Incorporating Microdevice Research into a Split-Level Elective Course for Undergraduate and Graduate Students

Adrienne R. Minerick
Dave C. Swalm School of Chemical Engineering
Mississippi State University
Mississippi State, MS 39762

Abstract:
It is widely touted that the use of research ideas can create excitement for learning in the classroom. Microscale research is a challenging area within which to do this because microscopes are required to observe most phenomena in microdevices. This paper describes the development of an Analytical Microdevice Technology (AMT) course for undergraduates and graduate students at Mississippi State University. The approaches used in this course were designed to overcome the challenges with directly observing microscale phenomena. The primary course goal was to get the students familiar with small-scale technology with a focus on biomedical diagnostic applications. 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. One day per week was a dedicated lecture day where the professor came with a structured set of material, in class activities, videos, etc. to provide a foundation of knowledge for the students. A second class day was dedicated to a Survivor Game modeled after J. Newell's 2005 article [1]. The third class day was comprised of student presentations and discussion of technical articles and current news articles on Analytical Microdevice Technology. The fourth activity was a semester-long open-ended concept development project. This activity included progress reports every two weeks where these intermittent reports built to a fully developed concept well grounded in the research literature and featuring a novel approach or device for a biological analysis. This paper will describe both the course content, its close influence with research, and conclude with results of student assessment of the four learning tools.

Introduction:

A multidisciplinary, split graduate level and senior undergraduate level course was taught on Quantitative Analysis and Electrokinetics in Microdevices, an active area of research for the professor and author. The course covered both theoretical and experimental advances in the realm of biomedical diagnostic applications. Course content is given in the adjacent table with the reference texts listed below the topic area by author [1-12].

The objective of the course was to provide undergraduate and graduate students with a background in analytical microdevice technology. Surveys of news and corresponding technical articles were intended to empower students with familiarity, skills and knowledge to envision microdevice applications, and apply this in research or in future job pursuits. Upon completion of the course, the student were to have command of the following topics and skills:

- Review of Micro / Nano technology news and critique of corresponding technical publications
- Micro and nano scale forces
- Materials and methods for device fabrication
- Existing and future detection tools
- Concept plan of a fully integrated device

Students were engaged in four main learning activities during the semester: Lectures, a Survivor Game, Article Presentations, and a large Concept Development Project. The lecture content was largely governed by the content given in the adjacent table. The Survivor game was modeled after J. Newell's Survivor: Classroom [13]. Questions for the game were pulled from each of the other three activities. Students were encouraged to actively read the literature as a learning tool and as a supplement to text information provided in class by weekly article discussions in class. Lastly, the students were arranged into four teams each having a graduate student leader. Each team worked together to develop a concept project and write it up into a journal article by the end of the semester. Each of these activities is discussed in turn below.

Two class tours were conducted. The first was of the microfabrication facilities (photolithography, electroplating, and epitaxy) at SemiSouth, Inc., a start-up company from Mississippi State University. The second tour was of MSU's Life Sciences Biotech Institute, a multi-user genomics and proteomics facility.

AMT Course Topics

1. Intermolecular and Surface Forces
   Israelachvili, Probstein [1,2]
   - Intermolecular interactions
   - Interparticle forces
   - Polar (izable) molecules
   - Electrostatic forces
2. Microdevice Designs & Considerations
   Literature, Rathore [3-5]
   - Shape & Materials
   - Fabrication techniques & Lab Tour
   - Sample Injection / Mixing
3. Pressure Driven Flow (micron length scales)
   Bird, Fournier, Truskey, Literature [6-8]
   - COMSOL Mulitphysics DEMo
4. Linear Electrokinetics
   Rathore, Li [5,9]
   - Electrophoresis
   - Electroosmotic Flow
   - Lab Tour: Life Science Biotechnology Institute
5. Nonlinear Electrokinetics
   Morgan, Delgado Literature, [10,11]
   - Dielectrophoresis
   - Magnetophoresis
   - Traveling wave DEP
6. Detection and Quantification of Analytes
   Webster [12]
   - UV, flow cytometry, fluorescence

Activity 1: Lectures

Lectures were held each Monday in order to provide the students a well-organized foundation in the physics of materials at the micro and nanoscales as well as fundamental knowledge of the optical and electronic tools utilized in microdevices. The topics covered are outlined in the adjacent list.

Lectures were of traditional format with content written on a whiteboard in a sequential fashion. Exercises and short class activities were interwoven into the lecture. Due to the open atmosphere of the classroom (likely facilitated by the other class activities), students regularly asked questions. When topics related to biochemistry or biology were included in the lecture, a Biochemistry graduate student would frequently add insight and instruction beyond what the professor presented. It was an excellent learning opportunity for the students and professor alike.

Activity 2: Micro-Technology Survivor

A game of Survivor: Classroom was conducted each week and based upon J. Newell's adaptation of this popular TV show to Mass and Energy Balances [13]. Two surveys were conducted during the semester to gauge student perception of this as a learning tool. The first was conducted after the first Survivor game day and was focused primarily for students to provide feedback on questions and logistics of conducting the game in class. The second was conducted halfway through the semester. In both surveys, the students were asked to respond to two questions on a 5-point Lickert scale from Strongly Agree down to Strongly Disagree. The responses are compiled in Table 1 and demonstrate positive student feedback to the game. Interestingly, the students do recognize that the fun factor is a little greater than the learning factor. There was a slight increase by mid-semester in the number of students who felt they were learning from the Survivor game.

Table 1: Student Assessment of Survivor game merits

	Q1: I learn a great deal from the Survivor Problems		Q2: I had fun playing Survivor in class.	
	Begin	Mid	Begin	Mid
Strongly Agree	4	6	10	9
Agree	8	6	3	4
Neutral	2	2	1	1
Disagree	-	-	-	-
Strongly Disagree	-	-	-	-

With the feedback from the first survey, a number of modifications were made to the rules of the game. Original rules are available in J. Newell's article [13], AMT class rules are summarized below.

- The class is broken into "tribes," which sit together in groups to solve knowledge / reasoning, calculations, and design-based questions. Students are permitted to use any resource (notebooks, computers, phones, etc.).
- The first tribe to have an answer raises their hand and their answer is compared against the professor's. If necessary, additional time is provided. The tribe with the correct (or most optimal solution) is immune from losing a member. A representative from the successful tribe works through their solution so that the other teams may consider their solution strategies or novelty of their concept designs.

- At the end of each round, non-immune tribes lose a member according to (sequence repeats in order): a) tribe members vote off a member of their own tribe, b) tribe with immunity votes off a member of other tribes, c) one member of each tribe is eliminated by drawing a name out of a hat.
- The tribe with fewer members is immune from losing a member the first round. Graduate students are immune from being voted off for the first 3 questions.
- Students who have been eliminated in any round join the Peanut Gallery. They are also given the task of designing and solving a problem to be used in later rounds. Each eliminated student will need to produce 1 problem for every gaming session. If a student does not turn in their problem by the start of the next game, they will lose 2 points. If a student question is used in the game, they will earn 1 point.
- Students in the Peanut Gallery can also work on the Survivor questions independently. If they "win" a round, they can choose to join any team they like (and earn 2 points). The team they join then earns immunity and the loss of a member of the other tribes proceeds as above for that round.
- Tribes will be revamped / reformed once a single player has been crowned Grand Champion. Successful students will be rewarded with bonus points on their final according to a) every player who survives to the second day of play gets 3 points, b) every member of the champion's tribe gets 2 points, c) the Grand Champion earns an additional 5 points, the points are additive, so the Grand Champion will earn 10 points (or more!).

Interestingly, the ability of members of the Peanut Gallery to answer questions independently to earn back a position on any team helped immensely with keeping those students who had been voted off engaged in the game and learning.

Activity 3: Current Micro / Nano News & Archival Journal Articles Discussions

This section of the class was modeled after the author's research group Journal Clubs [14]. Article discussions were intended to be a practice forum where one student would lead the class in a discussion of an article of his / her choosing. Undergraduate students were allowed to pull from popular news. However, graduate students could scan the science / technology news, but had to secure the archival article and present from that. When the student provided the article in advance, it was posted on webCT, but the other students were not required to read articles in advance. The professor did keep track of questions asked and those who participated in the discussion in order to give participation points, but did not control the progression of the discussion.

Given the number of students in class, each student presented once every 3 weeks. The students were told that a significant part of engineering research is oral and written communication with tangible depth and conveyance of understanding. As a result, emphasis was placed on the clarity, organization, and understandability of the student's presentation. It was strongly encouraged to present at the level of the audience such that an involved discussion could develop from the article. Students were allowed to use any method of delivery they preferred.

Activity 4: Semester Concept Development Project
The skills that serve graduates of engineering programs best are not all learned from textbooks. Tangible skills are harder to teach, but are essential to prepare students to be productive, technical, members of society include problem solving skills, information filtering skills, and logic skills. The traditional classroom does not focus on these skills nor does it usually provide individual practice linking unique concepts together. This semester long Concept Development Project was a concerted effort to strategically develop these skills in the students enrolled in this course.

The assignment for the project teams was a large, open-ended, concept development project. The students were integrally involved in deciding the small-scale technology that they wanted to pursue which would help address an important biomedical application using either micro or nanotechnologies. The concept was to build from both theoretical and experimental reported technologies in the realm of chemical, mechanical, optical and biological analysis. Their resulting virtual microtechnology was to be a novel extension of published work. Upon completion of the project, each team member was expected to be able to conduct an extended discussion of the following topics and skills related to their project:

- Review of pertinent technology from peer-reviewed publications
- Micro and nano scale forces acting within their micro / nano device
- Materials and methods utilized in their conceptual device (and why chosen)
- Why and how their project was novel from existing detection tools

The output of the effort was to be a concept plan of a fully integrated biomedical technology. The concept was to be articulated in an archival journal paper and presented via a team oral presentation. Progress reports were due throughout the semester and were designed to roughly build the sections of the final archival journal article. The reports were a) description of proposed novel analytical microtechnology, b) complete literature review on the scientific premises of the proposed analytical microtechnology (> 10 references, fully discussed), c) prototype drawing and accompanying description of the analytical microtechnology, d) final device design and a first draft of complete final report, and e) final archival journal article.

Assessment:
Student's preferences for each class activity were assessed via a short survey in the final day of the course. The 11 question survey was approved by MSU's IRB and the students present all signed consent forms for their data to be included. The survey was designed to test the hypothesis that the class activity that student's most prefer was influenced by their learning style.

The premise was that everyone has learning style preferences [15,16] which can be measured on a sliding scale between two extremes in four stages of learning: processing, perception, input modality, and understanding [17]. During processing, students favor either **active (ACT)** or **reflective (REF)** learning by introspectively thinking about material. In perception, **sensing (SEN)** learners focus on external input while **intuitive (INT)** learners focus on internal contemplation. Input modality preferences scale between **visual (VIS)** and **verbal (VRB)**. Lastly, learners can achieve understanding in **sequential (SEQ)**, linear logical steps or **globally (GLO)** where information is pieced together into a big picture.

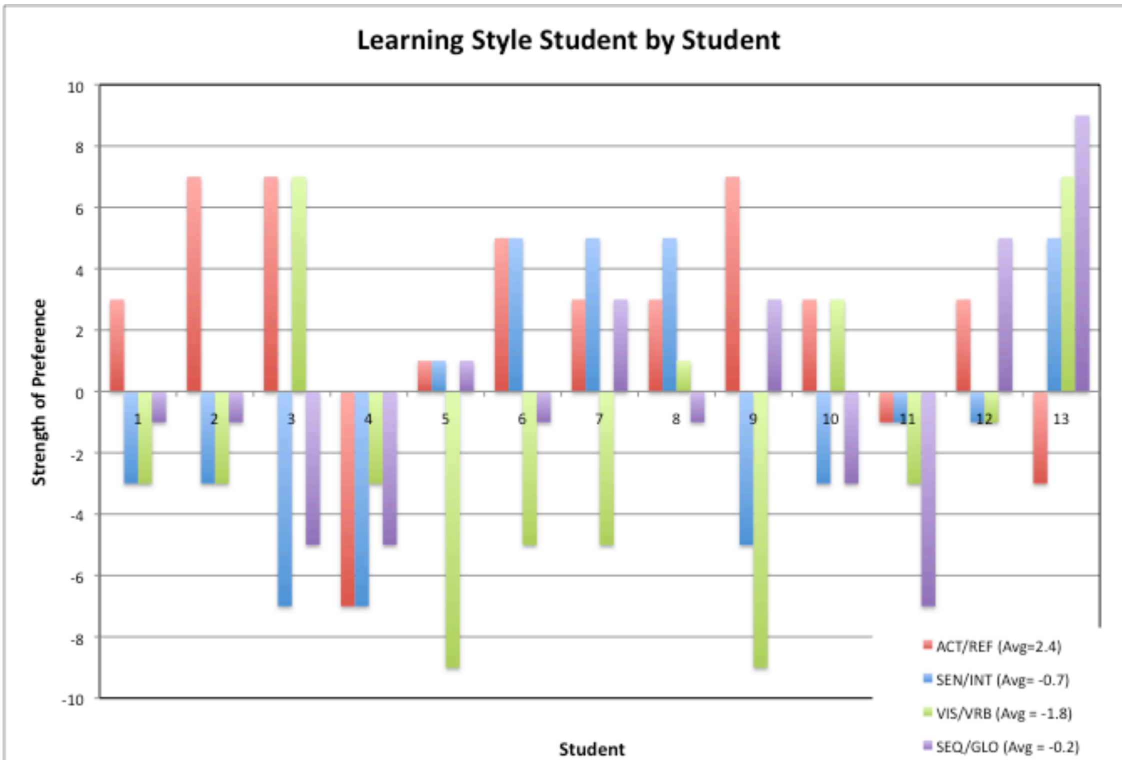

Figure 1: Learning style preferences for each student who completed the survey. Negative values indicate a preference towards the first of the two modalities. Non-weighted averages are provided in the legend labels.

To test this hypothesis, students were directed to the Soloman-Felder online learning styles inventory and asked to complete the 44 questions [18]. They then self-reported their scores on the written survey and proceeded to answer the remaining survey questions. In figures 1 through 3 reporting the student's learning style, the four stages of learning are reported as ACT / REF with a negative number indicating preference towards active learning while a positive number indicates preference towards reflective learning. The same nomenclature is used for SEN / INT, VIS / VRB, and SEQ / GLO.

Overall student learning preferences are included in Figure 1 and are slanted towards reflective (REF) with an average of 2.4, slightly sensory (SEN) with an average of -0.7, more visual (VIS) than verbal (VRB) with an average preference of -1.8, and nearly balanced between sequential (SEQ) and global (GLO). The SEQ / GLO average is slightly misleading as 8 of the 13 students were sequential learners, but did not show as great of a preference in this direction. Given that global learners historically have not gravitated into engineering, this is an interesting distribution of students in this course.

The first question asked students to rank their most favorite to least favorite learning activity in this class. The activities were: lecture, Survivor game, article discussions, and concept project. The most popular activity was the article discussions, which is interesting because this was the activity that students demonstrated the most apprehension over when the concept was introduced. While some students voiced dread over their turn to present, the remaining students became more engaged in the discussions as the semester progressed. Figure 2 cross correlates the student's preferred class activity with their composite learning style (style preference added together). The stronger active learners were skewed toward Survivor as the preferred activity (N=4 students) while the weakly active learners and reflective learners preferred the Article discussions. Overall, sensory learners preferred Article discussions while intuitive learners preferred Survivor. The stronger visual learners had a slight preference towards Survivor than for Article discussions. Overall, global learners preferred Article discussions while sequential learners preferred Survivor.

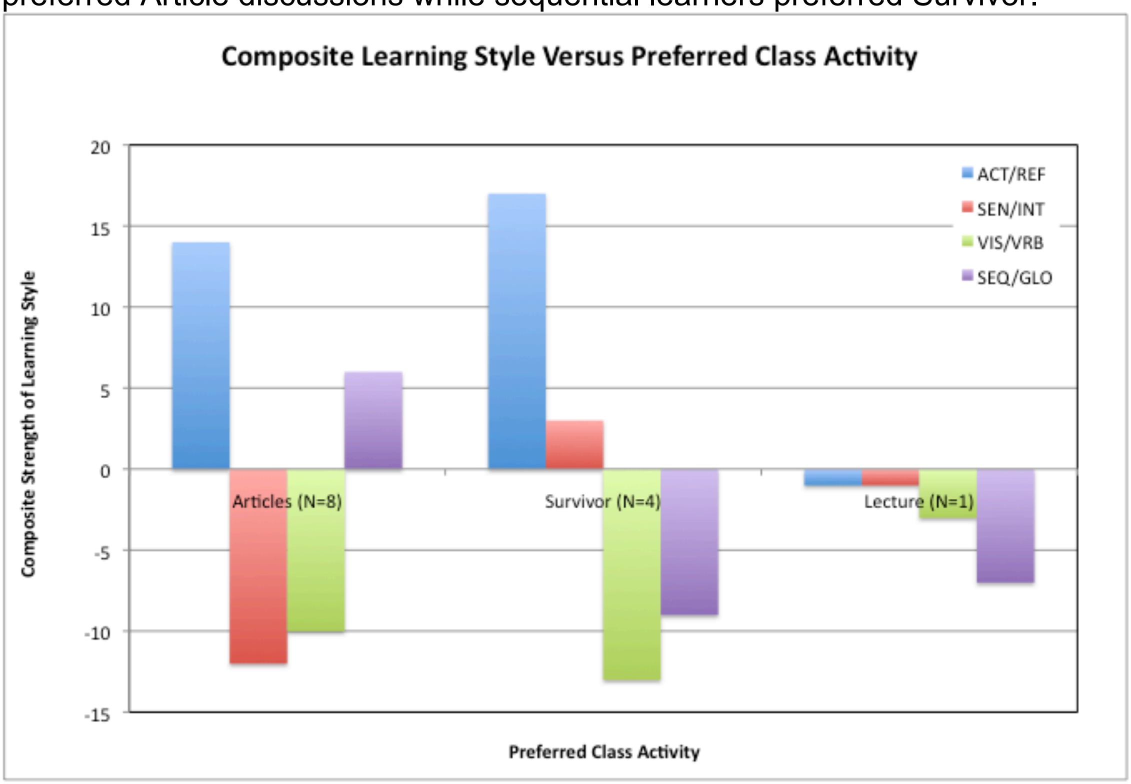

Figure 2: Composite (additive) learning style correlated with preference toward class activities.

One individual chose lectures as the favorite class activity and their strongest preference was toward sequential. Lectures tended to be quite linear in concept progression, while the article topics were random due to student's freedom of choice to obtain an article and the Survivor game questions were purposefully randomized.

Students were also asked to score how much they learned during each activity on a scale from 1 to 10 with 10 being "learned a great deal" and 1 being "learned very little". As demonstrated in Table 2, the students felt they learned the most from their Concept Development Project followed by their favorite activity, Article discussions. The student's learned the least from the Survivor game, but it should be noted that the average score here is still greater than average (5).

Table 2: Student self-rated learning in each of four class activities.

	Lecture	Survivor	Articles	Project
Average	7.7	6.5	8.2	8.5
Standard Deviation	1.5	1.3	1.5	1.3

This critique of their own learning was cross-correlated with their learning style and is shown in Figure 3. Trend lines are added to give an overall sense of which type of learner learned more. For example, active learners felt they learned more from the project, article, and lecture than reflective learners. However, reflective learners felt they learned more from Survivor than the active learners, which is surprising given the learning mechanism these modality suggests. The preferences in one direction or another are slight and given the population size, the numbers can be skewed by the response of a single individual. Only slight preferences are shown when comparing sensory and intuitive learners. Other notable trends include that visual learners felt they learned more than verbal learners from the lectures. In all cases, all types of learners rated Survivor lowest as a learning tool.

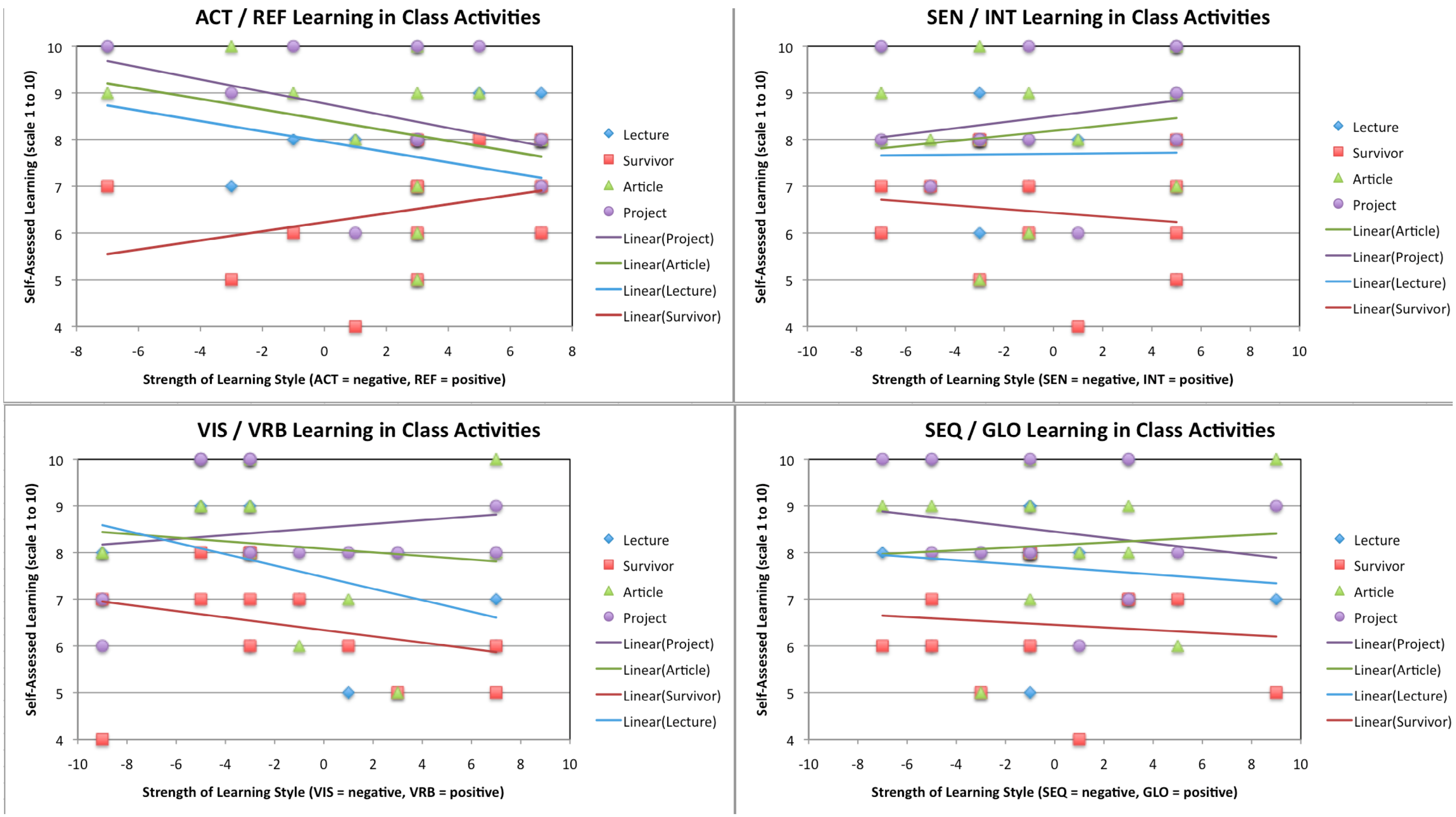

Figure 3: Student ratings of learning value of the four class activities (Lecture, Survivor, Article discussions, Concept development Project) cross-correlated with their learning style preference.

Students were also asked if there a particular combination of learning activities that was instrumental in helping them learn. The two most common combinations mentioned (by 4 of 13 in each case) was Lecture / Survivor and Article / Project.

The original Survivor paper [13] discussed a model where students had four primary types of motivation. The original work describing this was Biggs and Moore in 1993 [19]. They summarized the four types as: "**Intrinsic** – learning because of natural curiosity or interest in the activity itself; **Social** – learning to please the professor or peers; **Achievement** – learning to enhance position relative to others; and **Instrumental** – learning to gain rewards beyond the activity itself (better grades, increased likelihood of getting a high-paying job, etc.)" Students were asked to rate themselves against these four motivators on a scale from 1 to 10 with 10 being "very motivated by this" and 1 being "not motivated by this at all". On average, the students felt they were very intrinsically motivated (8.8 ± 2), fairly neutrally socially motivated (5.0 ± 2.2), a little more strongly motivated by achievement (6.5 ± 1.9), and even stronger instrumentally motivated (7.8 ± 1.5).

Conclusions:

A research focused special topics course on Analytical Microdevice Technology was taught for the first time in Spring 2008 with four different class learning activities. The activities were lectures, a Survivor game, Article discussions, and a concept development project conducted in teams. While the students showed a strong preference toward the article discussions, most felt they learned the most from the projects.

Correlations with student learning styles were compiled and demonstrated that while students have a preference for certain activities, learning is possible with all activities as demonstrated by quantitative learning rankings greater than neutral for all activities. Overall, the students rated themselves as intrinsically and instrumentally motivated. Grades were de-emphasized in this course, yet student participation in all except one student was greater than the professor has seen in core chemical engineering courses she has taught. The population size is rather small (13 completed the surveys), yet interesting trends suggest learning merits in each of the four class activities.

References:

1. Israelachvili, J., *Intermolecular and Surface Forces: Second Edition*, Academic Press, San Diego, 79,82,102, 1992.
2. Probstein, R.F. Physicochemical Hydrodynamics: An Introduction (Second Edition), Wiley-Interscience Publication, New York, 1994.
3. Rathore, A.S, and A. Guttman, Electrokinetic Phenomena, Marcel Dekker, New York, 2004.

4. Hill, P. J. "Introducing Technical Articles to Graduate Students Through Active Learning" presented at the Southeast Regional ASEE meeting, Chattanooga, TN, April 2005.
5. Micro / Nano Magazine. Sponsored by Nano Science and Technology Institute (NSTI). http://www.rdmag.com/micronano.aspx Accessed 18 July 2006.
6. Bird, R.B., W.E. Stewart, and E.N. Lightfoot, Transport Phenomena (Second Edition), Wiley, New York, 2002.
7. Fournier, R.L. Basic Transport Phenomena in Biomedical Engineering, Taylor & Francis, Philiadelphia, 1999.
8. Truskey, G.A., F. Yuan, and D.F. Katz, Transport Phenomena in Biological Systems, Pearson Prentice Hall, Upper Saddle River, NJ, 2004.
9. Li, D., Electrokinetics in Microfluidics in Interfacial Science and Technology V. 2, Elsevier, Amsterdam, 2004.
10. Morgan, H., and N.G. Green, AC Electrokinetics: colloids and nanoparticles in Microtechnologies and Microsystems Series, Research Studies Press, Baldock, 2003.
11. Delgado, A.V. Interfacial Electrokinetics and Electrophoresis in Surfactant Science Series V. 106, Marcel Dekker, New York, 2002.
12. Webster, J.G., Bioinstrumentation, John Wiley & Sons, 2004.
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." New Engineering Educators Division - American Society of Engineering Education Proceedings, June 2006.
15. Felder, R.M. and L.K. Silverman, *Engr. Education,* 78(7): 674-681, 1988.
16. Felder, R.M. *ASEE Prism,* 6(4): 18-23, 1996.
17. National Effective Teaching Institute (NETI), offered in cooperation with American Society of Engineering Education, 2005, http://www.ncsu.edu/felder-public/NETI.html, Accessed 19 July 2005.
18. Soloman, B.A. and R.M. Felder, "Soloman-Felder Learning Styles Questionnaire," http://www.engr.ncsu.edu/learningstyles/ilsweb.html Accessed 22 Sept. 2008.
19. Biggs, J., and P.J. Moore, The Process of Learning, Prentice Hall, Englewood Cliffs, NJ (1993).