

# Brain-Machine Interfaces: A Team-Taught Seminar Bridging Disciplines and Fostering Discussions

AnnMarie Polsenberg Thomas and J. Roxanne Prichard  
University of St. Thomas  
apthomas@stthomas.edu, jrprichard@stthomas.edu

**Abstract** - This paper describes an honors seminar on Brain-Machine Interfaces (BMIs) taught at the University of Saint Thomas, in Saint Paul, MN. Team taught by professors in psychology and engineering, the seminar examined the applications and limitations of brain-machine interfaces from both neuroscience and engineering perspectives. The first half of the course consisted of lectures and instructor-facilitated discussions about the mechanics of brain circuitry, diseases and disorders of the nervous system, and basic electrical recording techniques. In the second half of the course, students presented formal lectures on innovations in BMI technology and discussed the ethics of such technology. Students were evaluated on weekly writing assignments, discussions, and formal oral presentations. Overall, the focus on BMI technology captivated students because of its immediate relevance to medical and military technology, and encouraged extensive and critical dialogues about the need for interdisciplinary groups to monitor this technology. This paper describes the course structure and content, quantitative and qualitative student feedback, and offers guidelines for designing a similar course.

*Index Terms* – Brain-Machine Interfaces, interdisciplinary, seminar, team teaching

## INTRODUCTION

The purpose of this course was to introduce students, both those majoring in STEM (science, technology, engineering, and mathematics) disciplines and those from other majors, to the topic of Brain-Machine Interfaces (BMI). It is the authors' opinion that students who are not enrolled in STEM programs often lack confidence and experience in understanding, evaluating and critiquing advances in engineering and technology. To empower non-STEM students to directly engage with technological ideas, and to encourage STEM students to gain experience evaluating the implications of their work from a broader perspective and communicating with a lay audience, we created a discussion-based, interdisciplinary course, open to students from any discipline. This honors seminar, team taught by professors in psychology and engineering, examined the applications and limitations of direct brain-machine

interfaces from both neuroscience and engineering perspectives.

## COURSE MOTIVATION

BMIs were chosen as the topic of this seminar for a variety of reasons. BMIs are an active area of research, with a large potential impact, that tends to capture the interest of non-scientists and scientists alike. As the STEM background of the students could not be assumed to be greater than that needed for admission to the college, care was taken to choose a topic that would appeal to a wide audience. A recent push for research on neural prosthetics has led to more coverage of the topic in the popular written press, as well as on websites such as YouTube. Additionally, BMIs have played prominent roles in feature films such as *The Matrix*. [1]

BMIs also serve as a rich springboard for discussions on a variety of topics inherent to engineering research. Topics such as public funding of research, the ethics of animal and human testing, and the compatibility of religion and science were all discussed in the course through the medium of BMIs. Finally, as has been exhibited by popular books such as *The Physics of Super Heroes* [2], there seems to be a public interest in learning the science behind various pop culture topics. As BMIs are still in the realm of 'science fiction' to many people, it was the authors' belief that this topic would prove interesting and exciting to students, regardless of their major.

## COURSE GOALS

The primary content goals of this course were to explore the biology and technology behind BMIs, their potential applications, and their ethical ramifications. The secondary skill-based goals were to increase the students' scientific literacy. Assignments were designed to familiarize students with searching for peer-reviewed scientific literature, assessing the validity of statements made in the popular media, and investigating what projects receive public funding.

COURSE LOGISTICS

The official course description, as presented to students when choosing their seminar, read:

*What if you could control your computer just by thinking about it? In this seminar, we will discuss the potential applications and limitations of direct brain-computer interfaces from both neuroscience and engineering perspectives. Brain-Machine Interfaces are no longer just plot devices for science fiction movies. In the last two years, recording electrodes have been used to move robotic arms for amputees and to suppress nausea in children with severe digestive disorders. Stimulating electrodes have been used to provide sensations of sight and sound in blind and deaf individuals. As our understanding of the neural code and nanotechnology improves, scientists will have the ability to record from and/or stimulate not just hundreds, but millions, of neurons. Is mind reading or mind control really possible? What are the ethical and practical concerns of such advances?*

This two-credit course, first offered in the fall of 2007, is open to junior and senior level students who are enrolled in the Aquinas Scholars Program at the University of St. Thomas. Students in this honors program (approximately 10% of the student population) are required to take four honors sections of four-credit classes, as well as three two-credit honors seminars. These honors seminars are discussion-based, interdisciplinary team-taught courses with a capped enrollment of fifteen students. Historically, there have been few collaborative seminars between engineering and the social sciences. In the last few years, there have been only two other School of Engineering related Aquinas Honors Seminars, only one of which was co-taught with a non-STEM professor:

- **Rise of the Machines:** A discussion on the philosophical and technical questions surrounding artificial intelligence research co-taught by Dr. Jalkio (UST School of Engineering) and Dr. Degnan (UST Department of Philosophy)
- **Mathematics and Architecture:** An examination of the mathematics inherent to the field of architecture, co-taught by Dr. Hennessey (UST School of Engineering) and Dr. Shakiban (UST Department of Mathematics)

A total of eleven students enrolled in the BMI seminar, but two students dropped within the first two weeks. Of the nine students who finished the course, one student was a computer science major and one was a biochemistry major; the other seven students were enrolled in non-STEM programs in the humanities and social sciences. The seminar met once a week for an hour and forty minutes; each week students were responsible for reading approximately 20 - 50

pages of material, and preparing a two page thoughtful reading reflection paper.

This BMI seminar was taught in a largely active learning format. Students were evaluated based on weekly writing assignments, in-class discussions, a class debate, and formal oral presentations about emerging topics in BMI technology.

The grading breakdown was as follows:

- 60% Weekly Writing Assignments
- 20% Final Research Presentation and Bibliography
- 15% Class Participation
- 5% Debate Performance

The class was organized such that a typical session would consist of roughly 40-60 minutes of instructor prepared material, such as a presentation on a new topic, the viewing of a film, or a guest lecture. The remaining time was typically used for a class discussion of either the writing assignment or the new material that had just been presented.

COURSE CONTENT

The seminar was organized around three major questions:

- Why do we need BMIs?
- How can a computer interface with a brain in a functional way?
- What are the ethical implications of BMI technologies?

TABLE I  
COURSE SCHEDULE

Session	Topic
1	Course Introduction
2	How the Brain Works
3	Stafne: Guest Lecture on ALS
4	BMIs in sensory & Motor Systems
5	The Current State of BMIs
6	Techniques in Neural Recording
7	Johnson: Guest Lecture on Neural Recording
8	Hardware Design for BMIs
9	Ethics of Personal Identity
10	Ethics of Military BMI Use
11	Debate
12	Student Presentations
13	Student Presentations
14	Student Presentations

The first class session began with the viewing of a twenty minute clip from the 1999 film *The Matrix*[1], which depicts a futuristic society in which robots keep the human population enslaved by electrically stimulating humans’

brains in a way that gives humans the illusion of free will and genuine sensory experiences.

Because this course required no prerequisites other than junior standing and enrollment in the honors program, the instructors assumed that the students would have little or no background in neuroscience, engineering, and mathematics. To give students an overview of brain function, and disorders of the brain, Brain Facts [3], a free booklet published by the Society for Neuroscience was assigned as the first reading of the seminar. This primer, written for a lay audience, covers the electrochemical communication of neurons, the basic organization of the nervous system, and the major diseases of the nervous system. For the first week's writing assignment, students were asked to discuss the feasibility of *The Matrix*'s "brain-in-a-vat" illusion in the context of what they have learned about the organization of the nervous system from their reading of the *Brain Facts* material.

In the second meeting of the class, the instructors facilitated a discussion of this material, and highlighted diseases and conditions for which BMIs could be particularly helpful. After this introduction to BMIs through fiction and to neuroscience through fact, the course focused on the motivation for BMI research. The instructors felt it was important to expose students to the human side of this technology before diving into the technical and scientific aspects of the equipment. Accordingly, the next assigned reading, the 1998 memoir The Diving Bell and the Butterfly by Jean Dominic Bauby [4], provided a moving first person account of locked-in syndrome (a condition where individuals' brains are still functioning, but they are unable to control their body). This memoir has recently been made into a critically-acclaimed feature film, so in future iterations of this course there is the option of assigning the film instead of the book.

In the third session of the course, Scott Stafne, a mechanical engineer and filmmaker, discussed his experience as a person diagnosed with Amyotrophic Lateral Sclerosis (ALS), a fatal lower motor neuron disease that leaves a functional brain locked-in a non-functional body. Scott showed the film "Legacy", an autobiographical account which he made for his children, and discussed the timeline of the disease, funding options, his friends' experiences using BMIs and his thoughts on the future of such technology. The students agreed that this visit and the reading of The Diving Bell and the Butterfly early in the course were pivotal for framing the study of BMIs as an immensely relevant topic of study. In particular, the visit with Scott Stafne allowed them to understand how meaningful BMI technology can be in the lives of real people.

The second section of the course concentrated on the neuroscience, biology, and engineering behind BMI technology. We assigned primary research articles and review papers on electrical recording techniques, algorithms for decoding neural activity, and the constraints in creating long term brain-plastic interfaces [5-8]. Specifically, we

provided students with background information about the different techniques for neural imaging and recording, and discussed the limits of what one could really know or control through brain imaging and electric stimulation. A guest lecture by Adam Johnson, a graduate student at the University of Minnesota, reinforced the limits and capacities of neural recording of higher order functions such as memory and decision making. Again, students rated this guest lecture experience as one of the highlights of the course. Writing assignments for this section of the course challenged students to contrast the relative ease of recording brain tissue to create movements in a prosthetic device versus stimulating neural tissue to substitute for physical sensations in the case of blindness and deafness.

Because many, if not most, journal articles in this field are not easily read by non-scientists and non-engineers, the instructors used a few different methods in an attempt to make the articles more accessible. These techniques included:

- Choosing review articles that emphasize application of the technology/science, rather than specific scientific details.
- Asking students to focus more on the introduction, figures, and conclusion sections of the papers. (Students who wished to understand the entire article were encouraged to meet with the instructors during their office hours, and many students took advantage of this option.)
- Asking students to highlight all words/concepts that they found confusing. At the beginning of the next class session, these words/concepts would be written on the chalkboard and explained by the instructors.

As mentioned above in course goals, assignments were designed to encourage students to develop the skills necessary to research scientific topics in such a way as to find reliable information. For example, one such assignment challenged the students to:

*Find a peer-reviewed article or conference presentation that uses some form of neural imaging or neural recording to 'mind-read' (i.e, 'discover the neural correlates of') a complex human thought, emotion, or disorder... After reading this article, evaluate 1) to what extent the conclusion/discussion section is supported by the actual results, and 2) discuss whom might benefit or suffer from such technology. Please attach an abstract of the article with your response. The website [www.pubmed.gov](http://www.pubmed.gov) is a good search engine for peer-reviewed scientific literature. If you have trouble finding an article, please let us know and we can help you find one.*

STUDENT FEEDBACK

In the final section of the course, students presented formal lectures on innovations in BMI technology and discussed the ethics of such advancements. Readings for this section of the course were largely drawn from the 2006 book Mind Wars: Brain Research and National Defense by ethicist Jonathon Moreno. In lieu of one of the weekly writing assignments, students divided into teams to debate both sides of the following topics:

- Scientists should be allowed to develop BMI technology (both stimulating and recording) as far as technologically possible, as long as the human subjects are willing participants.
- Military development and use of BMIs, for offensive and defensive purposes, is appropriate use of this technology.

Following both debates, the class discussed the strengths and weaknesses of both sides' arguments. Given that all of the students at the University of St. Thomas are required to take two semesters of Philosophy and three semesters of Theology, students were both well prepared and eager to discuss the ethics of BMIs from an academically rigorous perspective. Many of the students drew on material from their other courses to help make their points in the debates. This proved to be a lively exercise and an effective means for fostering discussion.

The final three class meetings were dedicated to student presentations. For this project, students were asked to pick any BMI related topic of interest and create a 15 minute PowerPoint presentation on this topic. Their research for the project had to include at least three sources, including two peer-reviewed books or articles. The students in the fall 2007 class chose the following topics for their presentations:

- BCI2000: General Purpose BCI System
- BMI Technology: Deep Brain Stimulation
- Brain-Machine Interfaces in the Gaming and Entertainment Industry
- Brain Port: The Eye of the Tongue
- The History and Early Work of BMIs
- The Cochlear Implant
- BMIs and Operation of a Prosthetic Arm
- Funding for BMIs: Public and Private Development
- Optical Brain Machine Interfaces

These student project topics provided a mix of depth in presentations that focused on a specific BMI, as well as breadth in presentations that examined the wider impact of BMIs. The project also allowed students to spend time researching a topic of personal interest. For the following class, students were asked to pick one of that day's presentations and write a 1.5 page response. This assignment was intended to increase audience alertness during the presentations, as well as foster further reflection on the topics.

Students gave feedback on the seminar through anonymous surveys. Based on the students' written comments, the focus on BMI technology captivated students because of its immediate relevance to medical and military technology, and encouraged extensive and critical dialogues about the need for interdisciplinary groups to monitor this technology. When asked what they liked best about this seminar, one student wrote *"the chance to discuss topics I don't normally come across in my majors, with more variety of opinions than I am usually exposed to."* This, at least anecdotally, suggests that the course was successful in fostering discussion that broadened the students understanding of cutting edge science, and the issues surrounding it.

One trend that became clear was that nearly all (eight of the nine) students admitted to taking the seminar because it fit their schedule and fulfilled the seminar requirement of the honors program. As this was the first time the BMI seminar was offered, this was not unexpected. The initial lack of student interest may also reflect the students' inexperience with STEM topics; very few of the honors seminars are STEM-related. One student's comment that *"Maybe noting in the brief class description that being an engineering major is not necessary to take this seminar would draw more students"* hints at the possibility that students were intimidated by the topic. This may have contributed to the low enrollment numbers.

Students were asked to rate how useful various course components were in achieving the content goals of the course. Specifically, the goals were to address:

- A. The biology and technology behind BMIs
- B. The applications of BMIs
- C. The ethics of BMIs

Students answered on a scale of 1-5, where 1 is not at all helpful and 5 is very helpful. The mean scores are shown in Table 2.

TABLE 2  
STUDENT FEEDBACK

	A	B	C
<b>Readings</b>			
Mind Wars	4.56	4.67	4.11
Diving Bell and Butterfly	1.67	4.33	2.44
SFN: BrainFacts	3.67	2.22	1
Other Articles	4.11	4.22	3.28
<b>Lectures</b>			
ALS Guest Lecture	3.11	4.67	3.33
Neural Modeling Guest Lecture	4.56	4.33	1.88
Instructors' Presentations	4.11	4.22	3.22
<b>Assignments</b>			
Class Discussion	3.89	4	4.44
Weekly Papers	3.55	4	3.55
Debate	1.22	2.88	4.33
Mini Research Project	4.11	3.88	2.11
Final Project	4	4.67	3.11

From this feedback, it became clear that reading and discussing Mind Wars, and the neural modeling guest lecture were the most helpful activities in understanding the biology and technology of BMIs. While reading the other articles was also scored highly, it is possible that Mind Wars received a higher ranking due to the fact that it was written for a lay audience, and thus a bit more accessible to the students than the peer-reviewed journal articles.

For learning about the applications of BMIs, Mind Wars, Scott Stafne's guest lecture, and the final project were ranked highest. Interestingly, these three items all covered different aspects of BMI applications. While Mind Wars focused almost solely on the military applications of BMIs, Scott Stafne's guest lecture dealt with rehabilitative and medical uses for BMIs. As one student's comment on the course read, "I really like when we were able to personalize the technology and see how it could help a specific person." The final projects, as evidenced by the list above, covered a wide array of applications.

It is clear from the student responses that classroom discussion was the most effective method of addressing the ethical issues inherent to BMIs. Ethical concerns tended to bring out the most active and passionate student responses. As one student wrote, "Class discussion was great and was where I got the most out of it."

The most adamant negative comments dealt with the amount of work assigned to the students. Many students commented on having had difficulty reading the assigned articles. The measures to address this, mentioned in the Course Content section above, may not have been enough. One possible solution is to only present the Introduction and Conclusion sections of some of the more difficult articles. Another option is to choose less challenging articles. In general, summary and "state of the art" articles seemed to pose less difficulty than journal articles that focused on a specific method or technology. On open-ended assignments where students had to find their own articles, there were a few instances of students choosing articles which were above the level that they could comprehend, leading to student frustration. However, the process of searching for a peer-reviewed article on a topic that they are interested in seemed to be a great exercise for students, many of whom were unfamiliar with how to find scientific articles using library database resources.

## CONCLUSIONS

While most of the students in the 2007 iteration of this seminar admitted to being there only because it fit their schedule, and not due to any interest in the topic, the Brain-Machine Interfaces honors seminar seemed to have been reasonably successful in capturing students' interest. Students were exposed to some of the science and technology behind cutting edge BMI research, and encouraged to think about the ethical and societal effects of such work. This course will be offered again at the University of St. Thomas in the spring of 2009.

## ACKNOWLEDGMENT

This seminar was supported by the University of St. Thomas' Aquinas Scholars Program.

## REFERENCES

- [1] Wachowski, L, and Wachowski, A. (directors), (1999) *The Matrix*, United States: Warner Brothers.
- [2] Kakalios, J. (2005) *The Physics of Superheroes*. Gotham.
- [3] *Brain Facts: A Primer on the Brain and Nervous System*. Society for Neuroscience. (2006)
- [4] Bauby, J.D. (1998) *The Diving Bell and the Butterfly*. Vintage.
- [5] Lebedev, M.A., and Nicolelis, M.A.L. (2006) "Brain-machine interfaces: past, present and future", *TRENDS in Neurosciences*, 29, 9, 536-546.
- [6] Nicolelis, M.A.L., and Chapin, J.K., (2002), "Controlling Robots with the Mind," *Scientific American*, 46-53.
- [7] Hoag, H., (2003) "Remote Control," *Nature*, Vol. 423, 796-798.
- [8] Cham, J.G., Branchaud, E.A., Nenadic, Z., Greger, B., Anderson, R.A., and Burdick, J.W., (2004) "Semi-Chronic Motorized Microdrive and Control Algorithm for Autonomously Isolating and Maintaining Optimal Extracellular Action Potentials," *J. Neurophysiology*, Vol. 93, 570-579.
- [9] Gillett, G., (2005) "Cyborgs and moral identity," *J. Med. Ethics*, 32, 79-83.
- [10] Moreno. (2006) *Mind Wars: Brain Research and National Defense*. Dana Press.

## AUTHOR INFORMATION

**AnnMarie Polsenberg Thomas**, Assistant Professor, Engineering, University of St. Thomas, [apthomas@stthomas.edu](mailto:apthomas@stthomas.edu)

**J. Roxanne Prichard**, Assistant Professor, Psychology, University of St. Thomas, [jprichard@stthomas.edu](mailto:jprichard@stthomas.edu)