohexadienyl cation intermediate? Be sure to show all electron flow with curved arrows.

Figure 10. Setting the answers for a 2D structural question. The instructor draws the answer in the Answer Editor and then clicks the “Retrieve from Editor” button to register the answer.
3D Structures and Conformers

3D structural questions are based on JSmol. The instructor and the student use the JSmol model kit to author and answer questions respectively. There are two question subtypes that can be specified, 3D(SMILES) and 3D(RMSD), from the “Question Specific Options” tab. When the 3D(SMILES) option is selected, the student must draw the correct structure but does not need to be concerned with the conformation. The students structure is converted to unique SMILES string and checked against the SMILES string of the correct answer. The 3D(RMSD) subtype requires the student to draw the correct structure in a specific conformation. A SMILES string comparison is done and then a comparison of the RMSD values is performed. The RMSD is achieved using the RDKit cheminformatics programming library and does not include H atoms in the RMSD calculation. The 3D structure’s geometry can be optimized when designing the problem and when being attempted by the student. It good practice to optimize the structure when creating a conformer problem and you can provide a note to the student to do the same in the question text.
Animation 3. JSmol 3D model kit based question type.

<table>
<thead>
<tr>
<th>Question Sub-Type</th>
<th>Example Questions</th>
</tr>
</thead>
</table>
| **3D(SMILES)** - Students must draw a 3D structure, the conformation is not important. | Construct (R)-2-bromo-3-methylbutane in the editor below.  
Construct the product of the reaction of ethylene glycol with acetaldehyde |
| **3D(RMSD)** - Students must draw a 3D structure, is a specific conformation. | Construct (R)-2-bromo-3-methylbutane in its anti-periplanar geometry as is required for an E2 elimination to occur. Be sure to optimize your structure once you have drawn it. |
Construct the most stable conformation of methylcyclohexane. Be sure to optimize your structure once you have drawn it.

Localization

OpenOChem currently supports three languages (English, French and Spanish). The user’s language is automatically set based on their browser locality. In recent months there have been significant revisions to OpenOChem’s code, so some language strings have not been translated yet. We appreciate your patience.

Just-in-Time Teaching

Just-in-Time Teaching (JiTT) was co-developed by physicists Gavrin and Novak (Novak et al) and has been adopted by chemists. (Chambers and Blake) JM has used JiTT in her courses for several years (Muzyka 2015) and has recently incorporated OpenOChem quizzes as valuable tools in warm-up assignments that students complete before class.(Muzyka et al, 2018). Student responses to structural questions help identify common misconceptions about chemical reactions which can then be addressed during class. Students find the questions helpful in their learning and some have requested additional OpenOChem practice problems to assist in their preparation for tests.

Building Online Organic Chemistry Resources

CL currently uses OpenOChem extensively on his public facing Moodle server hosted at the Indiana University of Pennsylvania. (Carl LeBlond’s Chemistry Resources - http://penrose.nsm.iup.edu/moodle/). He has developed a series of online courses utilizing OpenOChem technology which cover Pre-organic chemistry, and Organic Chemistry I and II. CL’s Chemistry Resources initially were designed around the EasyOChem question types for Moodle and he is currently converting to OpenOChem. His pre-organic chemistry course is available to the public and eventually he would like to provide his Organic Chemistry I and II courses as well. His students use the resource regularly for homework and assessment (quizzes).

Prerequisite Knowledge and Post Activity Evaluation
EB has incorporated OpenOChem quizzing in collaboration with the activities he used from his guided inquiry workbook (Bucholtz 2016). Students are expected to come to class having self-assessed their preparedness for the new activity. Self-Assessment is directed by a series of “I am ready for this activity because I can …” statements. For example, prior to an activity on using enolates as nucleophiles, students are to determine if they can identify formation of kinetically or thermodynamically controlled enolates. Students are expected to bring college issued computers to class and are prompted to answer quiz questions in the first five minutes of class using OpenOChem. The following example question provides feedback for correct and incorrect answers to ensure students understand the concept before building on it in the activity of the day.

Figure 12. Collage of sample question and multiple correct answers and incorrect answer with feedback.

Students results are quickly assessed and the instructor can clarify further if needed. Students also have been able to self correct later in the class period. In the following example, a student initially got the question wrong, but after working with the material in
the class, was able to resubmit a correct the question during the class period.

![Figure 13. Student revision of attempt during a class period.](image)

Testing and Development

CL is the main developer of OpenChem. OpenOChem is constantly under development and as such constantly evolving. We don’t have a large team of software developers and testers and question/activity writers. If you have an issue, suggestions or comments concerning OpenOChem please feel free to email CL, JM and/or EB.

Getting Involved

We are always looking for contributors to join our effort. There are numerous ways in which you can help. Some examples include using OpenOChem in your instruction, creating and sharing questions, helping review questions or help us develop other language translations.

Requesting a Key

If you would like to try OpenOChem or learn more about its features please visit [www.openochem.org](http://www.openochem.org).

Usage Statistics

There are currently 1725 shared questions available in the question bank. A total of 325 activities (Quizzes) have been attempted 10490 times as of April 1st 2019.

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Muzyka, Jennifer L.; LeBlond, Carl; Bucholtz, Ehren C. OpenOChem to facilitate active learning. Presented at Biennial Conference on Chemical Education, South Bend, IN, July 30, 2018.


