Development and Evaluation of Educational Materials for Embedded Systems to Increase the Learning Motivation[*]

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Educational materials of embedded systems are currently used in many educational institutions. However, they have difficulties in arousing the interest of students. One of the reasons is that a poor CPU (central processing unit), which has been loaded in the current materials, cannot execute the multimedia processing. In order to make the exercises in embedded systems more practical, we developed an educational board, which we call "E+". "E+" is equipped with a RISC (reduced instruction set computer) microcontroller 32bit SH2 (SuperH), which is manufactured by Renesas Electronics Corporation. As I/O (input/output) interface, in addition to buttons and LEDs (light emitting diodes), it is loaded with sensors, such as light sensors and temperature sensors, a full-color LCD (liquid crystal display) display with a touch screen, voice input/output modules, Ethernet communication and an SD (secure digital) card on board. We introduced "E+" to the 3rd grade students (about 40 students) in the computer architecture class of department of electronics and information engineering at Ishikawa National College of Technology. This paper shows that the students are interested in the materials and that they learn the contents in an efficient manner. We conducted an evaluation after the one-year class of computer architecture. The question which asks "Are you satisfied with the learning in this educational material?" scored a high value of 3.80/5.00. The question asking "Was this exercise helpful to improve your general technical capabilities of making things?" also scored a high value of 3.54/5.00.

Keywords: practical embedded system, teaching material, increasing the learning motivation, multimedia processing, project-based learning, creative education

Introduction

Industrial-scale of embedded software is very large, and software development cost in embedded product development is in excess of six trillion yen according to Ministry of Economy, Trade and Industry survey in fiscal 2011.

In recent years, mobile devices and information appliances are spread by high-performance and diversification, and embedded systems have come to be utilized in various fields. Multimedia processing system using graphics, such as video and images, audio and network techniques have become necessary; development of

embedded devices has become more complex.

However, PIC (peripheral interface controller) microcontroller, which is used in many engineering educational institutions, has not been used much in the real society; it also cannot perform multimedia processing. We have not had an educational material where students can easily exercise multimedia processing. In a poor I/O (input/output) interface that consists only of a button or an LED (light emitting diode), it is difficult at present to stimulate the students' interest and motivation for learning.

We developed a new educational material for embedded systems "E+", which enables the students to learn practical contents and stimulates their motivation for learning. We also evaluated its effectiveness of using the educational materials in our class. The class using the "E+" was offered whole year in the third grade. After learning computer architecture in the first half of the year, the students exercise basic programming by using the "E+". After that, the students create an original application.

We performed in collaboration with Tokyo Drawing Co. Ltd., which is a company of embedded systems developer, while utilizing our achievements of embedded technology education. This developed on the industry-academia collaboration, incorporating the needs and perspectives of both the educational institution and the corporate side. This paper summarizes the effect of educational results using the "E+".

Current Issues of Educational Materials

Currently, educational materials of embedded systems, which have been used in many educational institutions and training for new employees, have the following problems.

Materials Do Not Stimulate the Learner's Interests

ARCS (attention, relevance, confidence, and satisfaction) model of motivational design was proposed by Keller (1987; 2010). It is important that educational contents are interesting, and thus, they attract the learner's "Attention" and make the learner feel that there is a "Relevance" to himself or herself. Currently, almost all of standard learning materials are made by poor I/O interface, which consists of buttons and LEDs. It is difficult to arouse the interest of learners and the motivation for learning in these materials.

They Do Not Support Multimedia Processing

Current embedded devices have been featuring low power consumption and high performance processors. Multimedia processing has been used widely, to produce sounds, images, and videos. In particular, the number of shipments of LCD (liquid crystal display) has continued to increase steadily in recent years. LCD has been used in variety of embedded devices. However, many learning materials are not equipped with an LCD. Even if equipped, most of them are a "character LCD". The colour LCD which displays images would require the vast wiring connection. It is also difficult to extend. Similarly, a voice processing requires the creation of the peripheral circuits. It is difficult to use them in the limited time of the class. In order to perform processing of image and voice, high CPU performance is also required. The eight bit PIC microcontroller is suitable for educational purposes since its structure is simple. However, it does not have sufficient processing performance for multimedia processing.

The Development Environments in the Previous Materials Are Not Very Common in the Real Society

Japan has an excellent semiconductor product, which has been using in embedded devices in many markets. However, it is difficult to utilize the learned knowledge of PIC, because it is not very common in practical business. The standard development environment "HEW (High-performance Embedded Workshop)"

of the real society is not used in the class.

We interviewed educational side (professors of INCT (Ishikawa National College of Technology)) and corporate side (two companies of the embedded systems). Table 1 summarizes their opinions. Both the educational and corporate side want the learner to learn the fun of developing. The educational side has an opinion that materials should be handled easily by teachers when a new training system is introduced. The corporate side wants learners to learn practical contents, using modules which are actually used.

Table1

Desirable Educational Materials From the Perspectives of Academic Side and Corporate Side

Educational side	wants the students to be attracted by the materials.
	wants to use them with minimal time, even if they introduce a new exercise system.
	wants to increase the time of the essential exercises by reducing preparation of wiring and parts.
	wants the students to learn important contents simply yet deeply.
Corporate side	wants the students to experience a fun of developing embedded systems.
	wants the students to learn practical contents by using a module widely used in the companies.
	wants the students to acquire the tenacity of problem solving.
	wants the students to experience all the procedures from the specification to design and development.

Development of the Educational Material "E+"

In order to solve these issues described above, we developed educational material, which we call "E+". This name comes from the "Education + Easy + Embedded". Figure 1 shows a picture of the "E+".

First, let us describe the function and module that is installed to "E+". The "E+" is equipped with a SH2 (SuperH) (7084) 80 MHz, which is manufactured by Renesas Electronics 32 bit RISC (reduced instruction set computer) microcontroller used widely in the embedded industry. Modules have a basic I/O interface, such as buttons and LEDs. They perform multimedia processing by a colour LCD with a touch panel, an MP3 decoder, and a microphone input circuit IC (integrated circuit). Thus, it can increase the interest of the learner for the material. We make it easy to use the sensor with infrared, light, temperature, and distance sensor, in class exercises. We made it possible to write and read files on an SD card, to install a Real-Time-OS, and to communicate on Ethernet. Table 2 shows a list of features and modules that are mounted on.
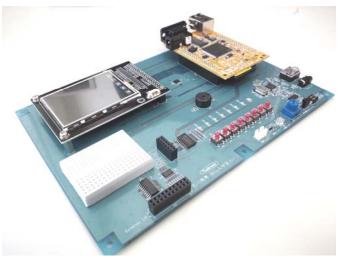

Figure 1. Learning board "E+".

Table 2

List of Items and Contents of "E+"

Items	Contents
CPU	SH2 (SH7084) 80 MHz
Flash memory	256 Kbyte
Internal memory	8 Kbyte
External memory	32 Mbyte (SDRAM (secure digital random access memory))
Interface	MMC (multi-media card) (SD card) Ethernet adapter RS-232C adapter
Display	2.2 inch color LCD with a touch panel
Sensor	Infrared sensor Distance sensor Temperature sensor Light sensor Potentiometer
I/O	GPIO (general purpose I/O) ADC (analog digital converter) Eight switches/Eight LEDs
Sound I/O	Microphone input circuit MP3 decoder IC
Other	8 bit DAC (digital analog converter) Piezoelectric buzzer Breadboard area Monitor for debug

Multimedia Processing

The "E+" is equipped with a 2.2 inch color LCD (built-in RAM (random access memory)) with a touch panel. "E+" is equipped with a MP3 decoder IC (integrated circuit) and an amplifier circuit; it can input audio by microphone, also play music files. It has become possible to connect to the network by using the RTOS (Real Time Operating System). Figure 2 shows a sample run of the software that controls the colour LCD. This program reads the BMP (BitMaP) image data from the SD card, and displays them to select the image on the touch panel. Students can develop a wide variety of applications, including a program that plays a song and displays a graph of the sensor data.
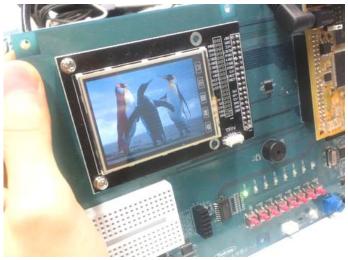

Figure 2. Example of image display.

CPU and Development Tools

The "E+" is equipped with a Renesas' SH2 microcomputer, which is very widely distributed in consumer electronics and automotive microcontrollers. The development environment is HEW, which is manufactured by Renesas' Electronics. HEW can be used free of charge. HEW is a standard development tool and used in many companies.

System on One Board

There is an issue that storing and debugging is time-consuming when developing embedded software. ICE (in-circuit emulator) tool is very expensive. It is very difficult to introduce it in educational institutions. In order to make it easy to debug serial communications, software debug monitor is pre-installed into the SH2 microcomputer. In the previous educational materials, students have sometimes destroyed the CPU by wiring the sensors and LCD wrongly. Some students had used more time to wire than to learn the contents. "E+" is equipped with the basic sensor modules pre-installed in a single board; students can learn smoothly.

Documents and Sample Programs

For beginners to learn embedded systems and software efficiently, it is essential to have the instructional documents. We prepared a manual and developed sample programs to accommodate various levels of students and a variety of educational settings:

(1) Start-up manual (23 pages):

  (a) Overview of "E+";

  (b) How to setup a development environment;

  (c) How to compile and run the program.

(2) Basic manual (34 pages):

  (a) Introduction to embedded systems;

  (b) Introduction of microcomputer control;

  (c) Description of the module with "E+";

  (d) Commentary of the basic sample project.

(3) Application manual (14 pages):

  (a) Commentary of the sample project application;

  (b) Application notes (13 pages);

  (c) Hints in the development;

  (d) Technical construction materials.

"Start-up manual" shows preparation of development environment and basic flow of execution of the sample project. "Basic manual" describes functions of the individual modules and the sample project. "Application manual" explains the combination of multiple functions used in the basic manual.

We were able to respond flexibly to the needs of students and teachers by offering the rich documents from basic contents to applications.

Sample projects are divided into two categories of "basic sample projects" and "application sample projects". Basic sample projects include how to get the value of the underlying sensor and LED flashing. Application sample projects contain how to control the touch screen combination and to play the MP3 file. The contents are shown as follows:

(1) Basic sample project (seven projects):
  (a) flashing LED;
  (b) switch input;
  (c) AD-conversion;
  (d) Buzzer-control;
  (e) DA-conversion;
  (f) Output serial character;
  (g) External interrupts processing.
(2) Application sample project (nine projects):
  (a) AD conversion value display on PC;
  (b) getting the coordinates of the touch panel;
  (c) infrared remote control;
  (d) text saving in the SD card;
  (e) BMP image display on the LCD;
  (f) Bar graph display of the sensor values on the LCD;
  (g) MP3 file playing;
  (h) servo motor control;
  (i) the I/O extension in the serial-to-parallel converter IC.
These manuals and sample programs are open to access on the Web-site http://koshinolab.jp/eplus.html.

Evaluation

Evaluation Before Teaching

"E+" has been used in the third grade class "computer architecture" of about 40 students since 2011. In order to investigate whether the purpose of this study has been achieved, we conducted a questionnaire survey in two parts before and after teaching a class "E+".

We made the first survey in the first class, using the "E+" before evaluation. We made a presentation to introduce previous educational materials "Easy PIC" by "MikroElektronika", and then provided an overview of the newly developed "E+". Students were then asked 16 questions about their interest in each of the "E+" and Easy PIC. Questionnaire score is set up from 1 to 5 for each question: 1 is the worst, and 5 is the best.

Table 3

Comparison and Evaluation in the "E+" and Easy PIC on Attention and Relevance

A and R	Question items	Easy PIC	E+
A: Attention	Are the application examples intriguing to you?	4.24	4.34
A1: Perceptual arousal	Do you think that this board is more useful than expected?	3.84	4.24
A2: Inquiry arousal	Are you interested in this board?	3.89	4.21
A3: Variability	Do you think that you can do various things by this board?	3.87	4.24
R: Relevance	Do you think that this board offers technology relevant to you?	3.92	4.13
R1: Familiarity	Do you think that this board is readily accessible to you?	3.92	4.13
R2: Goal-orientation	Do you think that what you learned in this board is useful in the future?	4.26	4.26
R3: Motive matching	Do you want to acquire skills from this board?	4.03	4.26
Average		4.00	4.23

The questionnaire items were set up by the ARCS model, which is proposed by John Keller, and is a theory to explain the motivation. In order to enhance the educational effect by stimulating the motivation, it is necessary to pay attention to the following four elements of ARCS: "attention", "relevance", "confidence", and "satisfaction". We have created the first questionnaire focusing on "attention" and "relevance", because educational materials should have these pointes. "Confidence" and "satisfaction" are evaluated after completing all the classes, because it needs a series of educational processes. Table 3 shows questions on the "A (attention)" and "R (relevance)". They evaluate each of the proposed material "E+" and the previous material "Easy PIC".

Both materials scored the same value in the question of R2 (goal-orientation) "Do you think that what you learned in this board is useful in the future"? For all the other questions, "E+" obtained more points than Easy PIC.

The average value of Easy PIC is 4.00, while that of "E+" is 4.23.

Evaluation on Class

In this class, students are required to create an original system using several modules for three to five weeks. After studying input and output items, such as switches, LEDs, AD converts, and an interrupt processing, students work on the exercise using the "E+" of their own. When students want to use other modules other than those installed in the "E+", they can order the necessary modules through Websites of electronic components. Students tend to start to create a program from the beginning without thinking. Therefore, after we give a lecture about program developments, we have students create a manual and specifications first. Then, students develop their own system, considering the whole system in their minds.

The goal of this exercise is to have the students acquire practical skills of embedded development. The instructors do not give advice until the students study well by themselves and check manuals thoroughly.

At the end of this exercise, students give a presentation of a few minutes. They provide a demo of the developed system and tell the points they devised. Some of the students' works are shown below:

(1) Breakout game;

(2) MP3 player remote control;

(3) Spectrum analyzer of music players;

(4) Electronic organ piezoelectric buzzer;

(5) Drawing software using the touch panel;

(6) Photo viewer with touch panel operation;

(7) LED colour changing illumination at a distance.

Utilizing rich sensors installed in the "E+" and the peripheral devices, students have developed a wide range of applications in a short period of time. It is not easy to make it by using the previous material, and students were able to learn practical contents of development in an efficient manner by using "E+".

Evaluation After Teaching

The second questionnaire survey was conducted after all the classes. The questionnaire items are about "confidence" and "satisfaction" of ARCS. Question C3 is added to ask whether the student was able to achieve the class goal.

Table 4 shows the questionnaire items and evaluation results. Because we have not done a survey in the previous year, we cannot compare the proposed material with the previous material "Easy PIC" in these aspects.

Table 4

Evaluation Results in the "E+" on Confidence and Satisfaction

C and S	Question items	Average
C: Confidence	Are you now confident with the developing embedded systems?	2.30
C1: Learning requirement	Was the goal of this course clear?	2.79
C2: Success opportunities	Were you able to work on the development and your study step by step?	2.47
C3: Personal control	Were you able to devise your project of your own?	2.93
S: Satisfaction	Are you satisfied with the learning in this educational material?	3.80
S1: Natural consequences	Was this exercise helpful to improve your general technical capabilities of making things?	3.54
S2: Positive consequences	Are you and others satisfied with your work?	2.59
S3: Equity	Were the instructors' evaluations fair?	3.05

The average score of the question "Are you satisfied with what you learned by using this board?" of S (satisfaction) is high 3.80. This shows that students are satisfied to have received this education by using "E+".

However, the average scores of items concerning C (confidence) are less than 3.0. We guess from the written comments that students might have lost their confidence. The contents of "E+" are advanced and students could not understand all of them. However, we also received many comments saying that "It was very difficult, but I found how that equipment can be familiar". The new material has given a positive effect for their future learning.

Table 5 shows the students' answers of a question "Do you think you are now more familiar with controlling method of the electronic devices by what you learned with the 'E+'"? The average score of the answers is 3.9/5.0.

Table 5

Question "Do You Think You Are Now More Familiar With Controlling Method of the Electronic Devices by What You Learned With the 'E+'?"

Answer	Percentage (%)
5: Absolutely	20
4: Mostly	46
3: Moderately	28
2: Somewhat	3
1: Not at all	3

One of the objectives to introduce "E+" has been to have the students study multimedia processing. Table 6 shows the level of understanding of programming and controlling method for 12 students who used the LCD and MP3 decoder for their own work. We could not explain how to control the LCD and MP3 decoder in the class. However, a total 58% of the students understand them "mostly" or "moderately", even though they are difficult contents. Two students (17%), on the other hand, answered that they could not understand them at all. In order to have more students understand multimedia processing, we need to prepare the documents and explain how to use them in the class.

One of the features of "E+" is that we prepared documents and samples. Table 7 shows the answers of the questions in "Please tell us which documents are useful". The score of "Start-up manual" is 35%. The one of the basic manual is 79%. The application manual score is 51%. More than half of the students used the basic and application sample projects. The average value of the question "Is it easy to understand the manuals?" is 3.56. This result shows that the manuals and sample programs of "E+" can be good enough to support learners.

Table 6

Understanding Level of the Color LCD and MP3 Decoder

Understanding level	Number of students	Percentage (%)
5: Perfect	0	0
4: Mostly	3	25
3: Moderate	4	33
2: Somewhat	3	25
1: Not at all	2	17

Table 7

Useful Documents and Sample Projects

Contents	Number of students	Percentage (%)
Start-up manual	14	35
Basic manual	31	79
Application manual	20	51
Basic sample project	28	71
Application sample project	24	61

Note. Multiple answers were allowed.

Conclusions

In this study, we developed practical educational materials for embedded systems to motivate learners. We also developed documentations and sample programs for the learners to study the subject in an efficient manner. We have introduced those materials into our school classes, and demonstrated that they enhanced the interest of learners' motivation compared to traditional materials by questionnaire surveys using the ARCS model. We solved several problems of traditional learning materials and improved the students' understanding of the multimedia processing.

In the future, we would like to continue the improvement of "E+" and to add further documents with Companys' cooperation, based on the survey results and student comments.

References

Keller, J. M. (1987). Development and use of the ARCS model of instructional design. *Journal of Instructional Development, 10*(3), 2-10.

Keller, J. M. (2010). *Motivational design for learning and performance: The ARCS model approach*. Springer.

Yamada, Y., Kanedera, N., Komura, R., & Okano, S. (2011). Improvement of learning process through project-based learning and repetitive learning. *ISATE 2011 International Symposium on Advances in Technology Education*, Singapore.