Chem101

Advice FROM Chem Instructors, FOR Chem Instructors

For teachers in their 1st through 51st year

Introduction

Whether teaching a class for the first time or the 51st time, we could all benefit from the insights of our fellow chemistry instructors. Only those who currently work, or have worked, as educators truly understand the complexities facing instructors both in and out of the classroom. Educational research can shine a light on the methods and resources that positively impact students. However, integrating what are commonly regarded as best practices can be complicated in an ever-changing educational landscape. As such, we could always use practical and contextual examples from our colleagues in the field.

After all, our fellow educators handle a wide range of student skill and knowledge levels. They manage large class sizes, with varying levels of TA support. They balance research and teaching responsibilities. They feel the pain of juggling 3+ different courses, at 3+ different schools. And they have seen many curricular resources come and go, evolve, and/or stay the same. They can speak to the merits and drawbacks of every textbook, tool, and tech option.

We wanted to hear (and learn from) these experiences so we spoke to instructors with General Chemistry, Introduction to Chemistry, GOB, and Organic Chemistry courses. They hail from across the continent, work in a variety of educational settings, and were happy to share both the challenges they faced and the solutions that worked for them (and could for you, too).

Although we've kept them anonymous, the quotes in this guide come from:

- Tenure track associate professors
- Adjuncts who teach at multiple schools
- Experienced faculty from 4-year and 2-year colleges and universities of all sizes
- Cottrell Scholars (early career faculty at US and Canadian research universities and primarily undergraduate institutions)

Our goal?

To highlight strategies that not only improve student engagement and learning outcomes but also reduce costs for all, save time for instructors, and prepare everyone for any future disruptions to in-person learning.

From prepping a full course to creating a homework assignment, we hope these words of wisdom from fellow instructors will resonate and inspire. And if you have some tips of your own, please contact us so that we can include them in next year's guide.

A note on educational technology

The promise of educational technology (edtech) -- to improve learning while saving time and money -- remains unfulfilled.

For one, some curricular resources and platforms create more work for students and instructors by having a high technology learning curve. Technical glitches and poorly designed user interfaces can hinder an instructor's ability to teach and a student's ability to learn the course concepts.

Furthermore, one of the most ubiquitous edtech tools -- clickers -- has become outdated, acting as an additional cost while offering a limited array of question types through which teachers can evaluate their students' conceptual understanding. "It's yet another device to lug around which does not integrate into my other systems and platforms," says a general chemistry instructor in Arizona.

On the other hand, some technology platforms and tools both improve the learning experience and generate time-saving experiences for both instructors and students. Some “Open Educational Resource” (OER) initiatives have produced free online textbooks that can replace costly commercial options. Meanwhile, other homework and assessment platforms assess question types well beyond the standard options, supporting student drawing of Lewis and skeletal structures, construction of ICE tables, visualizing dimensional analysis, and more.

This guide provides instructor insights that reveal positives and negatives of various technology options and instructional approaches.

SECTION 1: COURSE PLANNING

Synergy: Leverage the wisdom and work of others

Embrace the philosophy that imitation is the sincerest form of flattery, with credit where appropriate of course. As Picasso[1] himself once noted,

> "A good artist borrows, a great artist steals."

While a novel approach can bolster student interest, educators need not reinvent the wheel for every aspect of their courses. Instead, we can seek out fellow educators who can offer a rich array of helpful resources, ideas, and inspiration. Tap into your community and/or networks (both on and offline) as well as open courses and/or learning initiatives. You will find a well of ideas for exam and homework questions, visualizations that explain complex concepts, analogies and stories that spark understanding, and any number of processes to manage and organize your courses. Even if you rework much of these found materials, or have a different overall philosophy than the original content creator, you will find that you can benefit tremendously from starting with a draft rather than beginning de novo.

For better or worse, teachers cannot claim copyright on 'learning experiences' as musicians do on songs. Knowing this, we have no incentive to keep our good ideas to ourselves and can, instead, take satisfaction from a less munificent, more meaningful

[1] Beuning,P.; Besson, D.; Snyder, S. Teach Better, Save Time, and Have More Fun: A Guide to Teaching and Mentoring in Science; Research Corporation for Science Advancement, 2014.

approach to our work. By sharing our ideas with fellow instructors, we are scaling our positive impact on students. By leveraging the ideas of our colleagues in our own teaching, we are saving ourselves time and energy that can be better put to other areas of our work and lives.

While local colleagues can provide great ideas and resources to you as you teach courses that they currently or previously taught, always remember that you have a wider world of colleagues at your fingertips. The Facebook group, Strategies for Teaching Chemistry, is a fantastic community of nearly 5,000 chemistry instructors happy to share their experiences, opinions, and resources for labs, lessons, lectures, and exams. If you are not already a member, join and start sharing your wisdom and leveraging the brilliance of others. The majority of members teach at the college level though there are also high school AP chemistry teachers in the mix.

Another online community that can be a source of inspiration and practical advice is the Chemical Educational Xchange (ChemEd X). Formerly known as the Journal of Chemical Education, ChemEd X mostly skews to lower level chemistry learning. As per their mission statement, “A major emphasis of ChemEd X is to better serve our precollege and two-year college audiences for whom the journal may not be a central resource. We strive to deliver content that is more accessible to this audience while at the same time adhering to the scholarly principles of peer review and assessment of contributions.”

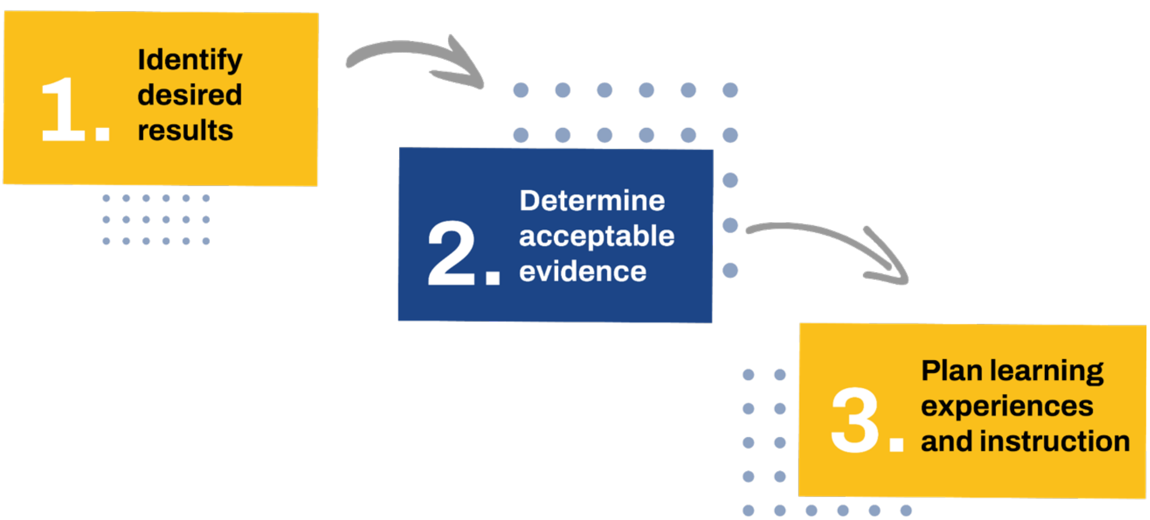
The Royal Society of Chemistry is yet another source of information with practical applications. A London-based organization serving the UK and Ireland, RSC provides free resources that can be of use to chemistry instructors anywhere. Classroom resources for Organic Chemistry, math prerequisite skills for chemistry, labs, even ‘real world’ context and scenarios for students.

BACKWARD DESIGN:

The efficient way to approach course planning

“Deliberate and focused instructional design requires us as teachers and curriculum writers to make an important shift in our thinking about the nature of our job. The shift involves thinking a great deal, first, about the specific learnings sought, and the evidence of such learnings, before thinking about what we, as the teacher, will do or provide in teaching and learning activities.”[2]

Stages of Backward Design



Grant Wiggins & Jay McTighe, Understanding By Design

Planning a course often begins with trying to wrangle the contents of a textbook or other source of knowledge into a curriculum with a rigid timeline. Instructors hoping to further bolster their students’ interest and enthusiasm may even take it a step further, pulling in real-world examples or engagement-boosting activities and labs.

However, as the course progresses, instructors may begin to struggle as they realize the standard exams they have inherited from colleagues or a publisher do not fully reflect

[2] Wiggins, Grant P., and Jay McTighe. Understanding by Design. 2nd ed., Pearson, 2005. Author(s): Grant P. Wiggins, Jay McTighe

any of the more compelling aspects of the course. Then, to match assessment with teaching, they find that their carefully laid plans have given way to a regimented slog through the content that tends to produce the usual unhappy results, contributing to the high percentage of students fleeing the STEM fields.

Those trained in curriculum construction know how to avoid this pitfall: they work backwards.

> *"Backward design is beneficial to instructors because it innately encourages intentionality during the design process. It continually encourages the instructor to establish the purpose of doing something before implementing it into the curriculum. Therefore, backward design is an effective way of providing guidance for instruction and designing lessons, units, and courses. Once the learning goals, or desired results, have been identified, instructors will have an easier time developing assessments and instruction around grounded learning outcomes.*
>
> *The incorporation of backward design also lends itself to transparent and explicit instruction. If the teacher has explicitly defined the learning goals of the course, then they have a better idea of what they want the students to get out of learning activities. Furthermore, if done thoroughly, it eliminates the possibility of doing certain activities and tasks for the sake of doing them. Every task and piece of instruction has a purpose that fits in with the overarching goals and goals of the course."*[3]

Of this approach, one General Chemistry instructor has this to say: "I decided to come up with a list of five different concepts that I wanted the students to really understand and to hopefully retain several years after completion of the course. Some of these concepts included: collision theory of reactions, the meaning of an equilibrium, the concept of pH, chemical bonding in molecules, and mass-energy equivalence. My approach now is to underline these fundamental principles as we go through the course. I develop and

[3] https://cft.vanderbilt.edu/guides-sub-pages/understanding-by-design/

reinforce these concepts through the duration of the semester and try to test conceptual understanding on exams."

Dr. Scott Reid of Marquette University agrees. "I've been restructuring our courses according to a core concepts model, because, traditionally, what chemistry has been is, 'We must cover everything!' And 'I've got so much material to cover that I'm not going to be able to get through it all.' I really think that's not a value-added approach for anybody.

Instead, I would say less is more. Let's take a step back. What are the core concepts and the core principles from chemistry that students need to master? And then how can I develop learning objectives that relate to those core concepts?

I've received some pushback from faculty who like to use standardized American Chemical Society (ACS) exams. They say, 'I've got to cover everything on the ACS exam!' And I basically say, why? Why do you have to do that? I am covering close to 100% of that stuff but I'm not beholden to the ACS exam in the way that I've structured my course. By focusing on key learning objectives, I can make sure students gain strong understanding that will prepare them for their next chemistry course."

This approach is backed by the book, Teach Better, Save Time, and Have More Fun: A Guide to Teaching and Mentoring in Science. In it, the authors state,"One highly recommended strategy is to identify your learning goals for the course and plan the entire course around those goals... Rather than planning a class chronologically, you should consider what you want your students to know or understand and to be able to do at the end of your course and then plan the course material and assignments around those goals.

In that vein, it may make sense to consider critical elements and learning outcomes/goals for specific units or topics of the course, especially the first time teaching a course, to break down that larger task into more manageable chunks. This global analysis may also help you decide what types of teaching strategies you will employ."[4]

Time-Saving Tips For Course Prep and Management

While much has been written about methods to engage students in learning foundational chemistry concepts, these strategies often presume much more time, energy, and resources than is commonly available.

This section suggests a few ways you can save yourself time while still delivering engaging and effective learning experiences.

"Activity before concept. Concept before vocabulary." [5]

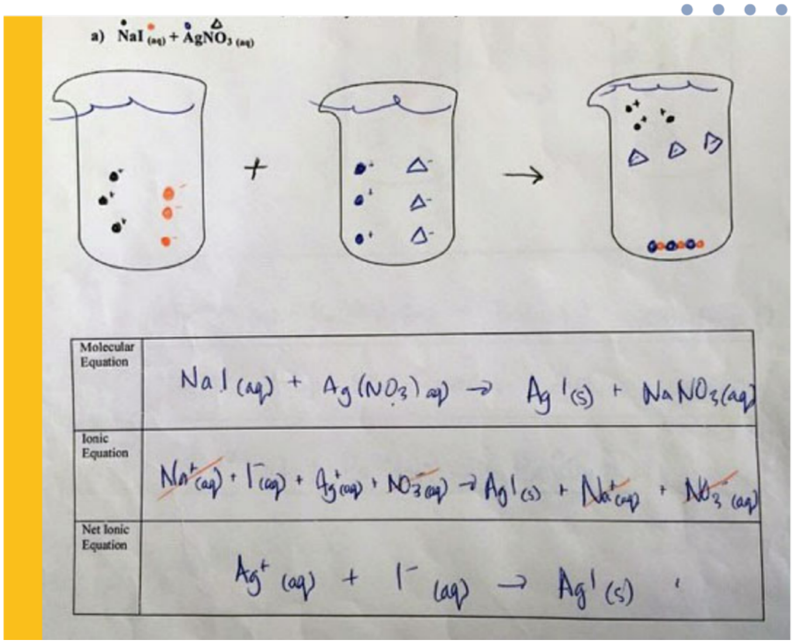
Kristen Drury shares this experience from switching her course to the flipped classroom model, "The concept invention stage is critical because it allows students to generate ownership of their learning and understanding. They are not force fed facts to memorize and retain. They are instead exposed to phenomenon, generate data and tease out evidence for their concepts before they are provided the facts. It leads to more learning retention and more engaged students all around. Then I assign the flipped videos. These videos are full of important facts and vocabulary students need to know in order to master chemistry. The videos are short, sweet, and to the point. But the videos are only assigned after the students have had exposure to the activity and the concept we are

[4] "Teach Better, Save Time, and Have More Fun: A Guide to Teaching and Mentoring in Science" Penny J. Beuning, Dave Z. Besson and Scott A. Snyder
[5] https://www.chemedx.org/blog/flipping-structure-my-flipped-classroom

studying. This gives the students more context for the vocabulary and provides more reasons for them to watch the videos - they include the answers to some of their own questions!”

Use particle diagrams, then use them some more.[6]

Kaitlin Johnson, a Connecticut-based chemistry instructor, recommends using a visual-heavy approach. “My first few years in the classroom, I tried teaching chemistry without particle diagrams. Students had a hard time understanding some of the most seemingly simple topics, like chemical reactions. When I started using color-coded particle diagrams to show how atoms rearrange in a chemical reaction, I started seeing understanding among students.



Stoichiometry? Use particle diagrams to show how one reactant can be left in excess, after another reactant has been depleted. Thermodynamics? Use particle diagrams to show that pulling apart atoms requires energy, or that particles must collide in the correct orientation to react. Solids dissolving? Use particle diagrams to show how solvent molecules surround and solvate a solute. This is a simple and powerful way to aid student understanding.”

[6] https://teachchemistry.org/periodical/issues/september-2019/tips-for-surviving-and-thriving-in-your-first-years-as-a-chemistry-teacher

Streamline feedback and student support

Another way instructors can reduce overhead and increase the value of their time spent is to not provide detailed exam feedback unless requested by the student. Reapply that extra time that would have been spent on grading to meet with individual students. An instructor at a large state school advises, “It’s not necessary to spend time commenting on all the final exams. Instead, make it clear you are available to meet with anyone who wants specific feedback, and DO make time for that. If you teach hundreds of students you will still probably only get a handful of students wanting this feedback.”

You can also save time by creating and utilizing video resources. This is especially significant if you are working towards a flipped classroom approach. Simply guide students back to relevant examples in existing resources -- many students will find that their questions are answered when they know where to look. A General Chemistry instructor found great success this way: “While we were remote, a couple students sent me screenshots of problems and asked if I'd do a video working it. Then, I could respond to other emails about very basic problem solving in the course with, ‘Have you watched video 17.3? I worked a problem very much like the one that has you stumped.’ I'm making more problem solving videos now in anticipation of questions -- it's faster in aggregate than answering dozens of ‘help I can't do #12’ emails that don't actually contain enough of a question to be answerable.”

SECTION 2: IMPROVING STUDENT OUTCOMES

Set students up for success - Clarify prerequisite knowledge and skills on Day One

Students who are not prepared for the course face higher learning curves and need more help surmounting them. This can be addressed by covering prerequisite material in a short self-test assigned as homework the first day. All students benefit from the review. Cautioned that the material on the self-test will be needed for the course, unprepared students are motivated to seek tutoring or to enroll in any missing prerequisite courses.[7]

This strategy is more effective than simply asking students if they are familiar with something or know how to do something, as they may not realize exactly the type or depth of knowledge that you expect or may be unwilling to admit they do not know.[8]

Engage students by inspiring interest in the subject

Bruner's words from 1962 ring true today, "The best way to create interest in a subject is to render it worth knowing."

One simple way to effectively garner enthusiasm and engage students is to pull relevant examples from the real world, current events, or popular culture. Put the course material in context for students, whether that context is in the world around them or other courses they have taken or may take in the future. Whatever your source of inspiration, make sure to use a variety of examples to help students from a wide range of backgrounds and learning styles.

[7] http://www.bu.edu/chemistry/files/faculty/pff/documents/JChemEdadvicefornewfaculty.pdf
[8] Teach Better, Save Time, and Have More Fun: A Guide to Teaching and Mentoring in Science" Penny J. Beuning, Dave Z. Besson and Scott A. Snyder.

Making your course material relevant to the future professions of students can also be a strong motivator. This is the most straightforward to do in tailored courses (e.g., GOB, Chemistry for Health Sciences), but can be just as effective in courses with a diverse student population who possess a wide range of preparedness levels. One way to accomplish this is by surveying the students at the beginning of class as to their planned careers.

Another is by tasking students with bringing in relevant news stories and explaining how they relate to the course. Most students leave their science courses with little to no awareness of the overlap between the different areas of science or different courses in the same field. But if you make the connections explicit, that problem can be solved![9]

Engage students with in-class, active learning experiences

At its core, “active learning” refers to cognitive science: to truly learn, our brains must “actively” create new neurons, connections, and structures. The general term often appears alongside a variety of pedagogies, and seems to mean almost anything, but in this guide, we intend its scientific meaning.

“For optimal learning to occur, the brain needs conditions under which it is able to change in response to stimuli (neuroplasticity) and able to produce new neurons (neurogenesis). The most effective learning involves recruiting multiple regions of the brain for the learning task. These regions are associated with such functions as memory, the various senses, volitional control, and higher levels of cognitive functioning.”[10] [11]

[9] “Teach Better, Save Time, and Have More Fun: A Guide to Teaching and Mentoring in Science” Penny J. Beuning, Dave Z. Besson and Scott A. Snyder, p. 10.
[10] https://gsi.berkeley.edu/gsi-guide-contents/learning-theory-research/neuroscience/
[11] https://gsi.berkeley.edu/programs-services/hsl-project/hsl-speakers/kaufer/

Even with large class sizes, it is critical to include activities, problem-solving, and discussion elements throughout class time. The more students are encouraged to participate and explore concepts critically, the more they will ultimately learn and retain.

One instructor advises the following; “How do you motivate students to learn? Many little things that don’t slap it in their faces:

- Spending a significant fraction of the time, at least one-third of the class time, in the classroom engaging students with questions, demonstrations, and concepts — not just the facts.
- Giving some complex problems that require multiple skills they have learned to be put together.”

Another instructor, Matt Leathen, believes flipping the classroom is an ideal active learning approach, stating, “Personally, I’ve been making continuous baby steps toward flipped for my entire time teaching. It’s all about maximizing that active learning time. Plus, our expertise is best applied by nudging students while they’re working through problems, which is my favorite part of teaching: watching their thought process and finding ways to help them understand the material.”

One of the best ways to have students actively work problems during class is to use an app-based edtech platform that allows you to assign quizzes and problems in real time. Students respond using a mobile app that provides instant feedback, giving you insight into where your students stand. An ideal platform will allow these problems to extend far beyond the true/false, multiple choice, or short answer limitations of traditional clickers.

Mallory Mentele of Colorado State shares her experience using this approach, saying, “Before Chem101, [my students would draw] Lewis structures on paper. But with the way they’re able to interact with the app, they found it fun! They woke up and came alive. They caught on to Lewis Structures faster because they had this fun tool, almost like a game, for building Lewis structures rather than just sitting and watching me do it."[12] She further states, "They'll be working on a problem and I can see certain incorrect answers coming up and I know that means, say, they forgot to convert to moles. So, while they're working, [I can] make an announcement: 'Did you forget to convert to moles first?' I can work with them since I can see what they're doing even though it's 250 students."

Elaine Bernal shares, "I used to lecture so much. But now I'm able to give a short lecture and do a Chem101 activity – we talk about it a little more and do another activity. It's made me think about how I deliver content and how I've moved from lecturing a lot to facilitating conversation."[13]

Lenny Vucolo adds, "We really try to increase the use of these problems to help students master concepts and to understand better how to prepare well for exams – how to piece material together. So, we really make sure to try to give activities in-class to help them better master the concepts in the course and synthesize and put the information together."[14]

Support student studying

Two fundamental strategies improve your chemistry student outcomes: problem-solving sessions (recitation, discussion sections, study groups) and homework assignments designed as learning experiences. Through these activities, students benefit from active learning outside of class.

University of the Pacific provides chemistry students with 'workshops,' supplementary weekly meetings led by students who completed the course in a previous semester. In these meetings, students work through problems selected by the instructor, with the help of a more-advanced student and their peers.

[12] https://101edu.co/success-stories/mallory-mentele-colorado-state-replacing-clickers/
[13] https://101edu.co/success-stories/elaine-bernal-sparking-interest-and-engagement-in-introductory-chemistry/
[14] https://101edu.co/success-stories/lenny-vuocolo-carnegie-mellon-customizing-rigorous-standards/

Boyd Goodson discusses how a ‘support group’ model helped improve performance for his struggling students. “One year our department offered an honors section of intro chemistry for the first time, and I volunteered to teach it. For the most part, the course was a dream — I loved the cohort of students as they were by-and-large intelligent and self-motivated. Attendance was high and I generally had great buy-in from my students in terms of doing the assigned work and studying (and performing well) on the increasingly difficult tests. However, I had a few students who were becoming increasingly exasperated with their poor performance. They were clearly trying as hard as they could, but were spinning their wheels — the material was just not sticking and they were on trajectories for Ds (or worse) in the course. It was past the drop date, and a couple of them were even trying to see if there was a way that the dean could make an exception as they were afraid for their grades. Instead of encouraging them to drop, I decided to get the students together and form a ‘support group’ just for them. We met at least once a week for a few hours, and worked on problem after problem so that I could catch their mistakes, and so that they could see where they were going wrong in each type of problem in a supportive atmosphere. The three students became increasingly confident (not just in our sessions but in asking questions in the lecture as well) and I could feel things improving. Indeed, they improved markedly in the last hourly exam and the final. You can’t imagine how happy and relieved they were to earn two Bs and an A(!) in the course, and I was very proud of how they worked to transform their understanding of the material.”

Results like Boyd’s can be achieved by implementing similar practices with TAs, students from previous semesters, and an online chemistry problem set designed to give helpful feedback when students struggle.

Across the board, instructors find the feedback and scaffolding of Chem101 to make learning chemistry more engaging and less challenging. Kysta Mass of College of St. Scholastica says, "I love that my students have immediate feedback. I give them multiple chances to get the answer correct to get an idea of how they're learning and how they're progressing through each problem."

Tips for choosing the right teaching tools for your course

- Curricular choice/s that are comprehensive reduce the need for multiple sources of info/questions
- Ensure you will be able to save all your work and notes about classes/assignments/etc. to leverage year-over-year
- In an educational technology platform for homework, activities, exams, try to author your own favorite questions into the platform before choosing that system
- Confirm any educational technology that collects student performance data can readily sync w/ your SIS/LMS
- Evaluate the student experience to confirm the only challenge for students will be mastering the concepts, not navigating a resource or platform
- Select programs that optimize student learning over assessment/drill. While assessments are essential, the bulk of the course is a learning experience and students will perform better on summative assessments only after mastering the course concepts
- When selecting an educational technology platform or tool, explore customer feedback to avoid 'buggy' 'glitchy' products and confirm tech support and customer service will be available to you in the form of actual human beings who will make time to speak with you.

Final Thoughts

Designing effective chemistry courses is easier than ever before - by pulling inspiration from fellow educators and pairing that with resources that support active learning. Use this guide to help you build your courses to both be efficient with your time and improve your students' learning outcomes.

Ready to save time and improve learning for your large class?

This was Florida State's goal for their chemistry program. Chem101 instructor, Stephanie Dillon, shared her thoughts:

"It takes almost no time to set up the homework. I used to type up homework sets, print them all out, write the keys – it was a lot of work. I sat down for the first time with Chem101 to put together the homework sets for my Gen Chem 1 class with 37 lectures and it took me about two hours total to set up all 37 lectures. That included going through the problems, deciding which problems would go into which sets, and then it was just 'point and click'."

To learn more about how Stephanie used Chem101 to help streamline her classroom experience and improve learning, read her story:

[Learn More]