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Electronic Pet Robots for Mechatronics Engineering Education: A Project-Based Learning Approach*

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To address the difficulties in teaching interdisciplinary subjects in engineering, this paper presents the process of developing a project-based mechatronics curriculum with the final artifact of an electronic pet robot. The curriculum was designed and implemented in a real mechatronics class for a semester in a university, and an evaluation study collected students' opinions on the effectiveness of this electronic pet robotic project-based mechatronics curriculum. The results of the study showed that the project increased student motivation, improved student performance, and gave students hands-on experience to develop skills in mechatronics system design. Students' responses to the evaluation study also demonstrated their positive attitudes towards the electronic-pet project-based learning, and the students also considered their teamwork to be successful.

Keywords: project-based learning; artifact; Mechatronics; engineering education; electronic pet robot; interdisciplinary learning

1. Introduction

Mechatronics, a newly-developed interdisciplinary field, integrates knowledge of optics, machinery, and electronics, which were originally independent of one another. As many recent studies in engineering education have noted, the inclusion of such a diversity of areas of engineering calls for attention to be paid to alternative mechanisms of learning and assessment [1]. In addition to the multiple engineering topics, including mechanical, electronic, computer, software, control, and system design engineering, that are the core of this interdisciplinary subject [2], it is also critical that students actually design and manufacture useful products as part of the teaching and learning of mechatronics. Nevertheless, most conventional engineering curricula do not offer application and system design until the later phase of instruction [3, 4], due to the nature of applied sciences such as engineering. Engineering educators are thus faced with even more challenges in helping students learn better, in a systematic way, to acquire fundamental knowledge and skills in each subject, while simultaneously developing a thorough understanding of mechatronics across multiple subjects.

In response to the aforementioned difficulties and problems in teaching mechatronics, this paper presents a detailed process for developing a project-based mechatronics curriculum with the final artifact of a mobile robot. The curriculum has been designed and implemented in a real mechatronics class for a semester in a university, and a survey was used to collect students' opinions of the instruction and learning in order to examine the effectiveness of the implementation of the robotic project-based mechatronics curriculum.

2. Project-based learning in mechatronics education

To cope with the interdisciplinary nature of a subject like mechatronics, we considered alternative perspectives on curriculum, instruction, and evaluation. Previous studies, applying the bottom-up fashion of engineering instruction and the structured curriculum, have explored a variety of endeavors and reforms in pedagogies and learning activities as supplemental aids to lecture-based instruction. For instance, collaborative and team studies have examined ways to increase student engagement [5–7], while others have employed more specifically- and structurally-organized strategies such as project-based learning to incorporate acquired knowledge into the manufacture of a product [2, 8–10]. Project-based learning involves the use of a real-life problem as the driving force to motivate and anchor student learning and partici-

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pation. It begins with an assignment to carry out several tasks and leads to the production of a final artifact [11]. This final artifact, in which project and learning activities converge, is viewed as a great motivator and deliverable to facilitate and encourage students to investigate and solve problems [12].

These foregoing studies in project-based learning have suggested several advantages that can be adapted to mechatronics education. For instance, project-based learning fits the self-regulation of learning needs [13, 14] that is expected of college engineering students, motivates students to participate through collaborative learning activities [15], and most importantly, centralizes learning through an accessible and evaluative representation of projects [16, 17]. In the past decade, project-based learning has received considerable attention in the international engineering education community [14], and it has been widely adopted in many applied electronics courses, such as optoelectronic sensing, power electronics, and control and system design [4, 6, 8, 18–21]. However, several studies have also reported problems in the form of unexpected learning outcomes [22], fragmental understanding, and inefficient teamwork during the project-based learning process [16, 20, 23]. Project-based learning has also been reported to entail difficulty and to require a high input of staff time and resources to monitor and facilitate student learning [24].

3. Mobile robot and project-based learning

In addressing the aforementioned difficulties and problems, computational tools are adopted and incorporated into phases of project-based learning on different scales, from computer-assisted instruction [25–27] to computer-aided design, that facilitate and enrich the product development [28, 29]. Due to the limitations of time, space, money, and resources, small units are often preferable as engineering project artifacts.

A general incapability or weakness of students to integrate knowledge to form an overall understanding of the subject matter has been found [1]. That is, groups of students who succeed in the mechatronics class may have acquired the necessary knowledge and skills to make a sensor, actuator, and interface collaboratively, but in the end, these experiences may not spontaneously lead to the individual's integrative learning. Such a finding should serve to remind engineering educators to pay attention to the structure and scalability of the project artifacts in order to ensure students' learning outcomes in project-based learning.

The term *mobile robot* refers to a platform with great mobility within its environment [30], as opposed to the industrial robot, which is stationary. The functional characteristics of mobility, autonomy, and perception, and the ability to react in the environment, are strongly emphasized in mobile robotics [31]. With the shifting emphasis on embedded intelligences, biorobotics studies that focus on autonomous mobility through sensing and reacting mechanisms have been very popular [32]. The artifacts of biorobotics mostly involve interdisciplinary collaboration with biology in order to comprehensively imitate life creatures and to realize the fundamental biological mechanisms on mobile robots. The design and control of mobile robots requires skills in many disciplines [33], such as physics, mathematics, mechanics, electronics, computer science, and automatic control. Also, a robot represents a tangible and self-contained deliverable good with real-world hardware that provides genuine feedback in real time [34], and the practical nature of the development of a mobile robot, accompanied by inaccuracies and imperfections to overcome, can be fascinating and inspirational [30, 35]. From the perspective of engineering education, designing a mobile robot allows flexibility not only for the students to be creative but also for the instructors to weave varying levels of knowledge and skills into the tasks.

This study therefore factors in the curriculum design and artifact structure when addressing the problematic phenomenon above. To balance teaching and learning efficiency is not easy, since the multidisciplinary nature of the curriculum in most engineering courses also suggests a complex network of antecedent prerequisites along with current learning topics [36]. Students who are not familiar with physics and mathematics might find the mechatronics class difficult. Therefore, it is necessary to employ a bottom-up fashion of instruction to boost student comprehension of the subjects.

On the other hand, artifacts in project-based learning, as the externalizations of the students' understanding, are critical, for they can be shared and critiqued. The resulting artifact should be genuine and self-contained for it to be used as a focus for review and reflection, while it also can be publicly displayed to motivate students to become involved. In addition, a quick indicator that summarizes and reflects the students' learning status is also required for critical feedback to be provided to both the instructors and the learners.

Instead of several motion units, the robot, as a macro-level artifact, was employed in this study. First, the design and control of mobile robots reflect the nature of mechatronics education. It requires interdisciplinary competences and knowledge for students to address a broad range of engineering fields [1, 23]. Second, the instant visual feedback of mobility helps students to test the artifact systematically. The automation of the details of production can free students to be aware of and explore greater levels of complexity in the content of the project and the design of the artifact. Third, mobile pet robots as biorobotics artifacts that emphasize the integration of fundamental biological mechanisms are preferred in terms of the structure and scalability for learners to exert both micro and macro levels of engineering knowledge and skills.

Due to previous evidence and the current research context, robots were adopted by this study as an educational platform for students to exercise interdisciplinary learning in mechatronics. Any overemphasis on the project work was to be balanced by the provision of timely articulation of engineering principles and fundamental knowledge during the development of every part of the final artifact. Additionally, making robots amplified the motivational appeal of immediate visual and mechanical feedback for students to examine in order to make adjustments quickly by exerting high-level coordination and manufacturing knowledge and skills.

4. Methodology

This study presents a project-based mechatronics curriculum with a mobile robot as the final artifact that was developed and implemented in an undergraduate level course of mechatronics. The methodology of case study is adopted to describe the process and outcome of the curriculum. The main question was whether the integrative intervention of curriculum and artifact structure design could effectively improve students' learning processes and outcomes in an interdisciplinary subject like mechatronics. Student performance and perceptions were recorded and collected to understand the effectiveness of the project-based mechatronics curriculum. Specifically, the purposes of the study were:

1. To design and develop a mechatronics curriculum with a project-based approach in which mobile robots are assigned as project artifacts for undergraduate engineering students.
2. To evaluate the effectiveness of the implementation in terms of student performance and perceived benefits of the project-based mechatronics curriculum.

4.1 The context

The study was conducted in an undergraduate-level course entitled "Mechatronics and Laboratory," offered by an academic program in bio-industrial engineering at a university at northern Taiwan. As one of the required courses in the program, "Mechatronics and Laboratory" is positioned in the last year of the curriculum, exclusively for seniors, in order to connect the students' academic learning to career competencies. The course highly emphasizes and values the ability to review, coordinate, and apply their learning in their undergraduate studies. The aim of the course is to develop students' skills in system design by providing hands-on experience dealing with real-world phenomena. To fulfill the instructional objectives, a term project on an "electronic pet robot," in which a mobile robot was the platform for students to practice and implement their learning of mechatronics, was identified as the main stream of learning activity to anchor student learning in this course. Following the emphases of biorobotics, it was expected that students would learn mechatronics knowledge and skills by actually engaging in making an achievable small-sized albeit complete artifact of electronic pet robot, which in turn would allow affective involvement to motivate and characterize their learning outcomes.

The 17-week course was composed of 30 hours of class meetings and 38 hours of laboratory activities, including weekly 2-hour face-to-face lectures and 2-hour laboratory sessions, concluding with a final presentation to demonstrate the project artifact. The curriculum covered six major sessions, from orientation on basic concepts of mechatronics, instruments, and manipulation, to the specific topics of mechanical, electronic, control, sensing, and actuating engineering. These topics were scheduled progressively according to the level of application and difficulty, and each was accompanied by weekly laboratory activities to recognize, manipulate, design, and develop the robotic units.

4.2 Design of the project-based mechatronics curriculum

The structure of the mechatronics knowledge was implemented with the project-based learning model developed in the prior studies [37] to determine the proportions and allocations of the weekly classes. More lectures were scheduled in the beginning of the semester in order to develop students' basic knowledge and skills in the subject. The scale and difficulty of the artifacts of the mobile robots increased progressively with the subject topics taught each week. Figure 1 summarizes the overall curriculum, with the corresponding instructional and learning activities.

Students were asked to work in teams to explore the knowledge and skills of mechatronics through designing, planning, and creating an electronic pet robot. To reflect the genuine nature of an engineering project, students had to evaluate and acquire necessary resources to carry out the project. They had to finish the robot while balancing issues of time, cost, institutional support, and publicity. The

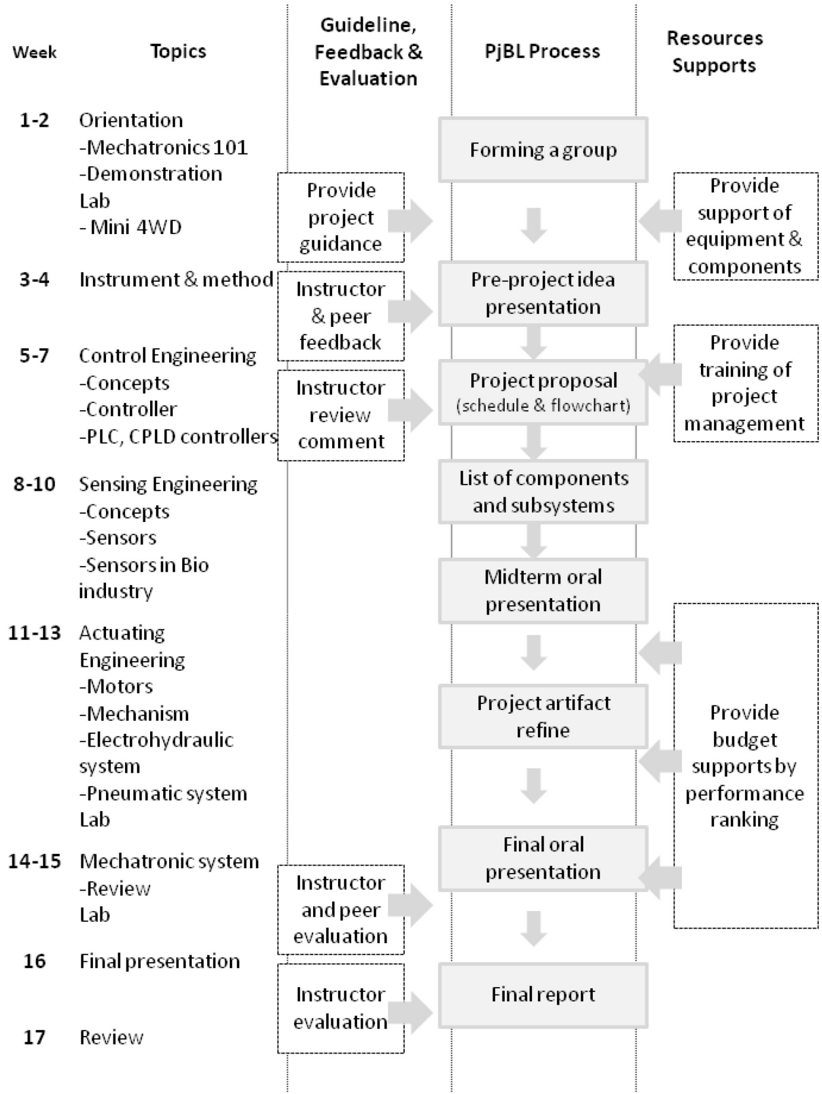

Fig. 1. Instructional plan, guideline and process of project-based learning.

instructors carefully followed the principles of project-based learning to design learning activities for different phases, incorporating scheduled resources, assignments, and assessments for each team.

4.3 Assessment and instruments

To understand students' learning outcomes and experiences within the project-based curriculum, we assessed their perceptions, appraisals, and performance. At the end of the semester, all students completed a survey questionnaire developed by the researchers. Information to be collected included student perceived helpfulness on the acquisition of specific abilities; perceptions of the robotic project-based mechatronics curriculum as compared to those of other project learning experiences; the problems that students encountered; resources that were difficult to access; their experiences of working in teams; and the benefits of the curriculum. All evaluation items were on a 6-point Likert-like scale of 0-5 indicating degree of agreement. To ensure the validity of the measurement, subject matter experts in mechatronics and engineering education were invited to validate the instrument. The reliability of the instrument was reasonably acceptable (Cronbach's alpha = 0.933).

5. Results

5.1 Participants

A total of 44 students took this course and responded to the questionnaires. There were 31 male (70.5%) and 13 female (29.5%) students. All of the students were biological mechatronics engineering majors in their fourth or fifth year of university, and most of them had hands-on and fabrication experience from courses they had taken previously (35 students, 79.5%). The aca-

Table 1. Student perceptions of the project-based curriculum (N = 44)

	Mean	S.D.
Improves my ability to fabricate concrete productions.	4.43	0.79
Improves my independent problem-solving ability.	4.39	0.65
Engages me to participate in groups to improve my cooperative skills and arouse my team spirit.	4.36	0.78
Helps me to inspect from others' work, which can help me to exchange experiences and learn with my peers.	4.30	0.70
Engages me to discuss the issue deeply and increases my ability to note connections to related topics.	4.23	0.64
Helps me to combine theory and practice.	4.23	0.64
Increases my interest in learning.	4.20	0.76
Engages me as an active learner to construct knowledge myself.	4.20	0.85

demic interests and expertise of the students enrolled in this program included biology (14.8%), mathematics (13.1%), and mechanical engineering (16.4%).

5.2 Student perceptions of the robotic project-based mechatronics curriculum

According to the instructors' observations, students generally had a positive attitude toward the curriculum, and the survey results also reflected high appraisals that supported the effectiveness of the project-based curriculum in this course. As shown in Table 1, students thought the project-based curriculum improved their hands-on and fabrication skills (4.43) and problem-solving abilities. They agreed that the project-based curriculum had encouraged and engaged them to collaborate (4.36) and discuss the issues profoundly. Students reported using the opportunity to associate their learned topics with more relevant issues, and thereby to increase their learning (4.23). They also inspected each other's work, exchanged experiences, and learned with their peers (4.30). The project-based curriculum was perceived to be effective in helping students to combine theory and practice (4.23), increase their interest in learning (4.20), and actively construct their knowledge (4.20).

The specific abilities that students perceived that they had acquired in this project-based curriculum included teamwork (4.41), system integration (4.39), creativity (4.23), circuit design (4.20), mechanism design (4.18), and programming (4.07), followed by appearance and art design (4.04). To further explore the integrative impact of the curriculum, students were asked to compare their experiences in this course to those in any other course related to robot design or mechatronics. The results showed that students felt more capable of integrating art and engineering (4.18) in this course. They also considered project-based learning as a whole to be a form of edutainment (4.05), and they felt collaborating with peers allowed more flexibility (3.93) and inspired them to complete the project (see Table 2 and Table 3).

It was noteworthy that the project artifact, an electronic pet robot, made students rate this course as more human-centric (4.16), creative (4.14), and active (4.07). And the instructors regarded students' artifacts reflected more affective and cultural features. As shown in Fig. 2, groups of students tended to project their preferences and characteristics on the design of the electronic pet robots. Students used the metaphors in not only the appearance but also the interaction design. For instance, a rabbit robot was capable of jumping, and an African wildcat robot was set to be of poorer color vision but good sense of smell in students' design. In addition to common images of companion animals such as dogs and cats, students also expanded the possibilities of pets by exerting their creativities to make new forms of creatures or develop extraneous functions to an existing form.

Table 2. Core competency the course help develop (N = 44)

	Mean	S.D.
Teamwork	4.41	0.79
System Integration	4.39	0.65
Creativity	4.23	0.60
Circuit design	4.20	0.73
Mechanism design	4.18	0.66
Programming	4.07	0.62
Appearance/Art design	4.04	0.71

Table 3. Perceived features of the robotic project-based mechanic curriculum (N = 44)

	Mean	S.D.
Integration of art and engineering	4.18	0.69
Human-centric	4.16	0.64
Creative	4.14	0.70
Active	4.07	0.62
Edutainment	4.05	0.61
Flexibility	3.93	0.66

5.3 Problems and difficulties encountered in robotic project-based curriculum

On the other hand, students also encountered several problems while proceeding with the project-based learning. To accomplish an electronic pet robot as Fig. 3, students were required to make, assemble and install each circuit, and integrate them into a system to enable the mobility of

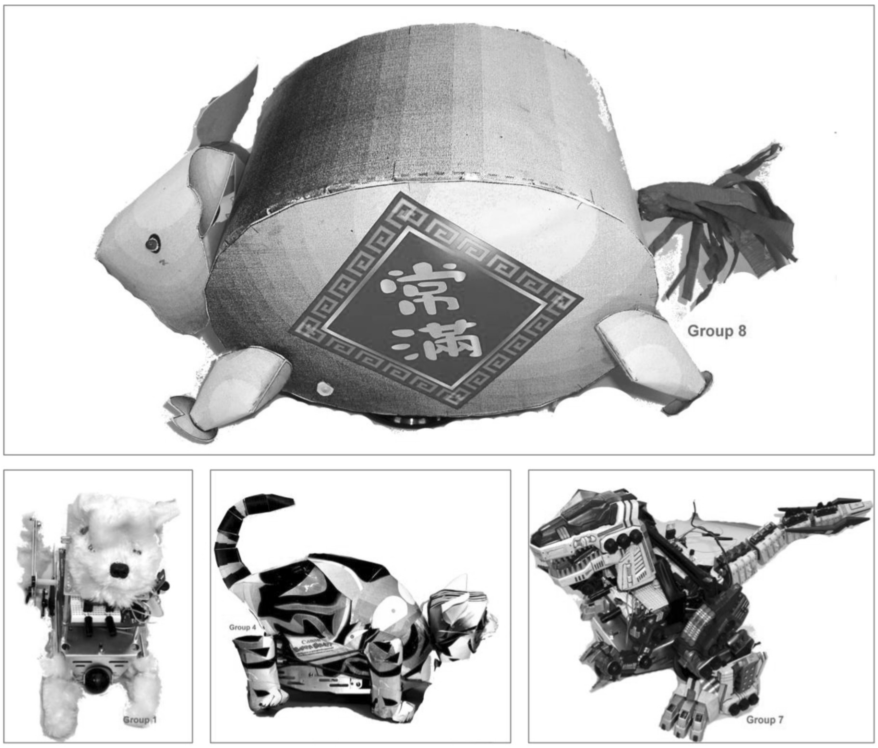

Fig. 2. Electronic pet robot of turtle made by students.

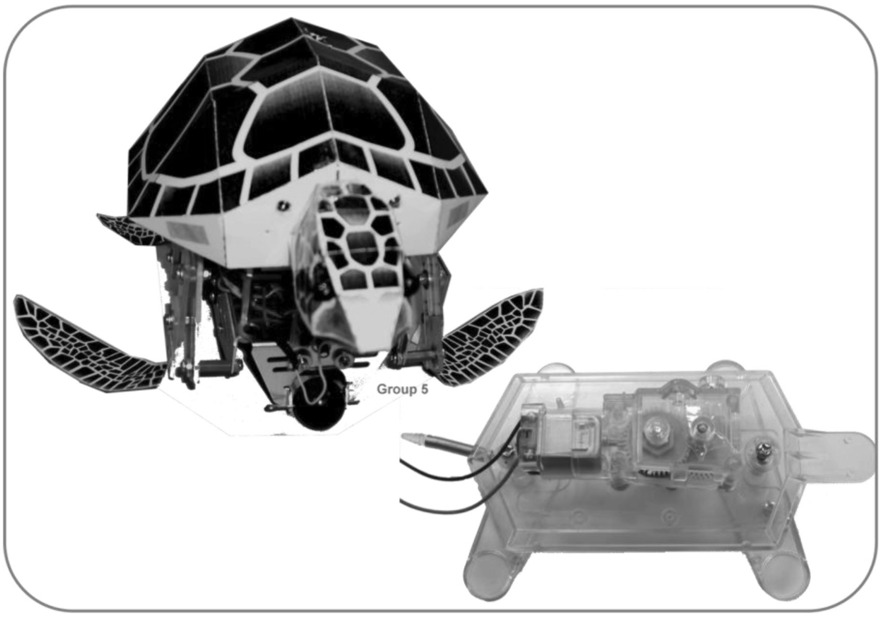

Fig. 3. The internal mechanism and external appearance of a pet robot.

the pet robot. As shown in Table 4, most of the problems they reported were related to the domain knowledge of mechatronics, including mechanism design (4.20), debugging (4.14), circuit design (3.89), and system integration (3.89). As for the project itself, work such as teamwork (3.36) and deciding project themes or topics (3.36) were, somewhat surprisingly, perceived as the least difficult issues. However, the students tended to attribute the difficulty of developing sufficient domain knowledge to internal factors, such as a lack of experience (M = 4.50, S.D. = 0.79) and proficiency (M = 4.32, S.D. = 0.88), instead of external factors, such as budget (M = 4.05, S.D. = 1.29), curriculum (M = 3.80, S.D. = 1.00), and instruments (M = 3.73, S.D. = 0.92). The findings suggested that students with a

Table 4. Problems encountered during robotic PjBL (N = 44)

Problems and Difficulties	Mean	S.D.
Mechanism design	4.20	1.19
Debugging	4.14	1.00
Circuit design	3.89	0.95
System Integration	3.89	0.99
Programming	3.77	0.99
Finding appropriate components	3.73	1.21
Appearance/Art design	3.68	1.18
Deciding topic of the project	3.36	1.16
Teamwork	3.36	1.14

tendency for internal attribution were more active learners and were more likely to view the problems as challenges that could be overcome.

5.4 Student learning performance in robotic project-based mechatronics curriculum

Generally speaking, students confirmed the effectiveness of this course. As shown in Table 5, students agreed that this course helped them find their academic area of interest (M = 4.59, S.D. = 1.06). They were able to apply their prior basic knowledge (M = 4.52, S.D. = 0.76) and prior fabrication skills (M = 4.36, S.D. = 0.72) in this course. Students reported that they had learned fabrication skills (M = 4.39, S.D. = 0.72), basic knowledge, and theory (M = 4.30, S.D. = 0.67) in this academic area. They also reported learning about integrating disciplines in cross-discipline learning (M = 4.25, S.D. = 0.72) and acquiring the ability to apply cross-discipline knowledge to solve problems (M = 4.18, S.D. = 0.58). They realized that cross-discipline learning covers different areas of academic knowledge (M = 4.16, S.D. = 0.75), with the result that students could improve their abilities in other academic areas (M = 4.09, S.D. = 0.83). Students demonstrated positive attitudes toward what they had learned in this course. From a comparison of the questionnaire data and the orientation test results, it is clear that students improved their self-efficacy in research (M = 4.30, S.D. = 0.73) and analytical thinking (M = 4.18, S.D. = 0.81) during the course. Finally, students agreed that this curriculum helped them to develop better competence for the future workplace (M = 4.18, S.D. = 0.76).

Essentially, electronic pet robots as the biorobotics artifacts in this study were proved to be successful to afford the integrative and interdisciplinary nature of mechatronics. The findings supported that students collected wide range of resources and materials actively in order to coordinate circuits and mechanisms for mobility. They were able to start with fundamental and learned elements, and moved to advanced applications with the collaboration and assistance of team members. Comparing to conventional engineering curricula [38] that offered application and system design in the later phase of instruction, in this study the students worked on individual parts along with the instruction, and their learning accumulated and anchored by the project artifacts. As the mobile robots, the scalability of electronic pet robots enabled a small but complete implementation of mechatronic engineering projects to leverage the problems of fragmental understanding and unexpected outcomes mentioned in previous studies [14, 20, 23]. Additionally, the creation of companion pet robots encouraged student affective involvement and commitment to the project artifact that enhanced learners' motivations.

6. Conclusions

This study designed and developed a project-based mechatronics curriculum that was effectively interlaced with the development of an electronic pet robot as the motivating project artifact. The content and instruction of the project-based design facilitated student experiences and performances in learning mechatronics. The instructors were satisfied and less burdened with the project-based instructional plan, which systematically incorporated teaching and learning activities. Selecting electronic pet robot as the platform also met the

Table 5. Perceived benefits from the robotic project-based mechanism (N = 44)

Items	Mean	S.D.
Introduction to an interesting new discipline/area	4.59	1.06
Application of prior fundamental knowledge	4.52	0.76
Learning of practical application skills in this course	4.39	0.72
Application of prior hands-on skills	4.36	0.72
Learning of basic knowledge and theories in this course	4.30	0.67
Ability to analyze things from multiple perspectives	4.30	0.73
Learning about integrating across disciplines	4.25	0.72
Ability to apply cross-disciplinary knowledge to solve problems	4.18	0.58
Improved study and research abilities	4.18	0.81
Greater competence for future career	4.18	0.76
New understanding of different subject-matter knowledge covered in the interdisciplinary area	4.16	0.75
Ability to apply cross-disciplinary knowledge on enhancing original professions	4.16	0.68
Extended ability other than those in original professions	4.09	0.83

instructional emphasis on integration and application, and fit the difficulty level of the curriculum for students to exert fundamental engineering knowledge and skills as well. The instructional decision to assign an electronic pet robot as the final project artifact was also viewed favorably and appreciated by the students. According to the results, the students recognized the success of the curriculum and instruction. They appreciated the broadened interests and visions of new and different disciplines provided by this course. In addition, the electronic pet robot, as the project artifact, granted the students opportunities to apply their prior knowledge and exercise their skills.

Despite the lack of experiences that challenged and held back students' progress, they were consistently motivated and attracted by the electronic pet robot and would work to complete the project. In contrast to the students' previous learning experiences with project works or robotics, electronic pet robots appeared to be more personalized and therefore motivating to make. Also the teamwork was considered generally to be more successful in terms of learning and to be more enjoyable than individual work. The findings also suggested that students appreciated the electronic pet robot as an aesthetic engineering artifact that incorporated perspectives of humanity and creativity.

This study provides a case of a well-structured project-based curriculum with a motivating robot artifact helping students to improve their learning of an interdisciplinary subject, mechatronics. A project-based instructional plan and a framework to incorporate robotic project artifacts were proposed and verified to be effective, according to the results of this study. It is expected that the findings of this study will be of help to engineering educators in setting practice. Due to institutional regulations and culture governing instructional hours and enrollment, the group dynamics of each project team were not thoroughly analyzed in this study. It is suggested that further studies explore student communication behaviors in project teams and consider the possible impact on student learning of homogeneous or heterogeneous compositions of the teams.

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