Semi-Flipped Learning Modules with Educational Design Patterns in Interdisciplinary Brain-Inspired Computing Course

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ABSTRACT

A new multi-disciplinary Brain-Inspired Computing course is developed for students majoring in Computer, Electrical and Micro-systems engineering. This interdisciplinary course entails short learning modules from four different disciplines and serves as an ideal candidate for a Semi-Flipped learning model. Such student-centric learning model enabled active student participation, enhanced critical-thinking development, and improved learning outcomes. For the first time, educational design patterns were introduced in a multi-disciplinary engineering curriculum to bring expert domain knowledge to students. This paper presents the motivation and methodology for these models.

Categories and Subject Descriptors

K.3.2 [**Computers and Education**]: Computer and Information Science Education

Keywords

Flipped classroom model, Design Patterns, Brain-inspired computing

1. INTRODUCTION AND MOTIVATION

Over the past few decades, pedagogical literature demonstrates that unidirectional learning through in-class lectures provides limited opportunities to develop essential skills and most often also results in lack of attention [12, 19, 1]. In tandem, a growing body of literature highlights the need to introspect our current learning models and redesign new pedagogical practices that foster higher-order thinking and enhance opportunities for active and applied learning [18, 4, 13, 10, 5].

Student-centric learning models, such as flipped learning, enable increased student engagement with the learning process, enhance critical-thinking development and improve learning outcomes[10, 5, 3]. Using a hybrid model, which encompasses computer-mediated instruction along with faculty mentoring, peer engagement enables constructivism [5, 3]. Active learning models, view knowledge as a continuous evolving stream of information and are dynamically constructed by both the learner and the facilitator.

In a traditional flipped model, most of the direct instruction is delivered outside the learning space either using video or other modes of delivery [3]. Instructor then provides guidance, motivation and one-one mentoring in the learning space. Employing such a fully flipped model for an interdisciplinary brain-inspired computing course, where the learning modules span across four disciplines, is limiting in several aspects. There is a continually evolving phase in the conceptual learning from one module to the other, and learning threads that connect across modules are not transparent. A semi-flipped model, which is still an inverted pedagogical model, offers more flexibility on the intentional content and to develop active interactions which transpose the learning threads across disciplines. Another challenge with this interdisciplinary course offering is the domain expertise required in different disciplines. A single instructor will typically be not equipped with such a deep knowledge base and didactical models can be counterproductive. To address this at inception we adopted the educational design patterns in conjunction with the semi-flipped model. Educational design patterns are growing significantly over the last decade in several pedagogical domains including Cognitive neuroscience, Computer Science, Software Engineering, and networked learning [6, 9]. To the best of our knowledge there is no other comprehensive brain-inspired computing course, which covers multiple disciplines with demonstrated application of educational design patterns.

In this paper, we provide an initial framework for developing such a course and the scalable design pattern. The rest of this paper is organized as follows: section 3 describes the educational design patterns, section 4 presents an overview of the course structure and design, section 5 emphasizes the preliminary evaluation methodology, and section 6 presents concluding summary.

2. BRAIN-INSPIRED COMPUTING COURSE DESIGN

The notion that the brain is fundamentally an intelligent prediction machine has been gaining more traction recently in the computing and neuroscience research communities. Brain-Inspired Computing is a new special topics course offered in the Department of Computer Engineering with 24 students (from Electrical and Microelectronics Engineering and Computer Engineering). This course is a cross-listed graduate/undergraduate research emphasized course and the learning modules covered in this course are shown in Figure 1. There are five different modules with emphasis given to the large-scale system level designs, that aggregate the concepts learnt in all the previous modules. Introductory class covered a high-level overview of the interaction between different disciplines along with a quantitative and qualitative comparisons with the brain are presented. There are several datapoints shown to reinforce this concept. Figure 2 shows an example of the computational capability of the brain in comparison with a supercomputer which forms a motivating information to understand the brain computing in depth. The robustness and the power dissipation of the brain are so efficient compared to any of the traditional computing systems, with a very small form factor. At this point, students envision that mimicking the brain will be a viable approach to achieve the same levels of efficiency. It is the instructor's undertaking to emphasize the fact that this course focuses on emulating the behavioral aspects of the brain with specific focus on the visual Pathway. We flip these modules for generating multi-faceted knowledge base.

Lecture	Topics
Lecture 01	Introduction to brain-inspired computing
Module 1	**Limitations of Conventional Computer Architectures**
Lecture 02	von Neumann basics and limitations
Lecture 03	Non von Neumann (harvard and memory-based architectures)
Lecture 04	Bio-inspired architectures
Module 2	**How the Brain Computes**
Lecture 05	Potential of brain-inspired computing and historical perspective
Lecture 06	Overview of neuroanatomy
Lecture 07	Basic neurophysiology
Lecture 08	Plasticity
Lecture 09	Guest lecture
Lecture 10	Module 1 presentations
Module 3	**Brain-Inspired Machine Learning Algorithms**
Lecture 11	What is machine learning and why hardware?
Lecture 12	From brains to neural networks
Lecture 13	Linear and logistic regression
Lecture 14	MLPs and backpropagation
Lecture 15	Topologies and applications
Lecture 16	Module 2 presentations
Module 4	**Neuromorphic Circuits**
Lecture 17	Neuromorphic circuit basics
Lecture 18	Synapse and neuron circuits
Lecture 19	Training circuits
Lecture 20	Networks and design challenges
Lecture 21	Guest lecture
Lecture 22	Module 3 presentations
Module 5	**Survey of Large-scale Brain-inspired Systems**
Lecture 23	Hierarchical architectures
Lecture 24	Large-scale chips
Lecture 25	Large-scale chips
Lecture 26	Large-scale chips
Lecture 27	Guest lecture
Lecture 28	Module 4 presentations
Lecture 29	Module 5 presentations
Lecture 30	TBD
Finals Week	Projects due

Figure 1: Overview of the modularized course syllabus for the brain-inspired computing course.

The interdisciplinary nature of this course entails learning modules from different disciplines, some of which are unexplored terrain for the students. There is an underlying research thread for all the modules. Moreover, learning modules also intersect with more than one discipline that is vital to understanding the aggregate concept. For example, the neuroanatomy and neurophysiology modules of this course are not part of a typical engineering curriculum. Within this field there are at least 100 different synapse designs that are available, depending on which aspect of the brain we are focusing on. Figure 4 and 3 show the preliminary introduction of these concepts in the course. Though these are the abridged versions of the actual designs, students require reinforcement of the topic through the use of different design patterns. For this specific topic, flipping the module itself was not sufficient. Students typically have minimal exposure to these concepts in their high-school curriculum, and a distant memory for most. For such topics, it is vital to contact domain-experts who can provide guidance to the instructor in developing digital content. We identified recurring design patterns that integrate systematic, interdisciplinary scientific research into scalable learning modules. Another important challenge is to present the topics from different disciplines at varying granularities, depending on the correlation to the overall course outcomes. For example, the alternative computing architectures topic is a motivating lecture to the Brain-Inspired Computing paradigm. However, due to the wide range of advanced computing paradigms (e.g.: stochastic, chaos, and approximate) it is not feasible to go over them in-depth during the class-time. We have provided a case-study and application for the important paradigms along with mandatory reading of expert models such as white papers. In all these cases it is important to show the translation from intent to scientific research question. We tied this through system-level application concepts taught in the last module. One of the systems was a large, randomly connected, recurrent network which is similar to the random connections in the human brain. There are two networks in this system and both are elucidated in Figure 5, an Echo State Network and a Liquid State Machine. These state-of-the-art systems incorporate conceptual basis from both neuroscience and machine learning.

By identifying the pivotal concepts of Brain-Inspired Computing, we were able to classify concepts and skills into the following interdisciplinary themes: i) new computing paradigms ii) Neuroscience modules iii) neuromorphic circuits iv) Machine learning v) architectures and systems. This study explores a teaching approach that integrates educational design patterns and facets of a semi-flipped classroom for an enhanced student learning.

3. EDUCATIONAL DESIGN PATTERNS

In 2012, Dr. Howard Gardner a world-renowned developmental psychologist (who has pioneered multiple intelligence's framework) has published a research article, which addresses an important question on "How can research in the special sciences (neuroscience) and insights from educational practice both inform a science of education?"[7]. He proposed the use of educational design patterns to overcome the obstacles in developing sustainable interdisciplinary science of education, along with explanatory models by educator's and domain-experts. Design pattern is a description of a recur-

	Human Brain	Conventional Computer
Size	≈2.17 l	≈204 m^2
Weight	≈3 lbs	≈6 tons
Power	≈20 W	≈87 kW
Latency	≈200 ms	≈200 ms
Robustness	Excellent	Poor

Figure 2: A quantitative comparison of the computational capabilities of the human brain Vs modern supercomputer (overestimation's/underestimations deemed in certain parameters).

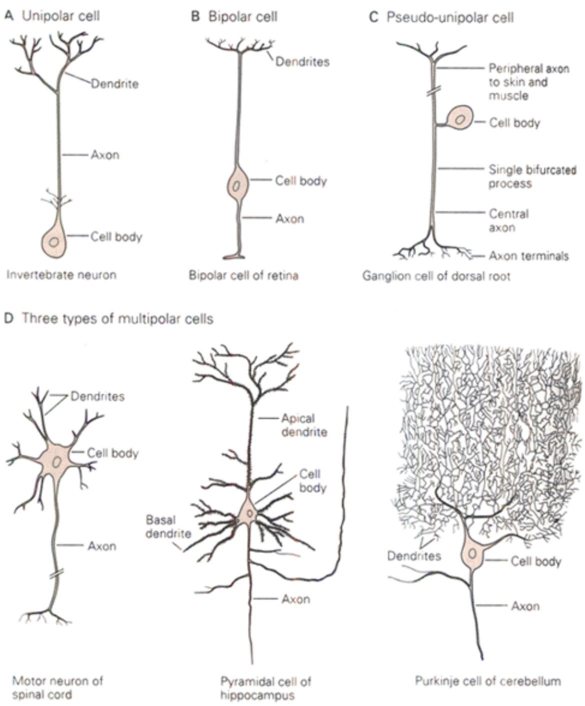

Figure 3: High-level representation of the different basic types of Neurons[15].

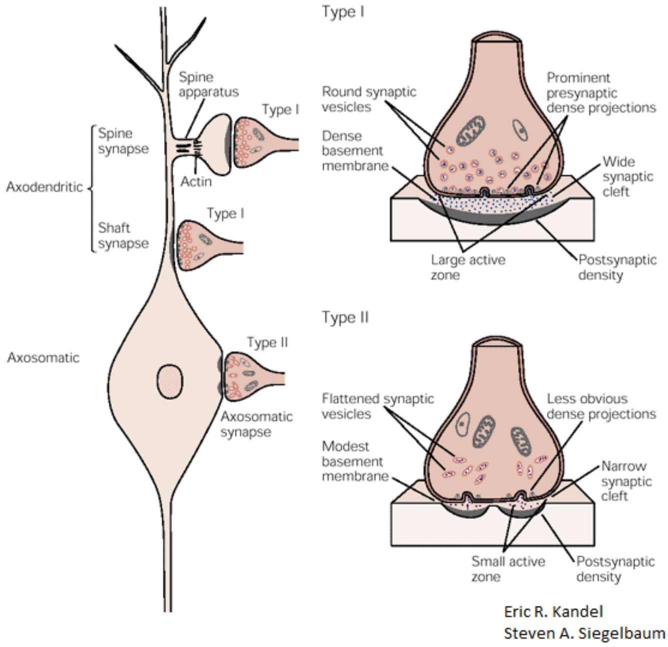

Figure 4: Overview of different types Of synapses that are present in the brain[15].

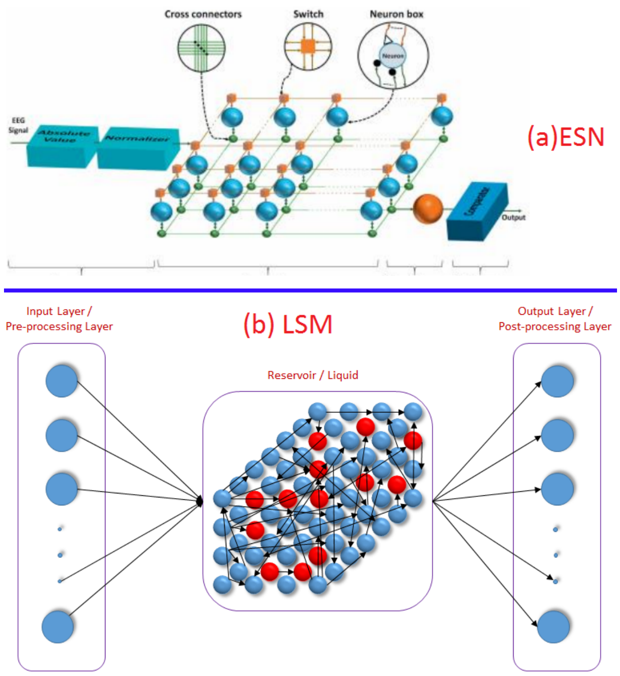

Figure 5: Overview of brain-inspired computing paradigms, that are inspired by the random synaptic links in the brain.(a) Echo State Network and (b) Liquid State Machine[16, 14, 2].

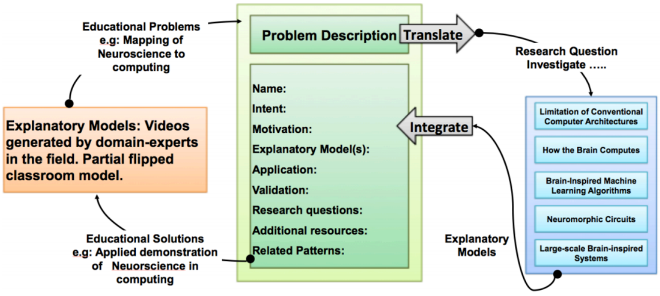

Figure 6: Educational Design Pattern Template for the Interdisciplinary Brain-Inspired Computing Course.

ring problem and a general solution to the problem in such a way that you can employ this solution flexibly over several contexts. According to Dewey [8], design patterns can marshal interdisciplinary dialogue, providing a practical framework for supporting the synthesis of insights from multiple disciplines such as computing, cognitive neuroscience, and educational practice.

Figure 6 demonstrates the overarching design pattern template that was developed for the Brain-Inspired Computing Course based on [7]. In this exemplary case, we build on explanatory models from neuroscience and neurophysiology. One of the explanatory models that was used was "FMRI to study brain organization", developed by Dr. Brad Mahon from Brain and Cognitive Sciences department at University of Rochester. As a domain expert and deeply interested in advancing the reach of his research, Dr. Mahon's module was context rich and apt in depth. Based on this explanatory model, we have developed a research problem for the students and integrated it into a learning assignment. We evaluated this research problem and 100% of the students demonstrated thorough understanding of the concept. The design pattern that we used with this explanatory model is known as "perceptual accessibility", similar to the one proposed by Gardner [7]. This design pattern is designed to address the inflexibility of educational content bound with one particular delivery mode, particularly to the mode when it was first generated. The intent is to *"separate the storage medium of educational content from its delivery mode so that the content and its delivery mode can be changed independently of each other"* [7]. The explanatory model that was used with this pattern is shown in Figure 7.

4. SEMI-FLIPPED LEARNING MODULES

For the aggregate concept students are taught traditional classroom lectures along with domain specific topics (loosely tied to students and/or instructors current discipline) accessed through various online resources [4]. For example, we flipped the class for the neuroanatomy sessions and students were referred to the expert digital media content (e.g.: TED Talks, Coursera modules, white papers) for an efficient conceptual understanding. The flipped sessions are substantiated with different video-content generation tools.

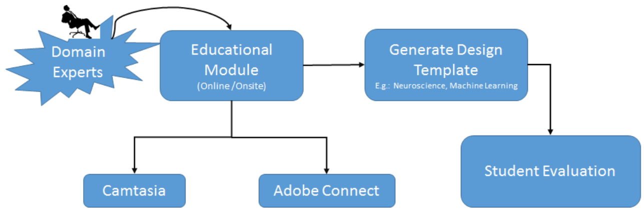

Figure 7: Explanatory Model with Semi-Flipped learning modules.

4.1 Video Content Generation

In the present market a wide range of software suites are available to produce screencasts for video tutorials [11, 17]. Camtasia studio, camstudio, Jing, EZVid, FFsplit, Fraps, and Screenr are few of the competing available tools. Lot of initial time was invested in experimenting with different educational software tools, to determine their pros and cons with respect to our specific use. While some of these tools are open-sourced, some are limited by bandwidth or content-generation and editing capabilities. We have selected 'Camtasia Studio' for video-production. We can create video files and also turn them into bandwidth friendly Streaming Flash videos. This content remains close to the native learning space and snapshots of important concepts are captured. There is also a campus-wide adoption of the software recently, which is beneficial for sustained use of this software. Intermediate feedback from students helped in regulating the speed, clarity, duration, details within each topic. A considerable amount of time was spent in post processing to ensure high quality modules. The content generated was all posted on the online portal for students to easily access outside the learning space. Attention was paid to ensure that the students are actively engaged in the learning by connecting back to the design patterns.

4.2 Dynamic Video Rendering

In one of our explanatory models, the domain experts presented a dynamic online explanatory model of a system level concept. We have used Adobe Connect software to populate this learning module. An interactive session with 'Adobe connect' provided a vibrant forum and Cartesian logic derivatives were initiated for rich discussions. Some of the fundamental questions that are asked in these sessions are: i) what would happen if you did use brain-inspired computing in emerging systems? ii) What would happen if you did not use brain-inspired computing in emerging systems? The explanatory model shown in Figure 7 describes how we used it in the course with a forward flow to the student evaluation.

5. MODEL EVALUATION

By creating tactile and independent modules using semi-flipped model, we also support students in building good analytical reasoning for big-picture problems that overlap across multiple disciplines. The modality of evaluation included both conventional methods and research methods. The course is divided into five modules and each module had a culminating assignment and a team-based research topic presentation. By identifying design patterns to teach these modules, we can develop more advanced exercises for in-class room and provide agility in learning medium and inquiry. In fact, by identifying the right patterns, students would be motivated to go back to the scientific theory in order to better understand the applied problems. We have persistently observed that students struggle with abstract/theoretical concepts in computer engineering curriculum and use "Pitfall diagnosis and Prevention"design pattern to improve the understanding and engagement. Usage of digital content in classroom coupled with current industry adoption of this topic showed highly positive response rate for these topics. This also avails additional instructor student time in the classroom and considerably improves the quality of their team-based projects.

The evaluations were also performed on team presentations which intersected topics across multiple learning modules, and a final conference paper article which is based on the student team‘s original research. Students from this course have already submitted two conference papers, a workshop paper, and one student has used this research as a baseline for his Master‘s thesis. Following are some of the feedback comments from the students *i) Multidisciplinary topics were taught in the class which gave a brief idea about the Neuroscience computing field. ii) These videos were useful to review the materials. They were good references. iii) Information was presented in a clear and concise manner. iv) I really liked the special guests that came in.* Few of the students felt the content was increasingly challenging as we were covering multiple disciplines. It was reflected in the feedback. For example, one of the reviews was *i) By not having very high expectation of the students.*

6. CONCLUSIONS

This course began with a goal of bringing interdisciplinary research topics closer to graduate students, using student-centered learning methods. Enhancing such models will provide a virtuous cycle of progress in pedagogy. The pilot framework that was developed for this course has to go through several development cycles before reaching a steady state. We showcased that the concept of design patterns and explanatory models can be equally beneficial outside the neuroscience community.

7. ACKNOWLEDGEMENTS

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