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Robotics and Sensor Technology Education Using LEGO Mindstorms NXT

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We investigated the effectiveness of integrating LEGO Mindstorms NXT robot kits into adult education to enhance learning enthusiasm and cultivate key skills. Utilizing a curriculum focused on programming, mechanical structure, scientific capability, teamwork, and robotics and sensor technology understanding, we conducted a questionnaire survey before and after the course with 45 adult students. The results showed strong reliability and validity and significant improvements in students' perceptions of course content, teamwork, programming logic, scientific capabilities, and technology understanding. While mechanical structure showed less significant improvement, strong correlations among factors highlighted the integrated nature of robotics and sensor technology learning. Hands-on robotics education, particularly involving sensor technology, effectively enhanced logical thinking, problem solving, and collaborative skills, which are important in Science, Technology, Engineering, and Mathematics (STEM) education.

1. Introduction

Developing technology has brought unprecedented convenience and well-being to humanity. However, rapid economic development brings economic pressures and requires continuous learning of new knowledge, which has become a new challenge. Consequently, lifelong learning and adult education are regarded as important. For adult students of different age groups, either educated or not, learning recent knowledge based on recent information and technology, especially in science and engineering, is difficult.[(1–3)] Therefore, it is essential to design creative and easy courses to enhance those students' learning motivation and assess students' learning outcomes in such courses.

A LEGO Mindstorms NXT kit combines LEGO bricks with computer technology to serve as educational tools. The research conducted by the Massachusetts Institute of Technology (MIT) Media Lab showed that integrating computer programming to control created models can train

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students to learn mechanical principles, computer control, and programming logic through hands-on experiences in a well-designed curriculum and activities. LEGO Mindstorms NXT robotics kits are often used with a standard set of sensors, each using different technologies to provide input to the NXT Intelligent Brick.

The sensors in most LEGO Mindstorms NXT kits include touch, sound, light, and ultrasonic sensors. In addition to these sensors, NXT motors have built-in rotation sensors to measure the motor's rotation in degrees or full rotations for precise control over the robot's movement. Beyond the basic kit, diverse compatible sensors, such as color, gyro, compass, infrared, thermal infrared, and magnetic sensors, as well as accelerometers, are used with LEGO Mindstorms NXT kits. The communication between the NXT brick and its sensors uses the inter-integrated circuit protocol through a serial communication bus.[4–6]

The LEGO Mindstorms NXT kit enables scientific knowledge to be integrated into an accessible, engaging, and practical learning process, guiding students to practice reasoning, problem solving, creative invention, and teamwork. It broadens students' understanding of science, logical analysis, and programming concepts, igniting a strong interest in science and enriching curricula with educational technology. This makes teaching dynamic and learning enjoyable.

Therefore, high schools, vocational schools, and middle schools are using LEGO Mindstorms NXT in courses related to Internet computer technology (ICT). Students are participating in various club and after-school activities, showing excellent results. In this study, we applied a curriculum using LEGO Mindstorms NXT to information courses in adult education. We explored its effectiveness in students' learning, developing their creative abilities, programming logic design, mechanical assembly skills, and learning interest in adult education.[7–10]

2. Methods

2.1 Research framework

Since LEGO Mindstorms NXT kits encompass training functions such as programming, mechanical structure, scientific capability application, and teamwork, we determined whether they are applicable to courses in continuing education. Five factors, namely, "course content," "mechanical structure," "programming logic," "teamwork," and "scientific capability and robotic/sensor technology", were defined in this study to assess learning effectiveness using LEGO Mindstorms NXT kits. The hypotheses related to the factors were proposed as follows (Fig. 1).

H1: Course content positively affects mechanical structure.
H2: Course content positively affects programming logic.
H3: Course content positively affects scientific capability and the application of robotics and sensor technology.
H4: Writing programming logic positively affects teamwork.
H5: Assembling mechanical structures positively affects teamwork.

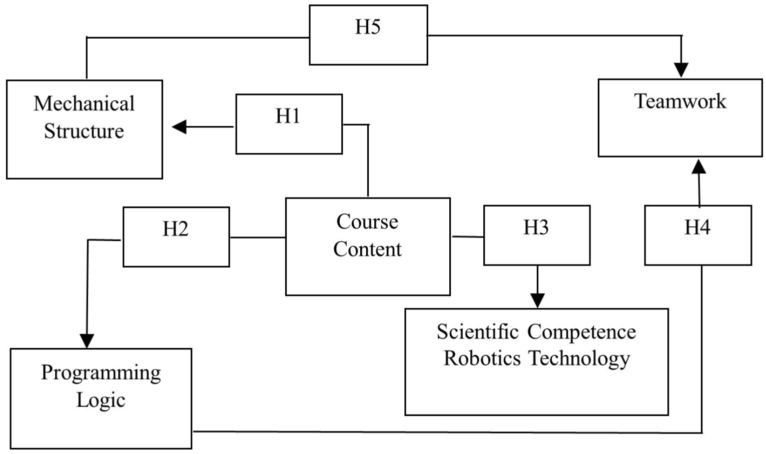


Fig. 1. Research framework on curriculum using LEGO Mindstorms NXT kit.

2.2 LEGO Mindstorms NXT 9797

LEGO Mindstorms NXT 9797 combines LEGO building blocks with computer science as a robotics teaching platform (Fig. 2). It includes a programmable NXT brick with a 32-bit advanced reduced instruction set computer (RISC) machine (ARM) processor and four types of sensor to detect light, touch, and sound. An ultrasonic sensor is also included.

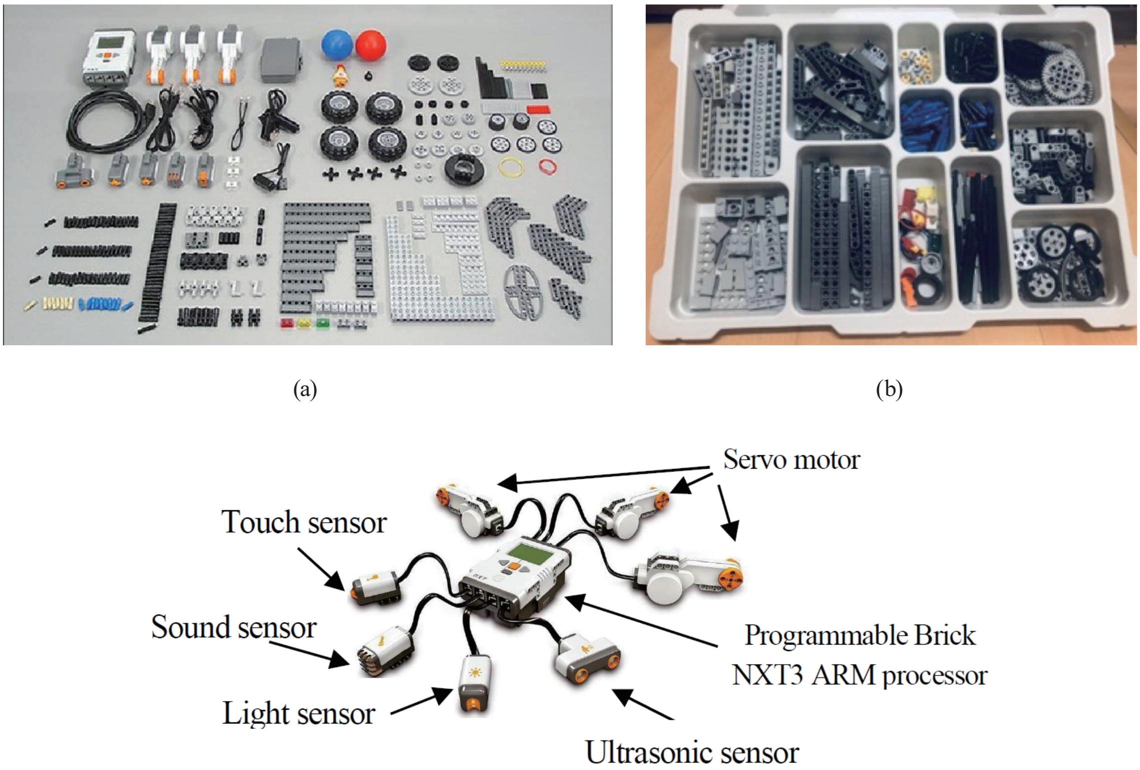
2.3 Course design

The curriculum was designed from multiple technical perspectives to teach students who are new to robotics.[11,12] The lesson plan of the course incorporates the LEGO Mindstorms NXT Creative Fan Course, LEGO Mindstorms NXT Whirlwind Car Course, LEGO Mindstorms NXT Catapult Teaching Material, and LEGO Mindstorms NXT Catapult Course.[13–16]

In the first week, students learned basic knowledge of robots to familiarize them. In the second week, students assembled LEGO Mindstorms NXT blocks. The session began with an explanation of the concepts of robotic structure, and students designed and created various robot modules (Fig. 3).[17–19] In the third and fourth weeks, students programmed the LEGO Mindstorms NXT robot. The students designed robots with different mechanical structures for various applications.[20–24] In the fifth week, a competition was held to assess the students' learning outcomes so far. Through the competition, the students could strengthen teamwork and interpersonal interactions. It also allowed students to better understand robotics in an enjoyable and relaxed manner. The competition presented significant educational implications, providing educational value and inspiration.[20–24]

2.4 Questionnaire survey and data analysis

After reviewing relevant literature on creative teaching, creativity, and the application of LEGO Mindstorms NXT in education, a questionnaire focusing on creativity and creative



(a) (b)

(c)

Fig. 2. (Color online) LEGO Mindstorms NXT. (a) LEGO bricks (Part 1), (b) LEGO bricks (Part 2), and (c) LEGO bricks (Part 3).

(a) (b)

Fig. 3. (Color online) Feedback on windmill design created by students using LEGO Mindstorms NXT kits.

teaching for online surveys was created. The questionnaire included items on course content, mechanical structure, programming logic, teamwork, scientific ability, and robotics technology on a five-point Likert scale. In the course activities, the activities related to science popularization were adopted.(19,25) We conducted questionnaire surveys before and after teaching the course(11–13) and analyzed the data to understand the differences in learning outcomes before and after the course and improvements in creativity and logical thinking.(14)

The participants of this study were 45 students who took Class Four Electronics III-A in the Continuing Education Division at National Kaohsiung University of Science and Technology in Taiwan. The class was divided into 12 groups consisting of 3 to 4 students. Ten students were 19 to 30 years old, 21 students were 31 to 40 years old, 3 students were 41 to 50 years old, and one student was older than 50 years old. Three percent of the students were interested in programming, 11% of the students were interested in mechanical structure, 69% of the students were interested in electrical engineering and electronics, and 17% of the students were interested in other fields. The data from the pre-course and post-course questionnaires were analyzed for descriptive statistics, reliability, validity, and factor analysis to determine significant improvements in learning outcomes.

3. Results

The reliability of the questionnaire survey was determined by assessing the degree of internal consistency using Cronbach's Alpha, which was greater than 0.7, indicating a high level of internal consistency (Table 1).

Factor analysis was conducted employing principal component analysis (PCA). According to Kaiser's criterion, principal components with eigenvalues greater than 1 were retained, and those with loadings higher than 0.5 were considered important factors. The Kaiser–Meyer–Olkin (KMO) value was calculated and Bartlett's sphericity test was performed before PCA to determine the appropriateness of factor analysis of the data. The results in Table 2 show that the statistical significance at $p < 0.05$ of the correlation matrix is appropriate for factor analysis. The correlation coefficients between the factors are shown in Table 3.

The factor analysis results are presented in Table 4. The scores and their differences in the pre- and post-course learning outcomes are shown in Fig. 4. The results were compared using *t*-test, and the *t*-test results are shown in Table 5.

Table 1
Reliability of questionnaire survey in this study.

Factor	Number of questions in questionnaire	Cronbach's Alpha
Course content	6	0.93
Teamwork	5	0.97
Programming logic	7	0.74
Mechanical structure	4	0.72
Scientific capability and robotics/sensor technology	8	0.92

Table 2
KMO test and Bartlett's test results.

Factor	KMO value	Bartlett's test of sphericity (significance level)
Course content	0.78	0.00
Teamwork	0.82	0.00
Programming logic	0.73	0.00
Mechanical structure	0.78	0.00
Scientific capability and robotics/sensor technology	0.86	0.00

Table 3
Correlation coefficients of factors.

Factor	Course content	Teamwork	Programming logic	Mechanical structure	Scientific capability and robotics/sensor technology
Course content	1				
Teamwork	0.54^{**}	1			
Programming logic	0.50^{**}	0.32^{**}	1		
Mechanical structure	0.70^{**}	0.54^{**}	0.59^{**}	1	
Scientific capability and robotics/sensor technology	0.61^{**}	0.70^{**}	0.49^{**}	0.66^{**}	1

(**: p-value is less than 0.01)

The results of the statistical analysis supported the hypotheses (H1–H4), indicating that course content helped the students improve their understanding of teamwork, programming logic, scientific ability, and robotics and sensor technology. Assembling a mechanical structure did not positively affect the improvement in teamwork (Table 6).

4. Discussion

The results presented the impact of a LEGO Mindstorms NXT robotics course on students in course content, teamwork, programming logic, mechanical structure, scientific capability, and robotics and sensor technology. By examining Cronbach's alpha, KMO, and Bartlett's test results, factor loadings, pre-test/post-test comparisons, and hypothesis testing, the effectiveness of the course, with a particular focus on the underlying importance of technology learning, was validated.

The t-test results comparing pre-test and post-test scores revealed significant improvements in "course content" ($t = -4.400$), "teamwork" ($t = -1.818$), "programming logic" ($t = -3.126$), and "scientific ability and robotics technology" ($t = -2.496$). The results suggested that the LEGO NXT robotics course was effective in enhancing students' perceptions and abilities in these areas. "Mechanical structure" did not show statistical significance in improvement ($t = -1.493$, greater than the threshold t-value of −1.6914). This means that the mechanistic structure of students' self-perception is less obvious and requires different teaching methods.

High correlations were observed between "course content" and "mechanical structure" (0.70), "teamwork" and "scientific ability and robotics technology" (0.70), and "mechanical structure" and "scientific capability and robotics and sensor technology" (0.66), highlighting the integrated nature of technology learning.

The results underscored the importance of sensor technology in robotics education programs. The direct positive effect of "course content" on "scientific capability and the application of robotics and sensor technology" (H3) indicated that understanding various sensor types (touch, sound, light, ultrasonic, and others), their principles of operation (e.g., echolocation for ultrasonic and light intensity for photoelectric), and their data output is essential for students to enhance their "scientific capability" to understand how robots perceive their environment. The high mean score for "scientific ability and robotics technology" in the post-test (4.30) validated the effectiveness of the course on the understanding of the technology.

Table 4
Factor analysis results.

Factor/question	Factor loading	Eigenvalue	Explained variance (%)
Course content		4.41	74.50
1. I think the LEGO NXT robotics course is very interesting.	0.8		
2. I think the LEGO NXT robotics course is well-planned.	0.9		
3. I think the content of the LEGO NXT robotics course is very substantial.	0.8		
4. I think the LEGO NXT robotics course is lively and dynamic.	0.8		
5. I think that the LEGO NXT robotics course has sparked my interest in robotics technology.	0.7		
6. I think that the LEGO NXT robotics course has taught me to collaborate with classmates to solve problems.	0.7		
Teamwork		4.43	88.60
1. I believe that the concept of teamwork is very important.	0.8		
2. Teamwork can enhance my interpersonal relationships with my classmates.	0.8		
3. Through teamwork, learning goals can be achieved more quickly.	0.9		
4. Teamwork can boost confidence in learning.	0.8		
5. The LEGO NXT robotics course helps me understand the importance of teamwork.	0.8		
Programming logic		2.41	77.80
1. I believe my logical thinking is very good.	0.8		
2. I believe programming is a very simple task.	0.9		
3. I believe I am capable of handling programming tasks.	0.8		
4. Taking the LEGO NXT robotics course will enhance my logical thinking ability.	0.5		
5. Taking the LEGO NXT robotics course will spark my interest in programming.	0.8		
6. Taking the LEGO NXT robotics course will make programming simple and fun.	0.6		
7. I want to pursue a career in programming in the future.	0.7		
Mechanical structure		2.88	72.00
1. I believe my logical thinking is very good.	0.8		
2. I believe programming is a very simple task.	0.6		
3. I believe I am capable of handling programming tasks.	0.7		
4. Taking the LEGO NXT robotics course will enhance my logical thinking ability.	0.6		
Scientific capability and robotics/sensor technology		2.41	77.8
1. I believe the LEGO NXT robotics course is helpful for the application of natural sciences.	0.7		
2. The LEGO NXT robotics course can help supplement some of my deficiencies in natural sciences concepts.	0.7		
3. The LEGO NXT robotics course can increase my willingness to learn about natural sciences.	0.8		
4. The LEGO NXT robotics course can enhance my understanding of robotics science and sensor technology.	0.8		
5. The LEGO NXT robotics course encourages me to be more interested in learning courses related to mathematics and science.	0.7		
6. The LEGO NXT robotics course makes me want to learn more about information related to robots.	0.5		
7. I hope to have more opportunities to participate in LEGO NXT-like robotics courses in the future.	0.5		
8. The LEGO NXT robotics course makes me want to enter the field of robotics and sensor technology in the future.	0.6		

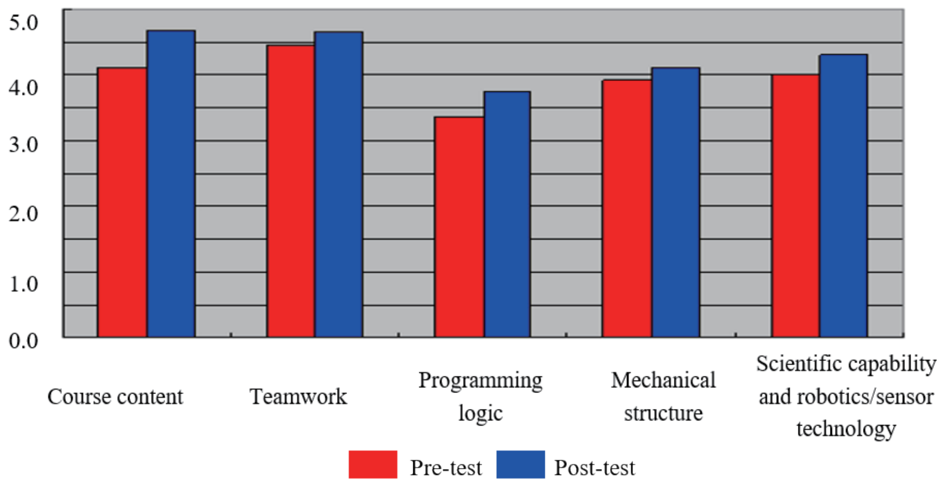


Fig. 4. (Color online) Comparison of scores and their differences in pre- and post-course learning outcomes for each dimension.

Table 5
t-test results.

Dimension name	Test	Mean	Standard deviation	Degree of freedom	Threshold *t*-value	*t*-test
Course content	Pre-test	4.11	0.65	34	−1.6914	−4.400
	Post-test	4.67	0.44			
Teamwork	Pre-test	4.44	0.55			−1.818
	Post-test	4.65	0.46			
Programming logic	Pre-test	3.35	0.52			−3.126
	Post-test	3.74	0.48			
Mechanical structure	Pre-test	3.91	0.66			−1.493
	Post-test	4.11	0.42			
Scientific capability and robotics/sensor technology	Pre-test	4	0.61			−2.496
	Post-test	4.3	0.49			

Table 6
Hypotheses tested in this study.

Research hypotheses	Test result
H1: Course content will positively affect mechanical structure.	Supported
H2: Course content will positively affect programming logic.	Supported
H3: Course content will positively affect scientific capability and the application of robotics and sensor technology.	Supported
H4: Writing programming logic will positively affect teamwork.	Supported
H5: Assembling mechanical structures will positively affect teamwork.	Not supported

The lack of significant improvement in "mechanical structure" suggested that their perceived capability in mechanical structure might not be as strongly boosted as in other areas. This could be due to the nature of pre-designed LEGO parts, where mechanical engineering principles might not be taught or applied as programming or scientific concepts related to sensors. It is necessary to explore if specific mechanical designs, particularly those driven by sensor placement and functionality, can enhance the understanding of the mechanical structure.

The results highlighted that sensor technology is an important component of robotics with its educational value. The effective learning of robotics and sensor technology empowers students to understand how robots perceive and interact, directly enhancing their programming logic, scientific understanding, and collaborative problem-solving abilities, all of which are vital in Science, Technology, Engineering, and Mathematics (STEM) education.

5. Conclusions

Integrating LEGO Mindstorms NXT kits into adult education significantly enhanced learning outcomes by enabling students to grasp mechanical structure and programming logic through interactive, hands-on experiences of robotics and sensor technology. The course effectively improved students' enthusiasm, understanding of computer technology, and vital skills in teamwork, problem solving, reasoning, and creativity. Through structured training and competition, students deepened their comprehension of robotics and sensor technology, fostering their creativity and logical thinking. This approach successfully supplements students' knowledge of robotics and sensor technology, promoting stronger interpersonal relationships and collaborative task completion, ultimately validating the educational value of robotics in adult learning.

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