AC 2011-1725: THE OUTCOMES OF AN INTERDISCIPLINARY UNDERGRADUATE COURSE INVOLVING ENGINEERING, SCIENCE AND ARTS

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The Outcomes of an Interdisciplinary Undergraduate Course Involving Engineering, Science and Arts

Abstract

An interdisciplinary undergraduate course that simultaneously involves the disciplines of Engineering, Science and Arts has been created and offered every semester since the Fall 2009 at our college. This course uses a robotic conducting system as a vehicle to bring together students majoring in mechanical engineering, computer science, interactive multimedia and music, and encourages them to share their knowledge and reach across the boundaries of their own disciplines. It is a project-based course that fosters creative problem-solving approaches, and advances computational thinking skills through an open-ended project requiring the synthesis of knowledge in robotics, interactive multimedia, computer science, and music. The model and implementation of the first offering of this course were presented in the 2010 ASEE Annual Conference and Exposition. This paper presents the outcomes of all the past three offerings including evaluations and assessments, our findings, and student deliverables. These analytical results will improve our understanding of effective approaches to teaching interdisciplinary courses that involve engineering and non-engineering disciplines in undergraduate collaborative problem-solving environments.

1. Introduction

Interdisciplinary education is becoming increasingly important in preparing undergraduate students to be able to participate in the emerging knowledge-based economy and meet complex social demands in the modern world[1,2,3,4]. It has grown at a progressively rapid rate in recent decades. More and more universities and federal funding agencies have set their initiatives in favor of and prioritized investment in interdisciplinary curricula and research activities[5]. The development of the course presented in this paper has been motivated by this trend.

Interdisciplinarity is acknowledged as an effective educational approach to engage students in critical thinking and synthesis beyond the capacity of a single discipline or major, and cultivate creative ideas, solutions and activities[1,2,6]. As these skills are crucial to engineering students, engineering educators particularly endorse this approach, and recognize interdisciplinarity as a critical component of modern engineering education[7]. Although a variety of interdisciplinary courses for engineering curricula have been developed[7,8,9], there still remains a lack of courses that involve disciplines that are fundamentally different from engineering such as arts, humanities, and social science. The course presented in this paper is an innovative example of a course that simultaneously engages the disciplines of engineering, science and arts.

This course, titled "Conducting Robots," uses an autonomous (robotic and/or graphic) musical conducting system as a vehicle to bring together students majoring in Mechanical Engineering (ME), Computer Science (CS), Interactive Multimedia (IMM) and Music in the same class. It is a project-oriented course that fosters critical thinking, creative problem-solving, and computational thinking skills through an open-ended team project requiring the synthesis of knowledge in all four core disciplines. Students work collaboratively to design and develop innovative robotic and graphical conducting systems that can direct an orchestra. Topics taught include robotics, visual music, abstract animation, computer vision, algorithms, data processing, music conducting, and project management.

2. Course Structure

The Conducting Robots course is one-semester course that has been offered three times, in the semester of Fall 2009, Spring 2010 and Fall 2010. It is a cross-listed elective course in the departments of ME, CS, IMM, and Music, and was taught by a team of four instructors, one from each department (the authors). Throughout the semester we worked with an independent evaluator to develop and administer student surveys and interviews. Students were asked to keep a reflection journal. The detailed information on course model and implementation are described in our paper published in the 2010 ASEE Annual Conference and Exposition[11]. A few highlights on course structure and enrollments are listed as follows:

Course Objectives

Enrolled students have different backgrounds, concentrations and goals. We established individual course objectives for each major based on their disciplinary background, as well as common course objectives for all students.

Assignments

There are graded individual homework assignments and graded teamwork assignments. The graded individual homework assignments require knowledge of robotics, algorithms and data structures, conducting, music visualization and project management. They are mainly used to assess technical knowledge related course objectives. These assignments are required to be completed by all students individually regardless of the nature of the homework and students' majors. By emphasizing the identical treatments for all students on these individual assignments regardless of their major, we created opportunities and motivation for students from different majors to interact and communicate with each other. Students were strongly encouraged to seek advice from peer students for assignments that were not in their fields. The graded teamwork assignment was used to evaluate the students' skill, hands-on experience, interdisciplinary collaboration, and certain technical knowledge related to the course objectives. The assignment included a 20-page final report, a 15-minute final presentation, and a working prototype.

Music Conducting Background

Many of the students were not very familiar with classical music, numerous opportunities were provided to give them exposure. In addition to the regular weekly class meetings, students were required to attend rehearsal sessions of our college Orchestra. The instructors arranged for a group trip to attend classical concert such as the Philadelphia Orchestra conducted by Charles Dutoit at the Kimmel Center in Philadelphia. The conductor of our college Orchestra served as a consultant on this project, and made himself personally available to the students for interviews and discussions about conducting technique.

Guest Speakers

Guest speakers were invited to provided expertise in different areas required by our project.

Enrollments
It is ideal to have a cap of 20 students for this class with five students from each major. However, this course involves students from four different departments in three different schools. It is extremely difficult to find a common time to fit majority of the eligible students for this class. The same situation is true for the four instructors. The actual enrollments for the past three offers are listed in Table 1.

Table 1: Enrollments

Enrollments	ME	CS	IMM	Music	**Total**
Fall 2009	3	7	5	5	**20**
Spring 2010	6	3	3	5	**17**
Fall 2010	5	4	6	1	**16**

3. The Outcome on Team Dynamics

The main theme for this course is that students work collaboratively to design and develop innovative robotic and/or graphic systems that can conduct a music ensemble. Multidisciplinary teams of four to six students are formed in the first week of the class. Every discipline was represented on each team with of few exceptions due to the lack of certain majors.

Students were asked to keep biweekly confidential reflection journals that documented whether they were aware of "aha" experiences, and who they learned from throughout the semester. The journals were collected by an independent evaluator who also summarized the results for the instructors. These journals show that teamwork changed students' perception of their own, as well as the other disciplines. Music majors started out intimidated by the technical majors to whom they referred to as "smart" majors. The realization that these majors didn't have any background on music and conducting was an important boost to their confidence. Students saw quickly that conducting systems could not function without musical expertise. While engineering and IMM majors came in knowing exactly what their task would be (build a robot or create a visualization of the music), they had to work with the music majors to understand the functionality of the system that was being built.

In addition to reflection journals, students are asked to assess their own and their teammates' teamwork, using a rubric developed based on [10]. This assessment, together with the instructors' perception of students' individual teamwork, was used to determine individual final grades in the course. The attributes in the rubric were:

- Process – includes caring about goals, exhibiting leadership skills, helping the group in setting and meeting goals, and exhibiting consistent on-task behavior
- Communication – includes sharing ideas, encouraging other group members to share ideas, listening skills, incorporating comments
- Interpersonal skills and social interaction – includes involving the whole group in problem solving, actively working together with the group, being aware and respecting the views and opinions of others, empathizing with others' ideas and feelings
- Contributions – includes contributions to decision making, work, and evaluation

- Responsibility sharing – includes active participation, completion of assigned tasks, and ensuring that responsibilities are evenly assigned

Since the evaluations were anonymous and instructors were the only ones able to read these evaluations, students did not hesitate to pinpoint those who did not contribute enough to their team.

Students were required to complete this form online. Each attribute was scored on a scale of 1 (weak), 2 (adequate), 3 (Good) to 4 (excellent). The frequency analysis results can be generated automatically by the online form. They show the percentage on the rating of the "good" to "excellent" on all these attributes is range from 82% to 98% for the past three offers. Figure 2 only gives the percentage on the rating of "Excellent", which ranges from 53% to 84%. These frequency analysis results indicate that most students rated their teammates as good or excellent. The results also show that students can work well in a multidisciplinary team.

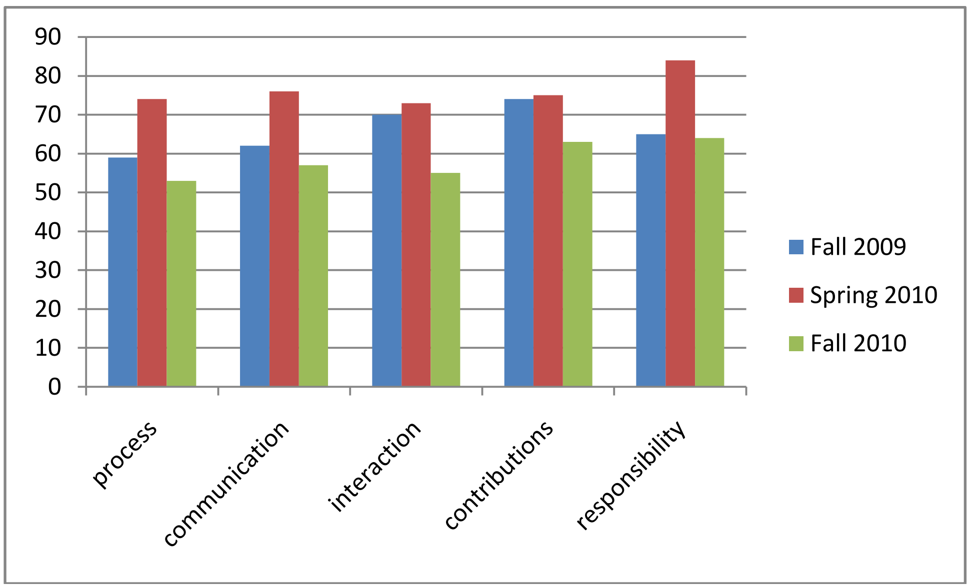

Figure 1. Percentage of teamwork attributes evaluated as "Excellent"

4. Course General Survey Results

A general survey related to the goals and objectives of this course has been conducted at the end of the class. The questions involve the knowledge expansion, interesting, challenging, problem solving ability, creativity, confidence, contribution and impact. They are rated on a scale of 1 to 10 where 1 stand for Not Much At All and 10 is An Extraordinary Amount. The average rating for all the questions ranges from 4.8 to 8.1. Most of them are above 6. The detailed survey questions and results are listed below.

(1) How MUCH did you expand your horizons with respect to the amount you know about the OTHER three disciplines? Which other discipline did you learn the most about?

All students reported that they learned about the other disciplines. The average rating was 6.3, with both the median and the mode is 7. They reported learning the most about Music and Mechanical Engineering.

(2) *How MUCH did you expand your horizons with respect to the amount you know about your OWN discipline?*

Students reported learning less about their own discipline. The average rating was 5.3, the median was 5, and the mode was 2.

(3) *How INTERESTING did you find this course?*

Students reported finding the course very interesting. Average rating was 8.1, with both the median and mode at 8.

(4) *How CHALLENGING did you find this course?*

Students reported finding the course moderately challenging with the average rating at 7.4. The mode was 5, the median 6.

(5) *How HELPFUL was the cross-disciplinary environment for the PROBLEM SOLVING needed for needed for completing assignments??*

Students reported finding the cross-disciplinary environment very helpful in completing the homework and developing the project. Average rating was 6.5. The median and mode were both 8.

(6) *How MUCH did the cross-disciplinary team environment increase the CREATIVITY of your solution?*

Students reported finding the cross-disciplinary environment quite helpful for increasing the creativity of their project solutions. The average rating was 7.4, while the mode was only 5, the median was 7.

(7) *How MUCH CONFIDENCE did you gain in your own discipline as you explained it to your team members?*

Students reported only moderate gains in confidence in their own discipline. Average rating was 6.1, the median and mode were both 7.

(8) *How MUCH were you able to make a contribution to the project in a discipline outside your own?*

Students reported making only moderate contributions in disciplines outside their own. Average rating was 6.0, while the mode was 4, the median was 6.
A *multidisciplinary* approach modifies this scenario through the participation of specialists

from different fields who have the necessary skills to communicate with each other and produce a collaborative solution through a common perspective

(9) *How MUCH IMPACT has participating in this course had on what you plan to do after you graduate?*

Students reported that the course had only moderate impact on their plans after graduation. The average rating was 4.8, with a tri-modal distribution (2, 5, and 6). The median was 5.5.

(10) *Would you RECOMMEND this course to others?*

Students were enthusiastic about recommending the course to others. The average ratingwas 7.7. The median was 9, the mode was 10.

The general survey results indicate the developed interdisciplinary course involving engineering and non-engineering disciplines is interesting and challenging. It motivates students to share their knowledge and reach across the boundaries of their own disciplines. The interdisciplinary approach fosters creative problem solving through the participation of specialists from different fields who have the necessary skills to communicate with each other and produce a collaborative solution through a common perspective.

5. Students Reflection Journal

The course objectives are also assessed through students' confidential testimony in the format of biweekly reflection journals. An independent evaluator oversaw the students' reflection journals. Students sent their reflection journals electronically directly to the independent evaluator who summarized their contents and reported the summary back to the instructors with no identifying information, so the instructors did not know who wrote what.

Students wrote journals biweekly reporting the most important thing they learned in each class and who they learned it from. They also documented their "aha" moments (i.e. a breakthrough moment, when new understanding "fell into place"), along with what conversation, interaction or activity lead them to a different way of looking at or solving an issue with respect to a class assignment or course related problem and challenge. These biweekly feedbacks had provided instructors with timely and constructive suggestions to the course developments, and led to several significant changes of class direction.

All the students reported "aha" moments during the semester and that they had a better understanding and appreciation of the other disciplines. The majority of the students said they learned different ways to look at or solve a problem through conversation or interaction with students from the other majors.

6. Prototypes Delivered by Students

The final objective of the course was to have students build non-human conductors that could conduct an orchestra. The minimum requirement was that each system should indicate beat patterns, tempo, dynamics and cueing to a human ensemble in real-time. The system can conduct one to three minutes of a piece. The pieces for Fall 2009 and Fall 2010 were selected by the conductor of our college orchestra. Students select their own pieces for the Spring 2010. The prototypes were tested with our college's Orchestra at the end of the semester, and were evaluated by both the orchestra musicians and an external faculty Advisory Board.

All kind of prototypes have been designed and built by the students. None of them are the same. Some of them are very innovative and created a new mode of conducting. A total of eleven prototypes were generated. They include humanoid and none-humanoid robotic conductors, abstract and humanoid graphical conductors. All kinds of available materials and software are used. Some were built from scratch and others were built using robotics tool kit such as LEGO NXT and VEX.

Figure 2 shows three different conducting systems developed by students in the Fall 2009. *C3* (*Cybernetic Conducting Contraption*, left) was built using the Lego Mindstorms NXT robotic kit, and had two arms. The right arm had two degrees of freedom and was used to conduct beat and dynamics; the left arm had one degree of freedom and was used for cueing. *C3*'s functionality was constrained by the limitations of the NXT kit, which can control only up to three motors.

Ahasimo (middle) was a non-humanoid graphic conductor implemented in Processing. It conveyed beats by means of two pulsing circles, while dynamics were controlled by the bar on the right. Its cueing functionality was modeled after the Guitar Hero graphical interface.

GUS (right) was a humanoid graphic conductor implemented in Maya. Just like the robotic conductor *C3*, *GUS* used its right arm to conduct beat and dynamics, while the left arm was used for cueing. Each arm had three degrees of freedom.

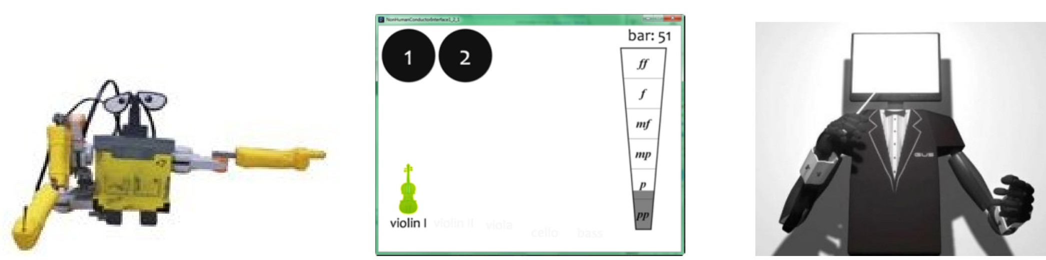

Figure 2. Prototypes built by students in the Fall 2009:C3, Ahasimo, and GUS

Figure 3 shows the prototypes built by the students in the Spring 2010. The *C4* robot (left) was humanoid, but was built using the VEX robotic kit and the Arduino microcontroller. Each arm had three degrees of freedom, and they used a mirrored motion to indicate the beat pattern and tempo. Dynamics were indicated by increasing the size of the gesture of the right arm while the left arm would be raised or lowered. Cues were indicated by the left arm pointing at the appropriate section. Articulation was communicated by the robot with both arms, the smoothness of the gestures corresponding to articulation. The robot also featured two real-time procedural animations implemented in Processing: an animated face for the orchestra, and an additional animation on its back to entertain the audience. This robot was the only one that could “hear” the orchestra, using the Chuck audio programming language for real time audio processing. The motion of the robot and the facial gesture are adjusted according to the tempo and dynamics played by the orchestra.

ACRE (middle) was the robot with the most advanced mechanical component. *ACRE* is a human size humanoid robot built from scratch without the use of any kits, and uses the Arduino microcontroller. It uses its right arm to indicate the beat pattern, and the left arm to indicate cueing and dynamics. Instead of using the score of the music, the robot learned to conduct from a video of a human conducting the same piece. The hands were tracked in the video using the system described in[12]. Inverse kinematics was used to define a robot motion that would mimic that of the human conductor. The robot simulates knee bending through the use of a linear actuator in the lower body, and could turn to face different orchestra sections. In addition, the robot’s head displayed a human face that expressed emotional changes according to the score.

The third robot, *Superconductor* (right) was not humanoid. It consisted of a “baton” that rotated on a square board with four LED lights. The rotation of the baton, together with the lights, conveyed the beat pattern. The lights could move closer together or further apart suggesting the dynamics. The team composed its own music to highlight the features of the robot.

Figure 3. Prototypes built by students in the Spring 2010: *C4*, *ACRE*, and *SuperConductor*

All the prototypes were tested by our college orchestra at the end of the semester and open to public. The quality of these prototypes was judged by the performing musicians by filling a survey form. The form provided scores in six different areas: tempo, dynamics, section cuing, conducting style/beat pattern, articulation and level of interaction (as follows):

1. How effective was the system’s portrayal of the piece’s tempo?
2. How effective was the system’s portrayal of the piece’s dynamics?
3. How effective was the system’s portrayal of the piece’s section cueing?
4. How effective was the system’s portrayal of the piece’s articulation (staccato, legato, etc…)?
5. How effective was the system’s conducting style and beat pattern?
6. What was the level of interaction between the conducting system and you, the orchestra?
7. Any other comments.

For the survey questions 1 to 6, they were rated on a scale from 1 to 10 with 1 meaning “not at all” and 10 “very”. The evaluation results obtained from the performing musicians show that the results on tempo, beat pattern and cueing are all above 6 on a scale from 1 to 10. These are the areas that we required the non-human conductors to achieve. The goal of this course is not to develop a perfect and fully functional non-human conductor. Instead, the non-human conductor is used as a vehicle to bridge engineering, science and the arts. Hence, we conclude that all prototypes got satisfactory results. We believe that the interdisciplinary approach was an important component of this success.

9. Conclusion

The outcomes of an interdisciplinary course involving engineering, science and the arts are presented in this paper. Due to the interdisciplinary collaboration our students were able to build creative working systems at a level that is rare in an undergraduate setting. By creating this interdisciplinary course, we introduced an innovative educational approach that fostered and rewarded creativity in teaching, learning and problem-solving activities. The experience and practice gained through this course could improve one's understanding on effective approaches to teach interdisciplinary courses in undergraduate collaborative learning environments.

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