CREATIVE LEARNING IN A MICRODEVICE RESEARCH-INSPIRED ELECTIVE COURSE

for Undergraduate and Graduate Students

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It is widely touted that the use of research ideas can create excitement for learning in the classroom.[5-9] This paper describes the development of a research-inspired Analytical Microdevice Technology (AMT) course for undergraduates and graduate students at Mississippi State University. Microscale research is a challenging area within which to do this because microscopes are required to observe most phenomena in microdevices. The approaches used in this course were designed to overcome the challenges with directly observing fluid and particle dynamics at the microscale, while still demonstrating the powerful nature of this area of engineering. 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 (15 weeks, MWF class): a lecture, a Survivor game,[1] discussions of technical articles,[2, 3] and a concept development project.[4] Mondays were dedicated lecture days (15 total contact sessions) where the professor came with a structured set of material, in-class activities, videos, etc., to provide a foundation of knowledge for the students. Wednesdays were dedicated to a Survivor game modeled after J. Newell's 2005 article.[1] This interactive game had student teams solving knowledge, calculation, concept, and design problems during class. Teams with incorrect answers lost members via a voting mechanism. Fridays were comprised of student presentations and discussions of technical articles and current news articles on Analytical Microdevice Technology. The fourth activity was a semester-long, open-ended concept development project completed in teams outside of class. These concept development projects included progress reports every two weeks; the intermittent reports built to a fully developed journal-style article outlining a microtechnology concept well-grounded in the research literature and featuring a novel approach or device for a biological analysis. This paper describes the course content and its close influence from the author's research, and concludes with results of student assessment of the four learning tools which have been cross-correlated with the student's preferred Felder-Silverman Learning Style.[10,11]

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Electrokinetics and Quantitative Analysis in Microdevices is an active area of research for the author and the development of this course was supported by an NSF CAREER Award. The course counts as a chemical engineering elective in MSU's curriculum, but was widely advertised as open to all majors and even enrolled a biochemistry graduate student. A total of 14 students—nine undergraduates and five graduate students—completed the course. Course content covered both theoretical and experimental advances from the perspective of understanding the fundamental forces dominating at the micron-length scales in both electric fields and small, confined channels. The phenomena were closely tied with known microdevice applications that harnessed those forces for a biomedical diagnostic application. Course content is given in Table 1 with the reference texts listed by author.[12-21]

Course objectives were structured to provide undergraduate and graduate students with preliminary research skills as well as a solid background and an enthusiasm for 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 students were to demonstrate proficiency in the following topics and skills:

- *Review of micro / nano technology news and critique of corresponding technical publications*
- *Fundamental understanding of micro/nano forces*
- *Materials and methods for microdevice fabrication*
- *Contextualization of existing and future detection tools*
- *Concept plan of a fully integrated device*

The four main learning activities during the semester—lectures, Survivor game, article presentations, and a large concept development project—were drawn from various sources. The lecture content was largely governed by the content given in Table 1. Questions for the game were pulled from each of the other three activities. For article presentations, students were encouraged to actively read the literature as a learning tool and as a supplement to information provided in class. Two facility 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 that uses a variety of electrophoretic profiling devices. Lastly, the students were arranged into four teams each having a graduate student leader, and each team worked together to develop a concept project, which culminated in a viable draft of a journal article. Each of these activities is discussed in the following sections of this paper. In addition, the course topic of linear electrokinetics is described under each activity to demonstrate how course content was related between the activities.

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 Table 1. Lectures were of traditional format with content written on a whiteboard in a sequential fashion. Calculation exercises, videos, 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 and began discussions to understand why fluids or particles behaved as they did in the confined geometries. 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.

For example, linear electrokinetics included coverage of both electrophoresis and electroosmotic flow. Students had previously learned charge interactions and particle behaviors in Section 1 of the course. The introduction included applications of electric fields including the geometry considerations (uniform, non-uniform) as well as energy considerations (Direct Current, Alternating Current). The linear electroki-

TABLE 1
AMT Course Topics

1. Intermolecular and Surface Forces, *Israelachvili, Probstein*[12,13]	
	Intermolecular interactions
	Interparticle forces
	Polar (izable) molecules
	Electrostatic forces
2. Microdevice Designs & Considerations, *Literature, Rathore*[14]	
	Shape & materials
	Fabrication techniques & lab tour
	Sample injection / mixing
3. Pressure Driven Flow (micron length scales), *Bird, Fournier, Truskey, Literature*[15-17]	
	COMSOL Mulitphysics DEMo
4. Linear Electrokinetics, *Rathore, Li*[14,18]	
	Electrophoresis
	Electroosmotic flow
	Lab tour: Life Science Biotechnology Institute
5. Nonlinear Electrokinetics, *Morgan, Delgado Literature*[19,20]	
	Dielectrophoresis
	Magnetophoresis
	Traveling wave DEP
6. Detection and Quantification of Analytes, *Webster*[21]	
	UV, flow cytometry, fluorescence

netics discussion was limited to uniform geometry and DC electrical configurations. Foundations in both electrophoresis and electroendoosmosis were covered as shown in cartoon in Figure 1. The apparent electrokinetic velocity observed in a microchannel is a combination of the electrophoretic (EP) velocity and the electroosmotic (EO) velocity as follows:

$$V_{EK} = V_{EP} + V_{EO} \quad (1)$$

where the particle's electrophoretic velocity is given by:

$$v_{EP} = \frac{q \cdot E}{r \cdot \eta} \quad (2)$$

and the electroosmotic flow velocity is given by:

$$v_{EO} = \frac{\varepsilon \cdot \zeta \cdot E}{\eta} \quad (3)$$

One concept that is important to keep straight is the difference between mobility and velocity. They are related as

$$\mu = \frac{v}{E} \quad (4)$$

The variables used in these equations are v as the velocity, q as the particle charge, E as the electric field (voltage per distance), r as the particle radius, η as the fluid viscosity, ε as the dielectric permittivity, ζ as the zeta potential (the effective charge difference between the wall and the bulk fluid in the normal dimension), and μ is the mobility. The complex wall charge / fluid charge interactions were examined in detail.

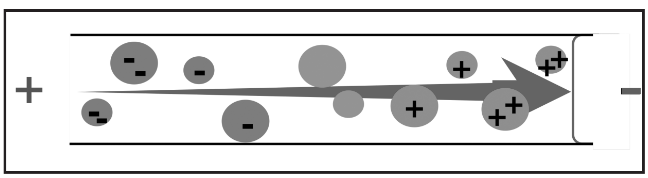

Figure 1. *In uniform, linear DC electric fields, particles will move due to a combination of the electrophoretic forces acting on the particle as well as the electroendo-osmotic forces inducing flow of the liquid. This diagram demonstrates the relative mobilities of highly charged small particles down to lowly charged large particles.*

TABLE 2
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	Middle	Begin	Middle
Strongly Agree	4	6	10	9
Agree	8	6	3	4
Neutral	2	2	1	1
Disagree	-	-	-	-
Strongly Disagree	-	-	-	-

Lectures were interactive in the form that in-class activities were also interspersed throughout the instructor-dominated discussions. Activities and discussions were frequent sources of questions for Survivor the following class period.

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 in his Mass and Energy Balances class.[1] This game served as means for the students to apply the information learned in the lecture and as such replaced a homework component of the class. Three types of questions were asked during the game that roughly corresponded to the levels of Bloom's Taxonomy.[22] Level 1 questions primarily queried knowledge and understanding of concepts; these were quicker-answer questions that probed the "remember" and "understand" levels of Bloom's Taxonomy. Level 2 questions ranged from plug-and-chug calculations (equations not provided, students could use notes) to more involved quantitative reasoning questions; these targeted the "apply" domain of Bloom's Taxonomy. Level 3 questions typically were a team effort and involved the novel design of microdevices that capitalized upon the phenomena of interest to achieve mixing, reaction, separation, or other micro-unit operations. These questions targeted the "evaluate" and "create" levels of cognitive development.[22]

Two surveys were conducted during the semester to gauge student perception of this game 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 an open essay question and two questions on a 5-point Lickert scale from Strongly Agree down to Strongly Disagree. The responses are compiled in Table 2 and demonstrate positive student feedback to the game. Interestingly, the students recognized that the fun factor was 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.

With the feedback from the surveys, a number of modifications were made to the rules of the game. Original rules are available in J. Newell's article[1]; AMT class rules differed in the following ways:

- *The tribe with fewer members was immune from losing a member the first round. Graduate students were immune for the first three questions.*
- *Students who were eliminated in any round joined the Peanut Gallery. They were given the task of designing and solving one problem per gaming session with the intention that it might be used in later rounds.*
- *Peanut Gallery students could also continue to compete independently. If they "won" a round, they could choose to join any team (and earn points). The team they joined then earned immunity from loss of a member for that round.*

The ability of members of the Peanut Gallery to answer questions independently helped immensely by keeping those students engaged in the game and learning.

Linear electrokinetics concepts were reinforced during the Survivor game. For this particular topic, level 1 knowledge questions were:

1. "Rank order the mobility of the following particles from slowest to fastest.

   A. Large, highly charged analyte,

   B. Small, highly charged analyte,

   C. Large, barely charged analyte,

   D. Small, barely charged analyte."

   ANSWER: C,D,A,B

2. "What happens to flow if a capillary surface is chemically modified to express densely packed positive charges? Describe the cause / effect relationships that lead to the final electroosmotic flow profile.

   ANSWER: The positively charged wall will attract a Debye layer of negative charges. In a DC field, these will pull the fluid toward the anode in the classic flat velocity profile.

Level 2 questions included the following:

1. "What is the electrophoretic mobility of an analyte with a net positive charge of 2 and an effective radius of 50 nm in an aqueous solution?

   ANSWER: Note that 1 Crulomb is equal to the charge of 6.24×10^{18} protons.

$$\mu_{EP} = \frac{q}{r \cdot \eta} = \frac{2C \big/ 6.24 * 10^{18}}{50\text{nm} \cdot 1\text{cp}} = \frac{3.21 * 10^{-19} \frac{\text{kg} \cdot \text{m}^2}{\text{V} \cdot \text{s}^2}}{50\text{nm} \cdot 1\text{m} \big/ 10^9\,\text{nm} \cdot 1 * 10^{-3}\,\text{kg} \big/ \text{m} \cdot \text{s}} = 6.4 * 10^{-9}\,\frac{\text{m}^2}{\text{s} \cdot \text{V}} \qquad (5)$$

2. "For a given analyte, does the mobility change if the electric field is doubled?"

   ANSWER: No, the mobility is a property solely of the analyte and characterizes the analytes' ability to move in an electric field. While mobility will not change, its velocity will increase in large electric fields and separations will occur faster.

One level 3 question was asked of the teams.

"Design a microfluidic device that is able to mix two aqueous electrolyte streams using only patterned alternating wall surface charge to accomplish the task. Draw your device and label, then include explanations of what the flow profile will look like."

While the level 3 problems were the most time intensive and hardest for which to judge team winners, the students who excelled on these questions were not usually the students who answered the level 1 questions that tended to be speed dependent. Also, it was interesting that all questions obtained from Peanut Gallery members for subsequent Survivor games were predominantly level 1 questions with a few level 2 questions and no level 3 questions.

ACTIVITY 3: CURRENT NEWS AND ARCHIVAL JOURNAL ARTICLE DISCUSSIONS

This section of the class was modeled after the author's research group's weekly literature discussion class termed "Journal Club."[2] 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. Graduate students, however, could scan the science/technology news, but had to secure the archival journal article and present from that. When the student provided the article in advance, it was posted on MyCourses, an online proprietary virtual Blackboard Learning System.[23] No incentive or monitoring occurred to see if the other students read the articles in advance, however. The professor did keep track of questions asked and who participated in the discussion in order to give participation points, but strove to not control the progression of the discussion.

Given the number of students in class, each student presented approximately once every three 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. Most students utilized the document camera to project figures from their paper to the video projection screen. Some students prepared handouts to overcome the awkward maneuvering of the document camera and one student put presentations into PowerPoint.

An example of a linear electrokinetic article discussed was that by Amy Herr, "Electroosmotic Capillary Flow with Non-Uniform Zeta-Potential," published in *Analytical Chemistry* in 2001.[24] The student presenting enjoyed discussing the charge-modified capillaries and the creative use of caged fluorophores to image the changing electroosmotic flow profile.

ACTIVITY 4: SEMESTER CONCEPT DEVELOPMENT PROJECT

The skills that best serve graduates of engineering programs are not all learned from textbooks. Tangible skills that 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. This activity strove to push students to the highest level of learning in Bloom's Taxonomy.[23] This activity, above all others, demonstrated student mastery of material.

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 that 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 nanoscale 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 sequentially formulate 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. The professor provided feedback using a structured assessment template after each report. The student teams were to demonstrate significant improvements guided by this feedback in the final journal article.

The projects included:

1. *"Ricin Dosimetry via Lab-on-a-Chip Antibody-Mediated Detection" by Daniel Barnes (Grad), Jennifer McContrell (UG), Parisa Toghiani (UG), and David Quick (UG). Castor oil from the castor plant is an economically important, international commodity. The castor seed contains around 50% oil by weight but grinding the seed releases an extremely toxic protein, ricin. Ricin has an LD50 of 3 to 5 μg/kg when inhaled, and there is no specific treatment for ricin poisoning. The device described in this paper is designed to detect airborne ricin particles and alert the wearer to the accumulation of dangerous levels in the atmosphere over the course of a 4-hour shift.*

2. *"Carbon Nanotubes as a Drug Delivery System" by Kaela Leonard (Grad), Miranda Smith (UG), Jason Strunk (UG), and Roberto Velasquez (UG). Osteosarcoma, bone cancer, is a rare form of cancer that attacks the bone tissue. This paper proposes a novel method specifically for patients suffering from osteosarcoma. Significant comfort and efficacy benefits for the patient are possible if drug delivery occurred directly to the affected area, and if the delivery system could be functionalized to attack only cancerous cells. By utilizing carbon nanotube technology, this paper outlines a plausible system, based upon existing advances reported in the literature, which would effectively deliver the chemotherapeutic drug while simultaneously providing structural reinforcement to the bone tissue remaining after surgery. Carbon nanotubes will be preloaded with micelles containing the anticancer drug cisplatin, which will then be released upon implantation in the bone, (and directed to any remaining cancer cells via folate functional groups on the micelle's outer surface).*

3. *"An Electric Field Gradient Focusing Method for Fluorescent Detection of Immunological Reactions" by Aytug Gencoglu (Grad), Eric Rutan (UG), and Zach Wynne (UG). A conceptual design is proposed for a novel microdevice that would be used for the investigation of immunological reactions between proteins found in body fluids and pathogens such as the flu virus is presented. The operation of the proposed microdevice would consist of two consequent phases. The first phase would be the separation of different proteins from a sample prepared from body fluids by electric field gradi-*

ent focusing (EFGF), where an electric field gradient would be formed within a square channel by the use of electrodes with varying potentials along the length of the channel. Control dyes would be used to determine the completion of the first phase. The second phase would be the contacting of the focused protein bands with the fluorescent tagged antigens and detection of reactions using fluorescence. This new technique could reduce the time required for the design of new drugs or vaccines, and could also be adapted to be used as a novel allergy testing technique.

4. *"Detection of Metastatic Breast Cancer: Prototype of a Rupturing Microdevice" by Sheena Reeves (Grad), Soumya S. Keshavamurthy (Grad), and Lekeith Terrell (UG). Earlier detection is recommended for preventing the spread of the disease especially for individuals who have had cancer previously. There have been many detection methods developed and explored by researchers over the past years; however, these methods are painful, intrusive, and time consuming for the patient. In this work, blood testing will be explored as a possible method for early detection of metastatic breast cancer. Cancerous cells are softer than the normal healthy cells as demonstrated by researchers. CTCs are found in the bloodstream and are obtainable for testing. Here, rupture rate of normal and cancerous cells will be used as a measure of detection. A device capable of rupturing the cells has been designed in order to quantify the rupture rate. A lab-on-a-chip system will be developed for faster and rapid diagnosis of breast cancer by using flow cytometer assembly with fluorescent markers for easy and early detection. The microdevice makes use of a channel, electrodes, an electric field generator, and flow cytometry. Normal cells rupture at a slower rate compared to cancerous cells since they are much harder than cancerous cells.*

The topic ideas were brainstormed and developed by the students with guidance from the instructor. In the following section, the assessment of each of these activities is discussed.

ASSESSMENT

Students' preferences for each class activity were assessed via a short survey on the final day of the course. The 11-question, instructor-derived survey and the 44-item Soloman-Felder questionnaire[11] were approved by MSU's Institutional Review Board (IRB) for the protection of human subjects; the 13 students present in class all signed the consent forms giving permission for their data to be included. The survey was designed to test the hypothesis that the class activity that each student most preferred was influenced by that individual's learning style.

The premise was that everyone has learning-style preferences[10, 25] that can be measured on a sliding scale between two extremes in four stages of learning: processing, perception, input modality, and understanding.[26] 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.

To test this hypothesis, students were directed to the Soloman-Felder online learning styles inventory and asked to complete the 44 questions.[11] They then self-reported their scores on the written instructor-derived survey and proceeded to answer the remaining 11 survey questions. In Figures 2 through 4, which incorporate the student's learning style,

TABLE 3
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

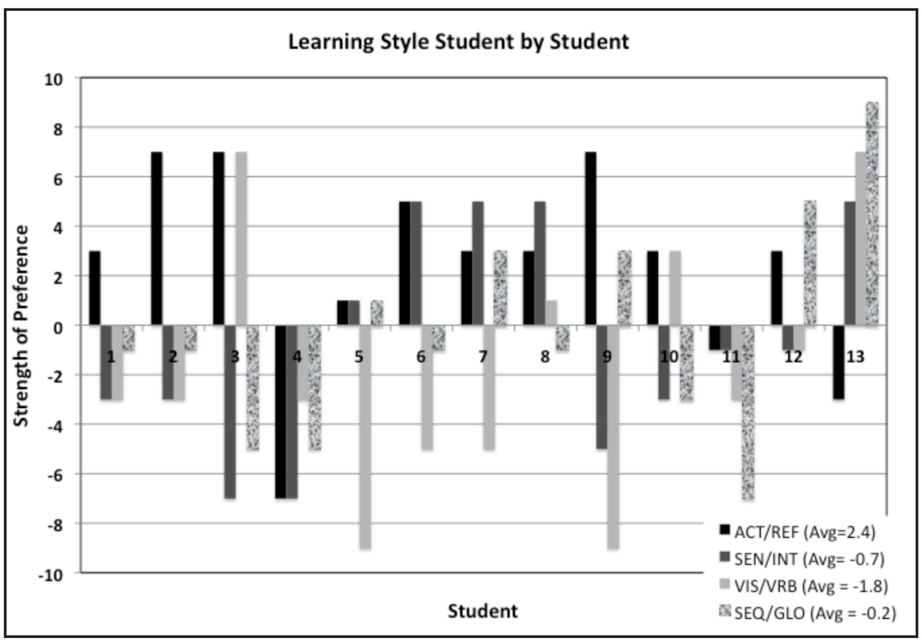

Figure 2. *Learning style preferences for each student who completed the survey. Negative values indicate a preference towards the first of the two modalities. Non-weighted averages are provided in the legend labels.*

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 2 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 equally balanced between sequential (SEQ) and global (GLO). The SEQ/GLO average is slightly misleading as eight of the 13 students were sequential learners, but did not show as great a preference in this direction. Given that global learners historically have not been known to gravitate 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 design 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 3 cross-correlates the student's preferred class activity with their composite learning style (style preference is summative). 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 for Survivor over article discussions. Overall, global learners preferred article discussions while sequential learners preferred Survivor.

One individual chose lectures as the favorite class activity and their strongest preference was toward sequential. Lectures tended to be quite sequential in concept progression, while the article topics were undirected due to student's freedom of choice to obtain an article. In addition, 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 3, the students felt they learned the

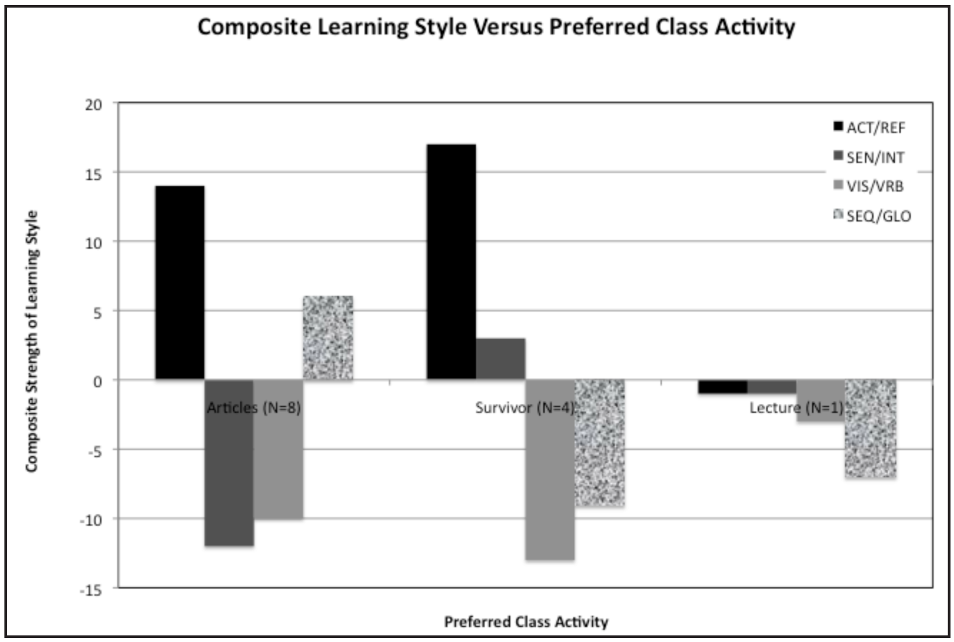

Figure 3. *Composite (additive) learning style correlated with preference towards class activities.*

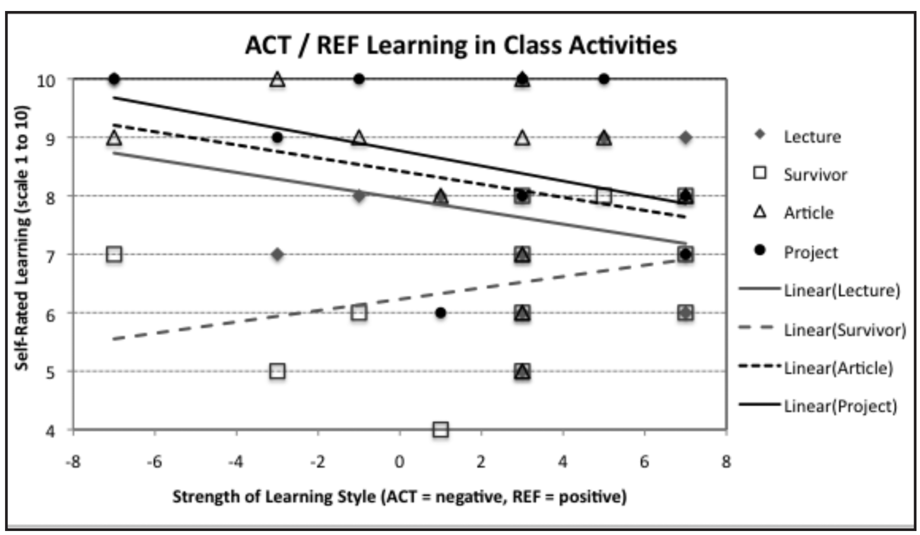

Figure 4. *Student ratings of learning value of the four class activities (Lecture, Survivor, Article Discussions, Concept Design Project) cross-correlated with their Active-Reflective (ACT/REF) learning style preference. This trend is presented in line 1 of Table 4 using the normalized covariance.*

most from their concept development project followed by their favorite activity—article discussions. The students learned the least from the Survivor game, but it should be noted that the average score here is still greater than neutral (5).

This critique of their own learning was cross-correlated with their learning style and is shown in Figure 4. Trend lines using a least squares method are added to guide the eye for an overall tendency. As shown, active learners felt they learned more from the project, article, and lecture than reflective learners. Reflective learners, however, felt they learned more from Survivor than the active learners, which is surprising given the learning mechanism this modality suggests. In all cases, all types of learners rated Survivor lowest as a learning tool.

Such trends can also be captured using a cross-correlation scheme such as the normalized covariance in a more concise form. For this reason, figures are not included for the other three learning styles and the data is in Table 4: sensory/intuitive (row 2), visual/verbal (row 3), and sequential/global (row 4). Students' learning style, l, was correlated with their course activity preferences, a, as follows:

$$C_{l,a} = \frac{\Sigma\left(l-\bar{l}\right)\left(a-\bar{a}\right)}{\sqrt{\Sigma\left(l-\bar{l}\right)^2\left(a-\bar{a}\right)^2}} \qquad (6)$$

where $\bar{l}$ and $\bar{a}$ denote average learning-style preference and activity preference, respectively. This linear correlation provides an indicator normalized between -1 where the two data sets demonstrate a perfectly linear negative correlation, 0 where the data sets are uncorrelated, to +1 where the two data sets demonstrate a perfectly linear positive correlation. The results are presented in Table 4.

Learning style vs. activity correlations are not particularly strong and given the population size (13 respondents), the numbers could have been skewed by the response of an individual or two. Negative correlations in this case indicate a preference towards the first dimension of the learning style modality, while positive correlation numbers indicate a preference towards the second dimension. For example, intuitive learners and sequential learners equally liked the projects. Other notable trends include that visual learners felt they learned more than verbal learners from the lectures.

Students were also asked if there was a particular combination of learning activities that was instrumental in helping them learn. The two most common combinations mentioned were lecture / Survivor (by 4 of 13) and article / project (by 4 of 13). This result is not surprising given that lecture served to provide a foundation and the Survivor game was a mechanism for students to practice applying this knowledge. Similarly, the article discussions enabled the students to be efficient and use their article presentation to read and present on articles of use to their team concept design project.

TABLE 4
Correlation of Students' Learning Style (l) With Preferred Class Activity (a)

l \ a	Lecture	Survivor	Article	Project
ACT/REF	-0.29	0.32	-0.32	-0.42
SEN/INT	0.01	-0.14	0.17	0.23
VIS/VRB	-0.41	-0.27	-0.14	0.16
SEQ/GLO	-0.11	-0.10	0.08	-0.22

Newell's Survivor paper[1] discussed a model where students had four primary types of motivation. The original work describing this was Biggs and Moore in 1993.[27] 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 more strongly instrumentally motivated (7.8 ± 1.5). It should be noted that by directly asking students to rate their motivation, the results might be biased to higher numbers because of the tendency to consciously or subconsciously rate higher.

Student's motivation, m, was correlated with their preferences for each course activity, a, using the normalized covariance as follows:

$$C_{a,m} = \frac{\Sigma\left(a-\bar{a}\right)\left(m-\bar{m}\right)}{\sqrt{\Sigma\left(a-\bar{a}\right)^2\left(m-\bar{m}\right)^2}} \qquad (7)$$

where $\bar{a}$ and $\bar{m}$ denote average of each activity and motivation, respectively. The results are presented in Table 5.

Intrinsically motivated students equally preferred Survivor and the concept development project. This preference is similar in instrumentally motivated students. Intrinsically motivated students, however, showed a slight preference for the article discussions with no correlation for the lectures while the instrumentally motivated students were the opposite. Most students felt they were not strongly motivated by social factors, which is likely the reason that negative correlations were observed for these against Survivor, article discussions, and the projects. The most surprising dimension of this is the negative correlation between social- and achievement-based motivations and Survivor, which suggests that those with a higher desire to please others and those who want to advance relative to others disliked Survivor. While the Survivor game provides immediate feedback from the professor and peers, it also tends to favor extroverted individuals (personal observation) and extroversion/introversion is likely not correlated with a desire to please others.

SUMMARY

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 towards 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. Overall, the students rated themselves as intrinsically and instrumentally motivated. Grades were de-emphasized in this course, yet student participation by all except one student was greater than the professor has seen in core chemical engineering courses she has taught. The population size was rather small (13 completed the surveys), yet interesting trends suggest learning merits in each of the four class activities.

Any individual interested in implementing these strategies or who would like course preparation materials may contact the author. The findings from this study can guide future implementations of this course by increasing time dedicated to those activities that most promote student learning. In order, they are projects,[4] articles,[2,3] and lecture. While the Survivor game was not rated as high in terms of learning merit, it was still rated higher than average (6.5 on a 10-point scale) and should remain included to complement the lectures and to introduce an element of fun into the course. In general, the inclusion of diverse learning tools into a single course is beneficial because one tool isn't sufficient to fully engage students of all learning styles.

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TABLE 5
Correlation of Students' Activity Preference (a) With Self-Rated Learning Motivator (m)

a | m	Intrinsic	Social	Achieve	Instrument
Lecture	0.01	0.02	0.19	0.25
Survivor	0.64	-0.29	-0.43	0.49
Article	0.18	-0.66	0.03	0.05
Project	0.64	-0.44	0.04	0.62

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