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# Semester-long Concept Development Projects in Chemical Engineering Electives Course

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# Semester-Long Concept Development Projects in a Chemical Engineering Electives Course


## Abstract

Elective courses in the chemical engineering curriculum can serve many purposes that include exposure to a specialized topic, survey of diverse topics, and/or enhancing the problem solving skills. This paper will describe the use of a semester-long project which serves the purpose of increasing depth of knowledge in a specialized topic, contextualization within a broader field, as well as a new skill-set. The specialized topic is an Analytical Microdevice Technology elective course, which is structured to reinforce concepts from transport, unit operations, and plant design courses – at the microscale. The topic is contextualized within the broader field by using example devices pulled by the students from the scientific literature, then outlining connections to traditional chemical engineering concepts and applicability in consumer/other markets. The course is intended to impart the students with new skills including creative optimization skills, information filtering skills, and logic skills as well as practice linking unique concepts together. Regular discussions and guidance are provided to the students via biweekly reports that are structured to build sequentially from general project concept to substantial depth in each supporting technology utilized in the final microdevice concept. Student teams complete simulations or experiments on the final concept, as appropriate.


## Introduction

Concept development projects are a concerted effort to strategically develop information gathering, filtering, organization, and synthesis skills in students[1]. These projects are also intended to foster creative thinking in the realm of soon be realized research. Students work in mixed graduate and undergraduate student teams to develop a novel concept via independent reading, discussion, and on-demand mini-lectures. Nearly all of the content in the course is student-driven and is developed dynamically based on the technologies that the student pull into their projects. This work is based on the premise that engagement of students in critical thinking and independent information gathering exercises increases student awareness of and excitement for chemical engineering and the likelihood of engaging in life-long learning in an industrial or academic setting[1].

This paper provides descriptions of project progression including detailed guidance through drafting a research manuscript, instructor feedback and guidance, final project outcomes, as well as assessments of student learning and attitudes. Project progression is covered in detail because a majority of students involved in the course had never read a research manuscript and every student involved in the course had never before written a research manuscript. Strategic mentoring of undergraduate and graduate students through this process teaches careful and sequential progression of logic, the key skill of *demonstrating* assertions/facts/observations instead of *merely stated* them, discerning and communicating to readers existing knowledge distinct from newly generated knowledge or suppositions, and self-consistency. Guiding students through construct of a numerical model demonstrates and encourages critical thinking about the fundamental physics acting within the proposed analytical microdevice technology, identification of key dependencies which is a cause/effect exercise from a physical perspective as well as an examination of governing equations, and guided demonstration of presenting the resulting complex concepts in a clear visual and verbal fashion to readers of the manuscript.

A few graduate programs have implemented formal training of students in the research process. Most notable is David F. Ollis' efforts described in his 1995 article[2] in Chemical Engineering Education on "The Research Proposition." Additional U.S. graduate programs include required courses in the curriculum on writing research proposals (University of Oklahoma[3]) and research methods (Michigan Technological University[4] and Arizona State University[5]). Structured training in research methods is also endorsed in international communities such as in Ersta Sköndal University College in Stockholm, Sweden[6] and National University of Singapore[7]. However, to the author's best knowledge, no course has tailored this for regular, full academic load undergraduate students, nor coupled it with development of original scientific knowledge. Full time research experience for undergraduates (REU) programs do regularly provide guidance on this topic. However, the structure described in this paper is unique because the graduate and undergraduate students enrolled in the course are not concurrently enrolled in research and they all carry full time course loads.

Instructor guidance within the course is frequent and equally focused on guiding written and visual communication skills as well as on the technical content of the analytical microdevice projects. Students are encouraged to draw on any research or news article, which catches their attention, and to identify the connections between articles and underlying concepts. Discussions within class are facilitated such that students dispel inhibitions related to asking questions to gain understanding, relate concepts in one article to prior discussed articles and to their own evolving research project. Discussions do follow tangents, but all reinforce the inter-relatedness of concepts, underlying physics, and microscale forces before returning to the initiating topic. This climate is carefully cultivated to re-invigorate students into questioning everything by asking *Why?* and *Is this self-consistent?* Questioning self-consistency against existing knowledge at the macroscale or against another microscale system is a valuable quality inherent with life-long learning. This process of questioning increases in frequency and depth as the semester progresses.

Due to the challenges assessing life-long learning in the short time frame of a single semester course, assessments are ongoing. The students were asked self-evaluative questions at the end of the course, again 3 months after course completion, and (yet to be conducted) 6 months after course completion about their habits and attitudes. The course completion and 3 month qualitative feedback is presented in this paper with the 6-month data included in the corresponding conference presentation. Course structure is briefly outlined in this manuscript followed by extensive detail regarding the pre-report guidance provided to students. Feedback provided back to students is discussed briefly, but was tailored to each individual project, which is difficult to describe in a manuscript such as this one. Lastly, qualitative student assessments are provided.

## Course structure & Role of concept development projects

It is widely touted that the use of research ideas can create excitement for learning in the classroom[8-12]. The primary course goals were to a) enhance student familiar with small-scale technology with a focus on biomedical diagnostic applications, and b) to develop basic information synthesis skills essential for research within a single semester. The course covered both theoretical and experimental advances in the realm of chemical, mechanical, optical and biological analysis. This was accomplished through four activities throughout the semester: a lecture, a Survivor game[13], discussions of technical articles[14-16], and a concept development project[1]. More detailed information on the general course structure can be found in this article[17]. However, this article did not describe the details of the concept development projects, which have evolved with each offering of this course. Initial implementations of the concept development project approach were loosely defined for students and student progress varied from minimal over a semester to achieving a viable concept. Refinements, as described in this manuscript, have achieved two key qualities. First, multiple student teams can be guided through this process simultaneously. The first implementation guided 2 groups simultaneously, 3 groups in the second offering, and 4 groups in this latest course offering. Second, the team progress over the course of a single semester has increased significantly. During the first implementation, reports were extremely weak and the information presented was not accessible to a reader other than the instructor. During the second offering of the course, one of the 3 reports was suitable for submission to a peer-reviewed journal and was later published as a book chapter[18]. After this third course offering, three of the 4 teams produced manuscripts viable or nearly viable for submission for peer-review, although only two of the teams have pursued this opportunity. This steady increase in quality is due to better guidance via biweekly progress reports as well as regular instructor feedback and content adaptation to each team project. This manuscript thus described the details of this guidance for other instructors to adapt and improve for their own courses.

## Progress Reports

The concept development projects were broken down into milestone progress reports due every two weeks. Teams were formed between the first and second class of the semester. Graduate students in the course were asked to define their broad interests both in class an in the discussion boards on the class website. Undergraduate students with similar broad interests could choose which topic was most interesting and join the team. Timing was such that the first item (the Agreement of Cooperation[19]) was due at the end of the first week of class so that the teams were started quickly with a clear, immediately milestone. Feedback was given on these agreements so that students had all discussed how to deal with conflict, differing work ethic, and how to best respect each other's ideas. The schedule and plan of progress reports were outlined in the syllabus on the first day of class for the students. The progress reports were:

- *Team's Agreement of Cooperation:* Outline goals and guidelines of group participation.
- *Progress Report 1:* Introductory description of proposed, novel analytical microtechnology
- *Progress Report 2:* Literature review on the scientific premises of proposed analytical microtechnology (> 15 references, fully discussed).

- *Progress Report 3:* Prototype drawing and accompanying description of analytical microtechnology (option open for students to conduct preliminary experiments)
- *Progress Report 4:* Figures, Tables & detailed captions for entire article.
- Presentation of project to date.
- *Progress Report 5:* Final device design and operation (AutoCAD or other scaled drawing), fully described. This is your section outlining or presenting data to validate your novel idea (COMSOL, experimental, compiled from literature).
- *Complete Report Due:* first draft of complete final report
- *Final Report:* Archival journal article format and tone.
- Final Project Presentations

Guidelines were given for each progress report. These guidelines were written for students who had never before surveyed the literature, developed an original research idea, nor written a research manuscript. These guidelines have gone through three revisions and are available upon request from the author. Only the complete report guidelines (i.e. first draft of the manuscript) are reproduced here due to space concerns. Once one progress report was completed and submitted via www.turnitin.com, the guidelines for the next progress report were made available. In addition, the rubrics used to assess the reports were concurrently provided to the students. Rubrics closely followed the bulleted guidelines. An example rubric for the first draft of the manuscript is also included in this paper.

*This progress report should include information from all previous reports (or equivalent if the project evolved). All figures should be professional quality and layout. The manuscript needs an abstract summarizing the entire article, an introduction that contextualizes your device within the field, a materials and methods section (device description & theory), a results and discussion section, and conclusions. Your report should describe the following for your proposed small-scale technology to address a biomedical/other application:*

- ***Title, Authors, Affiliations, Word Count, Keywords, Abbreviations.***
- ***Abstract (250 to 300 words)***
  - *Motivate the importance of the work (1 sentence)*
  - *Directly state what you have done (1-2 sentences)*
  - *Directly state the results (1-2 sentences)*
  - *Conclusions and implications of the work (1 sentence)*
  - *Remember that this is a scientific paper and you intentionally want to give away the punch line (i.e. key result and conclusions) in the abstract.*
- ***Introduction (not more than 1/3 of the manuscript or ~6-9 paragraphs):***
  - *The introduction should give a clear purpose, motivation and suggest implications of this work. It should review the closely related technologies in the field giving historical context, current status, and importance for innovations in the field.*
  - *Edit and improve upon previous version of the opening intro paragraph by incorporating feedback and making it more succinct and informative*
    - *Directly state the purpose and scope of your current effort. Use scientific terminology in the field, directly state what is novel and why it is better than previous technology.*
    - *Give stats and numerics of how many people/other your device will impact- use in text citations.*

- *One of the most challenging aspects of this section is to strategically improve and cull the information from your prior literature review report.*
  - *First, include only the directly or highly relevant articles.* *While you may have read multiple papers to arrive at your current device design, it is important to guide your reader through those that are most relevant to your final device.*
  - *Second, strategically organize information and tell your reader directly how it is organized and why.* *You may have combined three technologies into your final device. Tell your reader, "The device simulated in this paper improves upon technology one, technology two, and technology three. Paragraph A: Technology one originated with ZZZs work on YYY. It was improved to include WWW and now is capable of [give specific quantified results]. Paragraph B: Technology two…., etc."*
- *Writers who attempt to overpower the reader by including everything – similar to just dumping loosely related information – demonstrate to the reader that they have a poor mastery of the field and the manuscript topic. Hence, you want to demonstrate your mastery of the relevant field by mentioning the most relevant quantitative or qualitative information from the key articles and contextualizing this with respect to other related articles.*
  - *This requires sometimes 2 to 6 in text citations per sentence.*
  - *Almost every sentence in this section, since it originates from published work, should be cited.*
    - *Entire paragraphs with only 1 citation are an indication the reader should just read the original article.* *Your group should be synthesizing information from multiple sources together to yield a new perspective.*

- ***Materials & Methods:***
  - *This section should tell your readers what the device includes and HOW it was simulated. The results should not be included here.*
  - *First, guide your reader through each functional unit of your device starting from the inlet and progressing through the outlet. Figure 1 (see below) should be referenced and embedded here in the manuscript.*
    - *Describe what each unit is intended to do and clearly point out the supporting technology in the literature that inspired that unit. Justify the technology you chose for your device by comparing to other leading technologies*
      - *Example, "The device described herein builds upon existing technology to enable…" - higher throughputs, greater sensitivity, more versatility, - a new approach, etc. "…to existing technology that is…." –give brief list here [use in text citations].*
    - *As you guide the reader through these functional units of your device, tie back to the intro by reinforcing the premise/foundational technologies for your project. Emphasize how and in what way your implementations are novel from existing technology schemes.*

- *Second, describe the theory and physics considered when simulating each functional unit of your device. This should be included just after the description of each unit.*
  - *State the physics (i.e. creeping flow) and give the equation. Define terms and explain why relevant to the functionality of your device.*
  - *Describe the boundary conditions – equations are preferable. Justify and explain the assumptions.*
  - *Describe the parameters varied. For example, flow rates from 1 to 10 um/s were simulated.*
- *Include a table/other to succinctly and clearly organize your simulation conditions & dependencies that you explored.*
  - *Clearly identify fixed parameters and variables.*
- *It is difficult for many first time scientific authors, <u>but results should not be included here.</u> This is simply a guide to what was done and what was considered.*
- *The most common error here is to be too brief. Remember that you must succinctly provide enough information that another researcher could duplicate your results.*

- ***Figures:***
  - *Figure 1 should be a macroscale schematic/image of your device with appropriate insets demonstrating the microscale functionality. Include in the Materials and Methods section.*
  - *The following figures may be adapted slightly differently based on your design. However, do note the emphasis on your designs and results for each. These should be referenced and embedded in the Results and Discussion section.*
    - *Figure 2 should be COMSOL results of technology one. Include qualitative and quantitative comparisons using insets or subplots.*
    - *Figure 3 should be COMSOL results of technology two. Include qualitative and quantitative comparisons using insets or subplots.*
    - *Figure 4 should be COMSOL results of technology three. Include qualitative and quantitative comparisons using insets or subplots.*
  - *Figure 5 should include quantitative comparisons of your simulated results with published results.*
  - *Figures and Device drawing(s) should be of similar quality/layout and professionalism as device drawings in archival published journal articles*
    - *Combine multiple scales together into one figure with insets or subsections. Show the macroscale (i.e. what a user sees with the naked eye) as well as the key microscale components.*
    - *Include a side/top view or 3D drawing that is to aspect scale for important concentration/trapping/etc. regions in your device.*
    - *If more than one view is needed, multiple drawings are encouraged within a single figure. If multiple scales need to be examined, show magnified views.*
  - *Figures must be accompanied with a descriptive figure caption. Again, follow examples in the archival journal literature. Label sub drawings as a, b, and c, and describe clearly in the figure caption. Figure captions should almost stand-alone from the text.*

- *Figures should tell the visual story of your project and your final manuscript will rely heavily on this visual support of your novel concept.*
  - *Organize these carefully – make sure the figures progress through the device operation the same way the text progresses through this. Be self-consistent throughout the report.*
  - *Using color or cartooned shapes to indicate different species behavior in your device is an excellent way to illustrate expected functionality for your device.*
- *Label sub-regions of your device that are simulated in COMSOL*
  - *Use arrows to indicate flow direction.*
  - *Use color or other labels to indicate boundary conditions and visually convey the physics including fluid and object (droplet, analyte, etc.) behaviors.*
  - *Augment with supporting text in the body of the report.*
  - *Show results as a comparison between qualitative results (an image fro the device) and quantitative data (measured amount of a response/behavior).*

- ***Results & Discussion:***
  - *As you present the results from each of your simulations (functional unit one, functional unit two, etc.), start from the beginning and tell your readers the following in the following order:*
    - *State what was simulated and what was assumed. This is usually 1 sentence. Refer the reader back to the materials and methods section for how it was done.*
    - *State what each simulation shows. Example, "Figure 2a shows the electric field gradient spatially in functional unit one. This field induced a dielectrophoretic force in ZZZ cells such they were separated into channel A for live cells and channel B for dead cells as illustrated via streamlines in Figure 2b."*
    - *Discuss the physical meaning of results and justify why the results are important and make sense. Example, "Simulations predicted a positive DEP velocity at 1 MHz, consistent with Leonard 2011's results."*
    - *Next, describe the parameter sweep performed. Explain that since the results are verified at one point (see example in the bullet above), that extension of those results via a parametric sweep is insightful. State what the results of that sweep are and discuss physically why they make sense.*
    - *Show results first as qualitative results (an image from the device simulation with the pretty gradient coloration) and second as quantitative data (measured amount of a response/behavior when a dependent variable is varied).*
    - *Remember, throughout this section to reinforce and compare to results already reported in the literature.*

**Progress Report #6, Draft of Complete Manuscript**
**ChE 4770/5770 Fall 2012**

| | | | | | | |
|---|---|---|---|---|---|---|
| Team being Evaluated: | | | | | | |
| Topic Title: | | | | | | |
| Title: Authors, Affiliations, Word Count, Keywords, Abbreviations | E | VG | G | F | P | |
| Abstract: Importance, what done | E | VG | G | F | P | |
| Abstract: Results, conclusions, implications | E | VG | G | F | P | |
| Introduction: purpose/motivation (quantitative stats); implications | E | VG | G | F | P | |
| Introduction: Organization through key topics | E | VG | G | F | P | |
| Introduction: Relevant articles with history & contextualization | E | VG | G | F | P | |
| Introduction: Succinctly synthesize info from multiple sources | E | VG | G | F | P | |
| M&M: Organization of functional units of device | E | VG | G | F | P | |
| M&M: Supporting technology for each functional unit & novelty | E | VG | G | F | P | |
| M&M: Physics simulated for each functional unit | E | VG | G | F | P | |
| M&M: Equations and boundary conditions | E | VG | G | F | P | |
| M&M: Table with parameters & variables | E | VG | G | F | P | |
| Figures: Organization & Overall quality | E | VG | G | F | P | |
| Figure 1: Schematic of device, macro & micro | E | VG | G | F | P | |
| Figure 2: Results & caption, labeling | E | VG | G | F | P | |
| Figure 3: Results & caption, labeling | E | VG | G | F | P | |
| Figure 4: Results & caption, labeling | E | VG | G | F | P | |

**Progress Report #6, Draft of Complete Manuscript**
**ChE 4770/5770 Fall 2012**

| | | | | | | |
|---|---|---|---|---|---|---|
| Figure 5: Quantitative comparison- simulation results & lit. expmnts | E | VG | G | F | P | |
| Results & Disc: Organization & clarity | E | VG | G | F | P | |
| Results & Disc: For each functional unit, what simulated & assumed | E | VG | G | F | P | |
| Results & Disc: What simulation shows, physical meaning of result | E | VG | G | F | P | |
| Results & Disc: Parameter sweep | E | VG | G | F | P | |
| Results & Disc: Utilize both qualitative & quantitative | E | VG | G | F | P | |
| Results & Disc: Compare with literature | E | VG | G | F | P | |
| Conclusions: big picture, novelty, implications, tie back to intro | E | VG | G | F | P | |
| Conclusions: Summarize functional units in same order | E | VG | G | F | P | |
| Conclusions: Key findings from simulations, compare w/ literature | E | VG | G | F | P | |
| Conclusions: self consistent with intro and abstract | E | VG | G | F | P | |
| Peer Review: Completed for other group on time, valuable comments | E | VG | G | F | P | |
| Peer Review: Shared with Dr. M, addressed feedback | E | VG | G | F | P | |
| Originality: Creative, novel, uniquely written | E | VG | G | F | P | |
| Binder: Well organized, complete, and on time | E | VG | G | F | P | |
| **Overall** | **E** | **VG** | **G** | **F** | **P** | |

Figure 1: Rubric for Progress Report #6: First draft of a complete manuscript.

- *Note any regions where your group foresees device reliability issues. These should be embedded with the functional unit description*
  - *Give implications of each scenario and how device operation will be impacted. Any engineering you did should be included. For example, "An open circuit reading will indicated sample did not reach the test region. This was built in to verify the sample reaches a given location of the device."*

- ***Conclusions:***
  - *Wrap up the entire report by reminding the reader of the big picture functionality of the device (1 to 2 sentences).*
    - *Emphasize the implications of the conceived microdevice.*
  - *Revisit and emphasize the novelty of components/approach in the same order as in the report, but this time emphasize the inter-related nature of device function.*
    - *Support this with the key findings from your results. Example, "Simulations demonstrated a positive correlation between mixing efficiency and precipitation events. This work demonstrated that three orders of magnitude increase in sensitivity could be achieved beyond Smith, et.al. via optimized device designs described herein."*
  - *This should tie back to your intro, reinforcing the larger implications of this work and what insights it has added to the field that you described in the introduction.*
  - *Make sure this is self-consistent with the abstract as well!*

**Peer-review of Manuscripts**

An additional educational experience was student peer-review of the manuscripts from another group in the class. This exercise benefitted both the readers/reviewers and the manuscript authors. Students learned how to better organize information and figures to make the concepts and results more accessible for future readers. Students were given a rubric for the assessment (similar to Figure 1) and required to identify positive attributes and negative attributes of the project and of the manuscript. These assessments were concurrently reviewed by the instructor to ensure the guidance was content-intensive and professional. Informal feedback from class discussions following this exercise indicated that reading another group's manuscript had the biggest impact. Students struggled with providing constructive feedback, which is likely due in part to their burgeoning yet limited knowledge in the field of analytical microdevice technologies, and the unfamiliarity with this type of task. Beginning researchers and a majority of students have not been in a position to critique and edit other work. Upon completion of this peer-review exercise, student teams again revised their manuscript and then turned in the final version of their experiment/simulation results and manuscript to the instructor.

**Final product**

The ultimate goal for the instructor when editing and guiding students near the end of the project either in experiments or in COMSOL simulations was to assess if individual students groups had generated any new, publishable information. If the project had a sound scientific foundation, the students improved substantially based on the bi-weekly feedback, and the simulations or experiments generated new knowledge in the field, the students were encouraged to submit the manuscript for publication. There is not sufficient time within a single semester to completely achieve this goal, so it was made very clear that this extra step was completely voluntary and was not a requirement for the course grade. Three of the four teams wanted to pursue this in fall 2012, but only two teams had generated publication quality results upon course completion. These two groups also put in extra time after the end of the course to revise the manuscript for submission to a journal. External reviews have not yet been received and this aspect is ongoing.

**Assessment**

Student evaluations at the end of the course were utilized to assess the merits of this unique approach to guide students through the development of an original research concept, the testing of that concept either experimentally or via simulations, and the articulation of the concept into a viable research manuscript. The following quantitative assessments were obtained regarding the course and the instructor:

| | |
|---|---|
| Class sessions were thought provoking. | 4.40 ± 0.66 |
| The organization of the course helped me to learn | 3.80 ± 0.60 |
| Instructor encouraged students to seek additional help outside of class. | 4.50 ± 0.81 |
| Instructor explained importance of what we were learning | 4.20 ± 0.60 |
| Instructor welcomes student questions in class | 5.00 ± 0 |
| Instructor made connections between new material and material previously covered in class | 4.20 ± 0.60 |
| Instructor was enthusiastic about teaching the subject matter of the course | 4.90 ± 0.30 |
| Instructor used class time effectively | 3.90 ± 0.54 |
| Instructor provided timely feedback on my work | 4.40 ± 0.66 |
| I am more interested in the subject now than I was before I took this course | 4.50 ± 0.67 |
| Given the opportunity I would take another course from this instructor | 4.60 ± 0.66 |
| Taking everything into account, I consider this instructor to be an excellent teacher | 4.70 ± 0.64 |

Next, students were asked the open ended question, “As I, the instructor, prepare to teach this class again what aspect(s) of this course (teaching methods, assignments, areas of emphasis, etc.) should I preserve that effectively furthered your learning?” The responses included:

- Survivor & Journal presentations are good.
- I think the switching from lecture to survivor to articles kept things fresh and interesting. It encouraged learning from a multitude of angles.
- Survivor was a good way to apply class material.
- Need to spend more time on lectures early in the class and do more articles/survivor towards the middle/end of the course. Too much material to learn before starting project.
- Friday presentations [article discussions] were very interesting.
- The semester long project really encouraged the students to learn independently about subjects that were interesting to us.
- I liked that it mixes grads with undergrads. The progress reports helped summarize our progress, but I would’ve liked more detail, specifically about the literature review one.
- I like how each day of the week we do something different. It isn’t just sitting through a lecture every day.

- Presentation of new/novel device and article.
- It was helpful that the material covered helped with our projects – if we had a question, it usually got covered in class. Discussion days are nice to get ideas.

Student responses to the second open-ended question, "What aspect(s) of this course should I change to improve student learning? Specifically, what would you suggest?" included:

- COMSOL is a pain to work with; I'd like more class time to learn it.
- The day that is the driest is lecture days. Any way to make these more interesting would help. It's hard to say though. The use of videos and props is a good way, and has worked throughout this class. Maybe a few more of these.
- Survivor is fun and helpful, but slightly scatterbrained. Anything that requires the class to Google something should not be fair material.
- The Survivor game is interesting, but maybe decrease it to half a class per week.
- Having a day to get together a team via canvas was rough. I think you should have a better system for getting together students with similar interests.
- Since there is no textbook for this course, it would be helpful if more literature materials were posted that were pertinent to your lectures, especially early on in the class.
- Maybe have more individual opportunities to earn grades. Sometimes I felt like I didn't get a great chance to distinguish myself from my group members.
- Get instructions/rubrics up online ASAP. Post notes/resources before class so we can be better prepared.

Lastly, the final comments at the end of the course on feedback sheets and evaluations included:

- I think this project was an amazing learning experience. It challenged us, has us cooperating in groups, and helped improve many skills that we need – writing, making figures, literature reviews, and cooperation with others. It would have been more helpful to have information posted sooner.
- I like how the lectures were formal yet informal. YouTube videos, and stuff like that is a great teaching medium, and the articles and Survivor were fun too.
- Good! Beginning of the semesters was very interesting, helped know what to research. Then more technical stuff was helpful when we were doing project research. Survivor was good and the articles were super interesting.
- Good in overall. Personally, I would like to see the lecture parts take more percentage.
- I took one very similar class when I was an undergraduate (groups with mixed graduate and undergraduate students). One activity I preferred was when the professor brought in the latest technology (or paper) and discussed it in one class. Therefore, I think it would be better to discuss only one paper on Friday instead of 4 or 5. The student on duty should prepare detailed information and take it more serious. Or you can do it.
- I enjoyed the lectures. I did learn thinks and concepts better than I though I would.
- Overall, it was a great class that I'm glad I took.

Due to the challenges assessing life-long learning in the short time frame of a single semester course, assessments are ongoing. Students were asked self-evaluative questions 3 months after course completion, and will be asked these same questions 6 months (yet to be conducted) after course completion about their habits and attitudes. The response rate on the 3-month survey was almost 90% and no incentives were offered for responding to the survey. The course completion and 3 month qualitative feedback is presented in this paper while the 6-month data will be included in the corresponding conference presentation.

What advantages did you experience with the semester-long concept development project? (3 months)

- Graduate Student: This project is a good starting point to people who's new to this area. Team project mode is a good way to improve communication skills as well as teamwork ability. And I've learned how to do comsol simulation, which is essential important to the people who has no simulation background like me.
- Graduate Student: This semester long project has helped me become better prepared for graduate school. Taking this class as a grad student made me think about how useful it would have been to take as an undergrad, but my undergraduate university did not have a course set up like this. *The three main advantages that have continued to help me are learning how to search for information to compile into a literature review, learning the basics of COMSOL and where to find resources to help complete more complicated simulations, and learning to write a manuscript.* I was taking the graduate course titled 'theory and methods of research' at the same time as this class. I found that our AMT project was much more helpful than my other class. The theory and methods of research course required multiple presentations, but it did not require doing any research or writing. The AMT course provided me with the knowledge of researching literature and writing a manuscript that will help me throughout getting my degree. The AMT project also had groups working together which taught us how to best collaborate as a team in the future. Writing an agreement of cooperation, delegating tasks, and tracking each member's and the group's (as a whole) weekly progress were all very good tools to learn.
- Graduate Student: I took advantage of that course to get to know the field of microfluidics and lab-on-chip that I am interested in. I had read hundreds of papers during the course that opened my eyes to the latest development and research interests in the field. By reading different kinds of published papers, I understood what it took to accomplish what you want: laboratory skill, fundamentals, and so on. In a word, I think it is a very good course for those who just enter the field that they are interested in but not familiar with. ***Through repeated revision of the report, I definitely improved my scientific writing.***
- Undergrad: Cool subject for a class, felt like I was learning something important and valuable.
- Undergrad: After learning the basics in lecture, it was really easy to want to learn more. Researching was more fun than it was a chore because of how interesting microdevices are. Also, companies I've spoken with about the project are always interested and impressed with the concept and amount of independence.
- Undergrad: flexible deadlines were helpful to have assignments completed correctly, feedback from other groups was helpful, having it the whole semester left flexibility with our deadlines within the team, and reduced the stress that we

might have if it was just a few short weeks, gave us more time to develop our topic and improve upon our idea as well as learn new ideas throughout the semester

- Undergrad: The advantages of a semester long project include the opportunity to really learn about a subject and have time to familiarize yourself with the material and your group members so you can really put out the best final product as possible.
- Undergrad: Overall, I really enjoyed the class. It was a more involved way of covering the material than simply a lecture. By breaking up the classes between actual lessons, consistent reuse through the games, and bringing in our own topics, the class felt more personal
- Undergrad: It was a very good way to learn the concepts we were talking about in class in a more real-world setting. Obviously we weren't actually putting the concepts into practice but designing a device using the things we were learning about in class helped me really learn what they were all about.
- Undergrad: Working in a team to solve a problem was very advantageous. It allowed for each person to have an specific role for task completion and made it much easier to identify the strengths and weaknesses in the project. It also helped me to understand my strengths and weaknesses as an individual when it comes to working in a team.

What disadvantages did you experience with the semester-long concept development project? (3 months)

- Graduate student: It's kind of hard to find a good meeting time, especially for the busy undergraduates. Also it's very hard to guarantee all the team members can fully understand every single detail of the whole project.
- Graduate student: At times this project became stressful.
- Graduate student: What was covered in three lectures a week could be better for the graduate students if higher level contents were covered.
- Undergrad: Student led groups often felt a lack of focus and objectives.
- Undergrad: The workload was much heavier in the last few weeks of the semester. Don't give the same amount of time between progress reports; I thought we only needed a few days for some and a couple weeks for others. Be more critical early in the semester.
- Undergrad: Some communication barrier with team members, difficult to connect goals/material from the beginning of semester with our final project. Would have been helpful to have more concept lectures at the beginning of the semester but short on time
- Undergrad: I can't say anything that very disadvantageous as far as the course design is concerned.
- Undergrad: I really did like the concept. It's hard to think of negatives. I guess one negative is if something happens between you and a group member, you're stuck with them. Also, if a group member drops the class, it can be detrimental.
- Undergrad: Due to  the timing of the course (I took it at the same time as UO, Senior Design, and I had basketball) I found it very difficult to get all the reading

of the scholarly articles done. They always seem to be a big time commitment for me since the material takes me so long to understand and digest.

- Undergrad: My team member and I were at a disadvantage in that we did not have the guidance of a graduate student's mastery of subject-specific analysis {Note: graduate student on this team dropped the course}. We did not exactly struggle to make the connections between topics, we were however on a time constraint in terms of splitting the work between two individuals instead of three.

Have you read about any analytical microdevice technology since the course completion? If so, how often? (3 months)

| | |
|---|---|
| Grad: | 1-2/wk |
| | 5/wk |
| | 10/wk |
| Undergrad | 0 |
| | 1-2/mo |
| | 2/wk |
| | 0 |
| | 2/wk |
| | 1/mo |

- Grad: I read literature related to my research very frequently (daily), but I also look at specific journals, like lab on a chip and electrophoresis, to see what new material has been published. I do this every other week or so, or when I have some free time.
- Grad: Yes, I do. This course helped me develop a habit of following the latest research development and trend in the field. The main journal I am reading is Lap Chip. Because Lab Chip has new updates about every two weeks, I would say I read 20 articles every two weeks.
- Undergrad: Not much, more to do with being busy with senior design and lab work than the actual subject.
- Undergrad: I've read about analytical microdevice technology about once or twice a month. When preparing for my interview with 3M, I read a lot about the microdevice technology they use.
- Undergrad: Honestly, I have been very busy this semester, and have had limited time to read more about microdevices. Maybe around 3-5 times this semester.
- Undergrad: I am a subscribed member to COMSOL Multiphysics newsletter. When I find a topic in microdevice technologies that I feel is interesting I will take a look at it and sometimes read them. The work I have done in COMSOL has been continued and implemented in my Interdisciplinary Senior Design project. I prefer the smaller scale technologies to the larger scale technologies.

Did the course & concept development projects instill in you a desire to learn about new/different topics regularly throughout your future life? (3 months)

- As a graduate student, I think it's always good to bolster my background in different topics. Thanks for the opportunity the course/project gave.
- Graduate Student: This course did instill a desire to learn about new/different topics regularly. Seeing the range of articles that other students brought to class opened my eyes to how much is really out there. I spend most of my time looking for articles specific to my research, but doing general searches can bring new ideas that I would not have thought of otherwise.
- Graduate Student: I think I have this desire with or without the class, but the course definitely strengthened it.
- Undergrad: It let me get to look at things differently in the chemical engineering field.

- Undergrad: Yes, gave me ideas to future career possibilities, and areas that I am more interested in when looking for jobs
- Undergrad: While I enjoy reading additional material relating to the course, I haven't usually looked for it since then. However, when I do read of anything relating to micro devices now, I have a much better understanding of what I'm reading and a much greater interest.
- Undergrad: I have always had the desire to learn as much as I can about things that I do not know. It has, however, instilled within me the desire to understand fundamental transport phenomena. In undergraduate work this has been my weakest subject.
- Undergrad: This was actually one of my favorite classes I've had since I've been up at Michigan Tech. I feel like the semester long project helped me to learn about something that actually has a specific application in this world, and that is a nice change of pace from all the other classes where it's all general things, and real world applications are not discussed as much. I feel like learning about specific things like that in the future is something that definitely interests me.
- Undergrad: ***Taking the course definitely convinced me that learning about different topics regularly in the future would be fun. The course was set up so that by the end, I felt like I could independently research anything else I found interesting.***
- Undergrad: ***I don't know if it helped instill a curiosity to learn because I feel like that has always been there for me. If anything it helped me discover new ways of doing this learning.*** I wasn't very skilled in researching journal articles or scholarly articles in general and I didn't really understand the value of reading them. I always thought that they were more for people trying to invent new things or using them as references but I think they can be more than that. They illustrate the new technology that is coming about and even if I'm not using these articles to invent some new device they can still be useful/interesting to read.

These student self-assessments are suggestive that this unique course structure and guidance through a concept development project in one semester has educational merits. Students cited the benefits of receiving guidance on how to locate, read, and critique literature as well as how to write a scientific manuscript. Students cite the stress, timing and allocation of effort throughout the semester as negatives, which can be partially addressed by varying timing between reports and altering progress report content to more evenly balance the workload. The difficulty of assessing life-long learning in the short time frame of a single semester course remains, but 3-month assessments suggest that one third to one half of the undergrads enrolled in the course do currently read information about microdevices. This topic is not mainstream chemical engineering and thus, the reading is voluntary and a positive indicator of life-long learning habits. Further, the response rate of 90% (100% graduate students) suggests that students remain connected to their teams and/or the course experience and were motivated to respond. Additional data will be collected 6 months after course completion and included in the presentation.

## Conclusions

Concept development projects are a student driven creative exercise that concurrently teaches students how to locate, synthesize, organize information and generate additional knowledge via creative thinking and experiment/simulation validation. Via the process of writing a coherent manuscript, students learned the key skill of *demonstrating* assertions/facts/observations instead of *merely stated* them, discerning and communicating to readers existing knowledge distinct from newly generated knowledge or suppositions, and self-consistency. Nearly all of the content in the course was student-driven and was developed dynamically based on topics and technologies the students utilized in their projects. This paper described implementation with Chemical Engineering graduate and undergraduate student teams. Course structure is briefly outlined in this manuscript followed by extensive detail regarding the pre-report guidance provided to students.

This paper is also a resource for faculty who would like to strategically guide students through the process of writing their first research manuscript. Progress reports were designed to strategically develop the ideas and logical arguments between scientific foundations behind a research premise. A few graduate programs have implemented formal training, but to the author's knowledge, no course has tailored this for undergraduate students, nor coupled it with development of original scientific knowledge. Students also learned the construct of a numerical model, which reinforces understanding of fundamental physics acting within the proposed analytical microdevice technology, identification of key cause/effect dependencies, and visual demonstration of complex results. This paper also described frequent instructor guidance on written and visual communication skills as well as on the technical content of the analytical microdevice projects.

In 2010, the course had three student teams and one manuscript was submitted for peer-review and published at the end of the course. In 2012, the course had four student teams yielding two manuscripts submitted for peer-review and one requiring additional voluntary COMSOL simulations by the students before submission for peer-review. This exercise to develop a novel concept via independent reading, discussion, and mini-lectures is new for the students, but within a few weeks was widely embraced by the students.

The premise that student engagement in this course would increases student awareness of and excitement for analytical microdevice technology and the likelihood of engaging in life-long learning was preliminarily assessed at the end of the course and via a 3-month self-evaluative survey. Self-evaluative questions were asked, are included in their entirety in this manuscript and will be conducted again 6 months after course completion. Almost half of the undergrads and all of the graduate students enrolled in the course continue to read on the topic of microdevices. Thus, this course approach was judged to have merits and was detailed for readers.

## References


1. Minerick, A.R. and G.T. Thibaudeau "Use of Concept Development Projects in Science and Engineering Courses," American Society of Engineering Education Southeast Section Proceedings, April 2009.
2. Ollis, D.F. "The Research Proposition," *Chemical Engineering Education,* **29** (4), pgs 222-229, 1995.
3. Harrison, R.G, M.U. Nollert, D.W. Schmidtke, and V.I. Sikavitsas, "The Research Proposal in Biochemical and Biological Engineering Courses," *Chemical Engineering Education,* **40**(4), 323-326, 2006.
4. Holles, J.H. "A Graduate Course in Theory and Methods of Research," *Chemical Engineering Education,* **41**(4), 226-232, 2007.
5. Burrows, V.A. and S.P. Beaudoin, "A Graduate Course in Research Methods." *Chemical Engineering Education,* **35**(4), 236, 2001.
6. Fagerberg, I. and A. Norberg, "Learning by doing – or how to reach an understanding of the research method phenomenological hermeneutics," *Nurse Education Today,* **29:** 735-739, 2009.
7. Tang, Bor Luen and Yunn Hwen Gan, "Preparing the Senior or Graduating Student for Graduate Research" *Biochemistry and Molecular Biology Education,* **33**(4): 277-280, 2005.
8. Maase, E.L. and K.A. High, "Active Problem Solving and Applied Research Methods in a Graduate Course on Numerical Methods." *Chemical Engineering Education*, 42(1), 23-32, 2008.
9. Harrison, R.G., Nollert, M.U., Schmidtke, D.W., and V.I. Sikavitsas, "The Research Proposal in Biomechanical and Biological Engineering Courses." *Chemical Engineering Education*, 40(4), 228-231, 2006.
10. Krantz, W.B. "Membrane Science and Technology in the 21st Century." *Chemical Engineering Education*, 38(2), 94-99, 2004.
11. Lipscomb, G.G., "A Compendium of Open-Ended Membrane Problems in the Curriculum." *Chemical Engineering Education*, 37(1), 46-51, 2003.
12. Newell, J.A., Farrell, S.H. Hesketh, R.P, and C.S. Slater, "Introducing Emerging Technologies into the Curriculum Through a Multidisciplinary Research Experience." *Chemical Engineering Education*, 35(4), 296-299, 2002.
13. Newell, J.A. "Survivor: Classroom. A method of active learning that addresses four types of student motivation." *Chemical Engineering Education*, 39(3), 228-231, 2005.
14. Minerick, A. R., Journal Club: A Forum to Encourage Graduate and Undergraduate Research Students to Critically Review the Literature. *Chemical Engineering Education* **2011,** *45* (1), 73-82.
15. Minerick, A.R. "Journal Club: A Forum to Encourage Graduate and Undergraduate Research Students to Critically Review the Literature." New Engineering Educators Division - American Society of Engineering Education Proceedings, June 2006.
16. Hill, P. J. "Teaching Entering Graduate Students the Role of Journal Articles in Research" *Chemical Engineering Education*, 40(4), 228-231, 2006.
17. Minerick, A.R. Creative Learning in a Microdevice Research-Inspired Elective Course for Undergraduate and Graduate Students. *Chemical Engineering Education* **2010,** *44* (3), 189-197.
18. Adams, T. N., C. J. Yang, J. Gress, N. Wimmer and A. R. Minerick (2012). A Tunable Microfluidic Device for Drug Delivery. Microfluidics. B. Bofeng, InTech.
19. Sauer, S. and P. Arce, "Team Member Selection: A Functional-Based Approach," Annual Conference Proceedings, American Society for Engineering Education, ASEE, 2004.