Final Project for CIRTL Introduction to Evidence-based Undergraduate STEM Teaching: Lesson plan for course I might teach one day

Context
General Chemistry course for a mixture of mostly freshman natural science majors. The majority will be freshman, although some will be older, and the more students will be non-Chemistry majors than Chemistry majors. It is very likely that all or nearly all students will take a parallel lab section. There will be around 30 students in the class. The class would meet 3 times a week for about one hour, and meet in a regular class room with plenty of white board space. If there isn't much board space, I would have classroom set of medium-sized whiteboards to bring with me so there is enough for small groups of 2-3. We will have previously discussed acid-base chemistry and the preceding class would have focused on a titration with a weak acid with a single acidic proton. The students will have read the section in the course reading materials on titrations with multiple acidic protons, which is the subject of today's lesson.

Learning Objectives
Course-level objectives:
Students should able to use a titration to determine an unknown concentration.
Students should be able to connect the procedure of a titration in lab (eg. picking an indicator) with the conceptual map and necessary calculations done in class (eg. at Eq. point of weak acid titraiton, pH=pKa, a relevant fact for indicator selection).

Topic-level objectives:
Students should be able to sketch titration curve of weak polyprotic acid titration curve, including annotating the key features on the curve.
Students should be able to relate the above annotated titration curve (a conceptual picture) to the calculations necessary to make use of a titration.
Students should be able to apply the skill of a titration to a practical problem, such as you might encounter in a lab setting.

Activities
Welcome students to class, and introduce the daily historical example of a chemist: Dorothy Crowfoot Hodgkin, crystallographer who played pivotal roles in solving x-ray crystal structures of biomolecules like penicilin, vit B12 and insulin. She was awarded the Nobel prize for this work. As a part of this story, I will mention that much of her work was done in collaboration with other scientists (both men and women). I will emphasize that although in the past (and still today) the roles of lone geniuses working by themselves is romanticized and even rewarded, it is not always the only way to view the work that was done.

Assign small 2-3 person groups, show the opening warm-up questions. These two questions are for small groups, but the students may remain seated if they desire. One concerns something seen before, one begins them thinking about the new subject.
1. Sketch a titration curve with proper annotations as we worked on in the previous lesson.
2. Sketch a titration curve (with annotations as possible) of a weak acid with two donatable protons rather than one.

Brief instructor-led discussion / lecture, which will briefly go over motivations, concept map, small overview of information from the chapter reading. An example of a misconception warm-up question #2 may surface**:** *Why does the titration proceed discontinuously, with separate jumps?* One might expect some the acidic protons to dissociate gradually and randomly, rather than in stages. I might provide the metaphor of stealing someone's snacks. If they have several, it's easy to take an initial one and they may not notice. But after each is taken, they become more protective of the ones that remain.

At this point, the lesson is underway, and I will show the randomized pair/group assignments. During this period, we will alternate between working in the small groups while I move around the room, providing instruction or guidance as required, and then stopping all groups in order to ask one to present their work on one such problem.

List of questions:

1. Consider a weak acid with two acidic protons such as for example H_2CO_3. How many acid dissociation constants will it have, which acid dissociation constant will be the largest? Why? Given the triprotic titration curve we had from the warm-up, where could we annotate the dissociation constants, and does this graphically match your expectations for which protons is easiest or most difficult to dissociate?
2. Suppose you titrate the weak polyprotic acid H_2CO_3 with a strong base, how many equivalence points and midpoints would result? Finish annotating the titration curve qualitatively, and think about how much acid or base is present in solution.

Re-group, ask one group to present each problem, time for questions or comments from me or students. Select groups which try to give as many different students as possible a chance to present as possible. If we aren't ready to move on after at most 15 min, allow groups to move on. Thank students who presented, asked questions, or gave comments for their hard work or careful thoughtfulness/reflection on the problem.

3. How does pH relate to pKa at any point on the titration curve? Begin from the acid-base equilibrium equation for a single-acid/base reaction to re-derive the H-H equation we derived previously. Hint: take the negative log and look for terms like pKa and pH.
4. What are the pH's at each of the points on our now annotated curves? This is a multi-step problem; start where few protons are dissociated and proceed step-by-step.

Once about half of the groups are done (or with 10 min left in class), and all groups have worked sufficiently long, ask some groups to work through their solutions. Given time for questions and comments from instructor or students. This is a chance for me to ask someone to rephrase the explanation, or for me to do that. As some groups finish early, they may move on to the final questions, which will be taken from the homework directly.

5. (#30 in textbook) Given that K_{a1}=___ and K_{a2}=___, find the pH after titrating ___ mL of ___ Molar H_2SO_3 with ___ of ___ Molar KOH.
6. (#31 in textbook) What would be the concentration of solution of H2CO3 if an indicator X (relevant properties listed in chapter) is mixed with ___ mL of acid and then ___ mL of ___ M NaOH were titrated until the indicator turns color.

End of Class:

Announce that the homework assignment includes problems similar to what we saw, so the students have already seen how to work through some of them. Thank the students for their diligence and hard work, and say goodbye until next time.

Assessments
Informal assessment: as I walk around, I will give ample feedback and guidance. Students asked to present will give an example of a reasonably good solution, and other groups or the instructor can give more clarification of good solutions. That means groups who need feedback will have seen where their solutions fall short.
Lab and lab report: There will be at least one lab with a titration, where the students will need to use their ability to calculate pH and concentration of reagents in order to analyze the data and make a nice report. Some details of the calculations will be required on the report. A key example of an application would be to require that a titration is necessary to achieve the results of a lab, but not explicitly state that a titration is required or how to perform it. This is common in general chemistry lab courses I've taken and TA-ed.
Homework questions: There will be homework questions similar to or identical to the problems worked through in class, in addition to problems which require the students to build on what was discussed in class or the textbook. These will be graded in a traditional sense, with a chance for them to be reworked with clearly corrected mistakes and resubmitted to regain up to 50% of originally possible points.
Exam questions: There will be exam questions concerning titrations or related subjects. An exam question might for example, concern the acid/conjugate base found in the work H_2CO_3. It is commonly used in our blood's buffer system, making it feel like a highly practical problem relevant to people interested in physiology, nursing, medicine, life science, etc.

Objectives – How have you followed recommended practices in identifying your learning objectives? In particular, have you expressed your goals in terms of what students will achieve or be able to do? Are your goals well-defined and measurable? Are they at appropriate levels of Bloom's taxonomy?

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I have refined my goals by creating an initial sketch of them prior to the lesson, then refining them after I realized where I wanted to take the lesson and resulting assessments (backwards design). They are student-oriented, in that they focus on what the students should be able to do, know, etc. It was clear from discussion of the syllabus that making a syllabus or student goals which are rich in technical jargon might not be helpful for students, so I tried to make them accessibly worded.

The topic objectives do build up in bloom's taxonomy. If a student read the chapter or did a quick google search, they could easy find a sketch of a polyprotic acid. The point of both a course and topic level objective is to roughly be able to connect a set of conepts to a set of calculations, and to connect those things (done in class) to a situation you might encounter in a lab or practical situation. That can begin to be addressed or built up easily in this lesson, as it is in many of the assessments, but it can only fully be realized in some of the harder homework / end of lesson problems, and then in questions which need a titration as part of a larger series of steps, as would be necessary in a lab setting (where determining some concentration might be a single step in a larger procedure) or in a exam question where the type of acid and other information which might signal the specific calculations to be followed from memory might be obscured in some way to make it more practically relevant.

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Misconceptions – What potential student misconceptions have you identified in your lesson plan? How have you planned to surface and respond to these misconceptions?

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An example of a misconception warm-up question #2 may surface: Why does the titration proceed discontinuously, with separate jumps? One might expect some the acidic protons to dissociate gradually and randomly, rather than in stages. I can provide the metaphor of stealing someone's snacks. If they have several, it's easy to take an initial one and they may not notice. But after each is taken, they become more protective of the ones that remain.

As other students present there solutions to successively deeper questions or activities, there will be more chance for students to encounter their misconceptions and either defend them or see ways to dismantle them.

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Practice & Feedback – What opportunities for students to have meaningful practice and feedback have you planned for this lesson? What kinds of feedback would you expect students to receive and from whom?

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During the lesson, there is ample practice and feedback from the instructor and the students. It is essentially structured to that end. I will walk around and provide guidance towards better solutions. Their group mates will provide a similar kind of feedback while the groups work towards a solution. Then, I will select a group to present their solution, at which point groups can compare their solutions to the presented one as a form of student feedback. I can provide comments on the solution to make it clear if the solution has some flaws or if alternative

viewpoints are possible. Students are also encouraged to provide their own comments, questions and alternative solutions. This cycle then continues on the next set of problems. Groups which haven't finished the given problem fully might move on, but they might also pause to finish before moving on. The incentive to finish is that the problems are part of the homework, either directly or related in some fundamental way. In addition, students who want notes will need to take photos/records of the whiteboards after a solution is finished.
More traditional feedback will come from the related homework problems, the related exam problems, and laboratory reports.

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Inclusive Teaching – What aspects of your lesson plan are intended to create a learning environment that welcomes full participation by all students? Why might they do so? Have you planned activities that might leverage the diversity of perspectives and experiences among your students?

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By splitting into small groups, I have relieved some pressure for students to feel they must alone have the solutions to problems.

If a student would rather present or speak up in class than work silently, there is opportunity to do so. If they do not feel comfortable presenting yet, they may rely on their group mates. It should be relatively easy for students to gain confidence in this area, since they will know I'm not calling on them so they can be an example of 'what not to do' in front of the class, but rather because their solution is mostly correct. I may totally randomize groups at first, but as I get to know students, I may begin to place students into groups which maximally distribute or enhance their diversity of perspectives. I could also experiment with allowing groups to form naturally, while ensuring that I intervene if groups or individuals are not productively engaged consistently.

I have a plan to give a brief introduction of a historical chemist who either currently is not or was not at the time a typical 'picture of a scientist'. This will counteract somewhat the constant subtle messages that scientists are of a certain gender or ethnic background, but providing an explicit message: scientists can look like to and to some extent they always have looked like you, whoever you are.

At the end of class, I have marked that I will thank the students for their diligence and hard work. I can also provide this kind of feedback as I walk around the room or during a regroup comment in front of the whole class. This will emphasize a growth-oriented mindset where students who are presented as successful are also presented as those who are working hard on the problems or engaging in thoughtful questions, rather than as ‘having a knack for it’.

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Sequencing – Why have you sequenced the learning activities you describe in your lesson plan in the order you have planned them?

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Students will read the relevant section of a textbook prior to coming to class to prepare for the lesson, so that they are already exposed to the ideas to some degree but have not practiced or mastered the subject much or at all yet.

I put the historical scientist intro at the beginning rather than the end because it will ensure there is always time for it and because it feels more natural to continue on a subject once it is introduced rather than have a kind of abrupt addendum at the end. An exception might be when a relevant scientist does something related to the subject.

The warm-up questions come first and are the least challenging questions. The first one related to something very familiar, as it was the subject of the previous lesson and possibly a previous lab. In addition, students haven't had to move to new groups yet, so they may still be allowed to feel like the lesson is in warm-up mode.
The successive questions also build upon one another in complexity. The warm-ups ask for a titration curve they haven’t seen in class yet. The next questions build on the idea, asking for a qualitative annotation of features of that curve and relationships between the previous kind of acid-base reaction and the new one. The next questions quantitate those annotations. Finally, the last questions describe relevant situations to how a chemist would use a titration in a laboratory setting.
After the lesson, there are homework problems that naturally continue what was worked on in class. In some cases, the in-class problems were exactly on the homework It should feel emotionally to the students like they are directly spending time working through things they need to know.
Later in the parallel lab class, they will need to understand a how to use a titration, which gives a much more hands-on sense of why this practice is useful.

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Alignment – What are 2 or 3 ways your objectives, assessments, and activities are in alignment? Be specific about connections you have planned among these three components.
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The warm-up questions ask to begin to form that conceptual picture literally, then in successive questions the titration curve is annotated qualitatively then quantitatively. Finally, there is a question for the end of class or homeworks which provides an idea for how a titration is useful for identifying unknown concentrations, directly relevant to what a chemist would need to know. These are activities which will be assessed on the fly by the instructor and group mates, as a class as a single group presents a relatively good solution, and in a traditional fashion on the homework.

A course objective is to be able to see connections between the conceptual picture of an acid-base titration and the practice of using one. Many of the assessments in class deal with building up the picture of titration curve qualitatively then quantitatively. Finally, end of class or homework problems introduce the use of this kind of reaction to gain useful knowledge. An exam question might take this further, since for example, the acid/conjugate base found in the work today is commonly used in our blood’s buffer system, making it feel like a highly practical problem with relevance to people interested in life science, medicine, etc.

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Evidence-Based Practices – How has research on STEM teaching and learning, including but not limited to studies mentioned in this course, informed the teaching choices you made as you planned your lesson?
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There were a lot of references that support the idea of having interactive group work during class. Here are some:
Smith, M., Wood, W., Adams, W., Wieman, C., Knight, J., Guild, N., & Su, T. (2009). Why peer discussion
improves student performance on in-class concept questions. Science, 323, 122-124.
Chi, M. T. H. (2000). Self-explaining: The dual processes of generating inference and repairing mental
models. In R. Glaser (Ed.), Advances in instructional psychology: Educational design and cognitive
science, Vol. 5. Lawrence Erlbaum Associates Publishers.

Carol Dweck's work on growth-mindset (Mindset: The New Psychology of Success) informs my strategy of thanking students for working hard, thinking carefully, rather than being natural chemists or having a knack for calculations.

I made tentative objectives initially, then formed a lesson plan, then reflected on how well the objectives pointed towards my assessments. I modified the objectives in a backwards-teaching manner, as well as modified some of the assessments to better align with good objectives.

In this course, but especially in the Intro to Inclusive STEM teaching course, I learned about using references to scientists of diverse backgrounds to counter the subliminal messages that scientists are white men of European descent.

The practice of giving students the chance to resubmit graded work to regain credit was referenced in the assessment section. In addition, it was said that putting grading in a positive light (earning points) rather than a negative light (losing points) was better.