

Two-dimensional Barcodes: An Effective Real World Example To Teach Design and Programming

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ABSTRACT: *In this paper, we will discuss the experience of developing projects based upon a central real world example to introduce first year students to engineering. We will outline how the theme of two dimensional barcodes was used to introduce our students in the freshmen Foundations of Engineering I (ENGR111) course to the key skills of engineering design, problem solving, teamwork and computer programming. Results show that the students found the experience positive.*

Keywords: Active Learning, Freshmen Engineering Courses, Engineering Design, Problem Solving, Programming Courses

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1. Introduction

The Foundations of Engineering I (ENGR111) course at Texas A&M University at Qatar (TAMUQ) is a freshmen course in which all incoming students are inducted into the basic skills needed in their practical life as engineers. This course is taught to all the first year students from the four majors offered at the campus (Petroleum, Chemical, Electrical and Mechanical). A significant portion of the work given to ENGR111 students is project oriented in which they apply the key skills of engineering design and computer programming. The assigned projects are targeted at encouraging independent thinking, technical presentation and problem solving skills; all of which are crucial skills for the four engineering programs at TAMUQ.

The hands-on project based learning experience provided in the course introduced the students to teamwork and engineering as they work with their peers from other disciplines to solve real life problems. The course provided a whole new culture to a group of students who had limited exposure to teamwork and engineering.

During the term, the projects given to ENGR111 students were selected such that they were based upon a common theme of a real world example to keep continuity in the course and maintain student interest. The pedagogy of developing projects based on a central theme was initiated based on feedback from the students in previous terms. The course was organized such that material was presented in the lectures and laboratories in a 'just-in-time' mode to provide the students with the required background for the projects. The projects were set out such that the students needed to identify and document the various steps of the complete design cycle; including defining the problem, identifying constraints and criteria for success, searching for solutions, analyzing and implementing the solution, and communicating their results. In this paper, we discuss how the real world example of two-dimensional barcodes was used to create two projects in the ENGR111 course.

2. Two-Dimensional Barcodes

The fundamental principle of 2D barcodes is simple: they are basically graphical images that store information both horizontally, as one dimensional barcodes do, and vertically as shown in Figure 1. Each square in the grid represents one bit (i.e. 0 or 1). A white square represents a '1' and a black a '0'. As a result of this construction, 2D codes can store thousands of characters, significantly greater storage than is possible with the 20-character capacity of a one-dimensional barcode [1]. There are about 20 types of 2D barcodes used in a wide variety of applications, including security, logistics & transportation, retailing, healthcare, government, identification, and manufacturing [2]. As 2D barcodes are often used in conjunction with smart phones and in advertising, it is a current technology that a large number of the incoming freshmen have been exposed to but still novel enough to not be completely familiar with.



Figure 1. An example 2D barcode

2.1 EZcode

The EZcode [3] layout is pictured below in Figure 2. It consists of the following elements:

- a larger and a smaller guide bar for determining the location and orientation of the code,
- three cornerstones for detecting the distortion, and
- data area with the actual code bits.

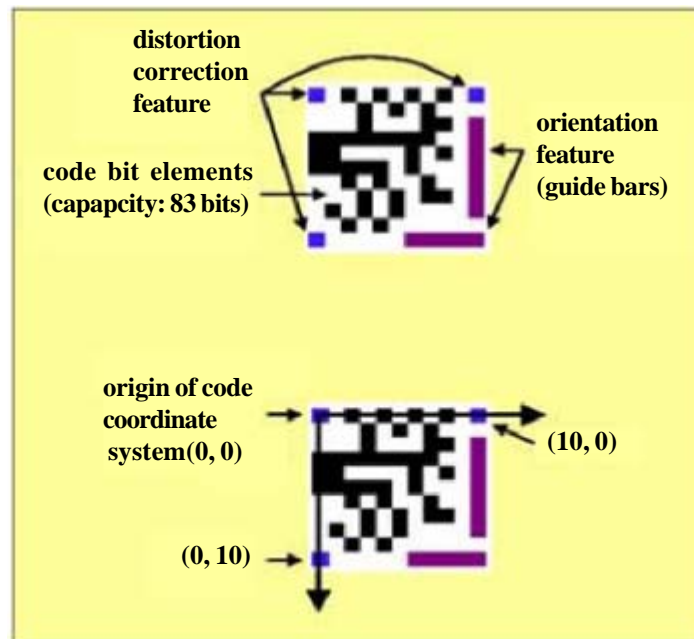


Figure 2. The layout of the EZcode and the coordinate system [3]

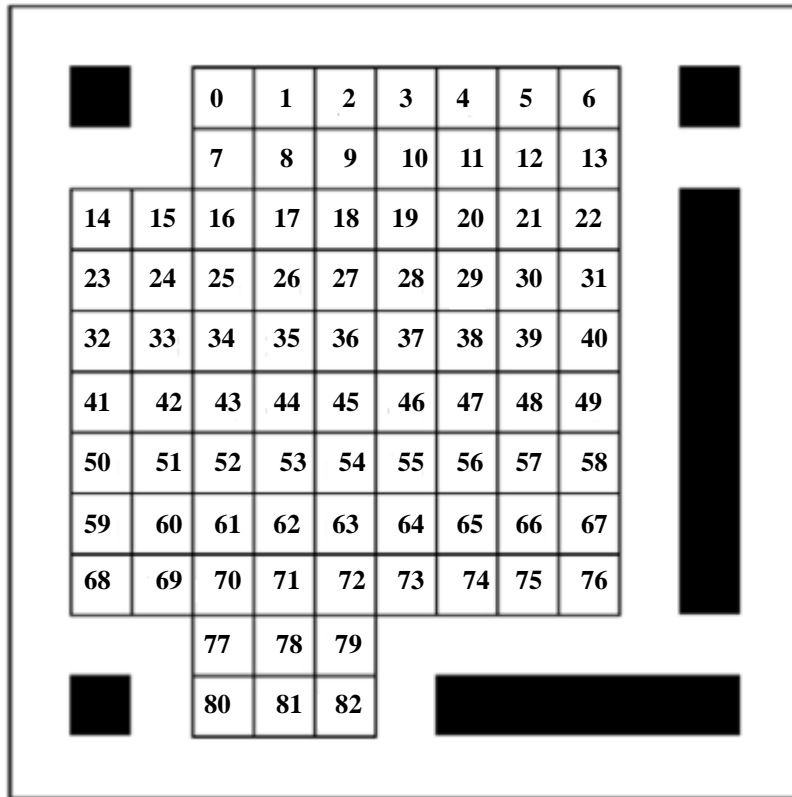


Figure 3. Data region and encoding order of EZcode

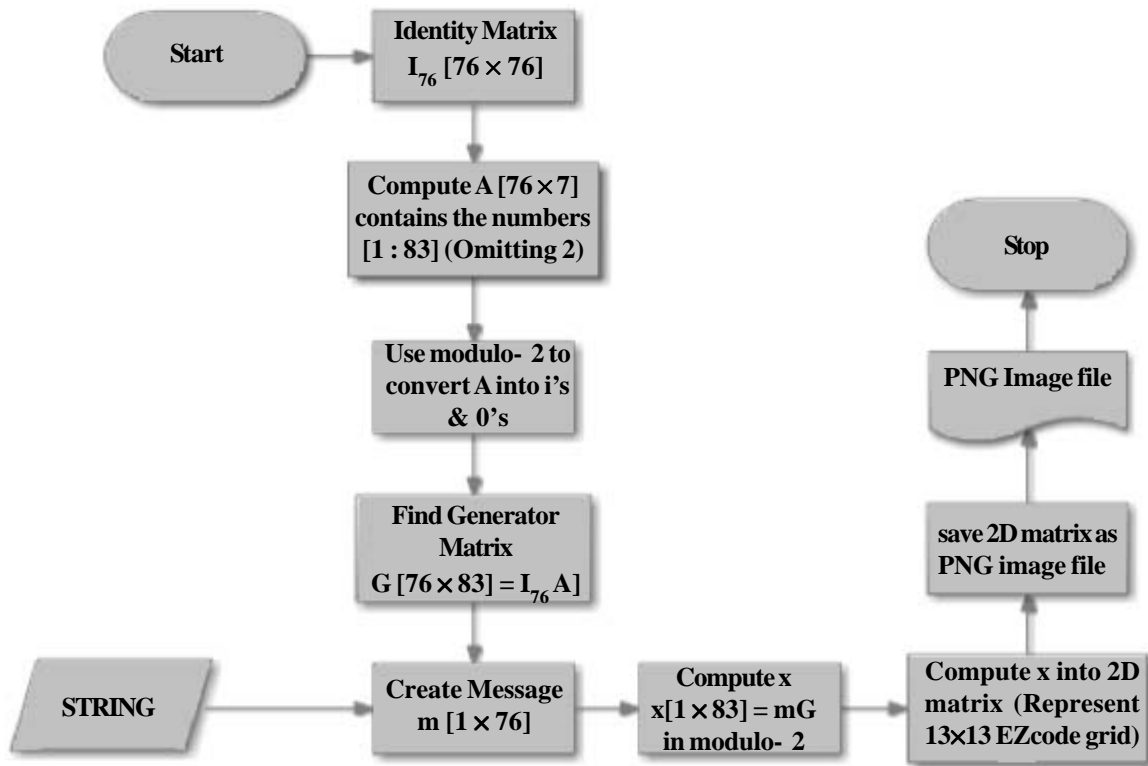


Figure 4. Project 1 – Flowchart

Deliverables	Assessment criteria
1. Project plan	Format, feasibility of plan, fairness of task distribution
2. Logic flowchart	Correctness, logic presented, clarity
3. Project poster	Tests for encoding and decoding, required correct plots, description of problem, presentation style
4. Final MATLAB code	Correctness, use of functions and loops, use of conditionals

Table 1. The deliverables in project 1

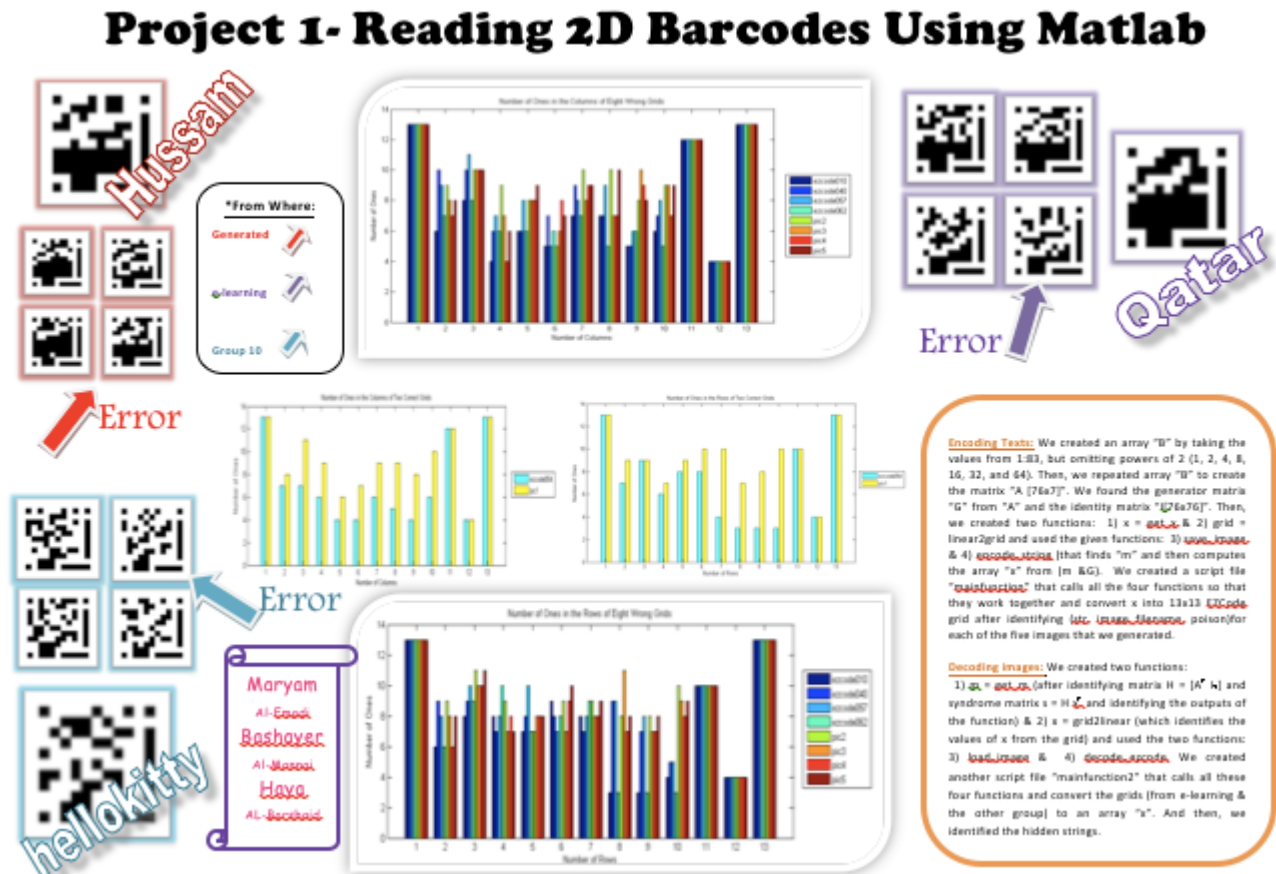


Figure 5. Project 1 - Final poster

The EZcode has a storage capacity of 76 bits. In order to detect pixel errors and false orientation features, the code bits are protected by an (83,76,3) linear code that generates an 83-bit code word from a 76-bit value and has a Hamming distance of 3. The 83-bit code word is embedded in the data region of an EZcode. As illustrated in Figure 3, all bits inside the data region are marked from 0 to 82. The highest index corresponds to the most significant bit and the lowest index corresponds to the least significant bit.

3. Fundamentals of Engineering (ENGR111) Projects

This course is based upon a project based learning approach. The projects in ENGR111 were designed such that the students needed to become competent in basic programming and engineering design skills while working constructively in a team to complete the projects. The projects culminated with a technical presentation to allow the students to develop skills needed when presenting results. To expose the students to a real world engineering problem, the projects were centered on the common theme of two-dimensional barcodes. As the defacto programming tool in the majority of the courses in all four disciplines at TAMUQ is MATLAB, it was chosen as the language in which to teach the freshmen students programming. Detailed surveys of the faculty in

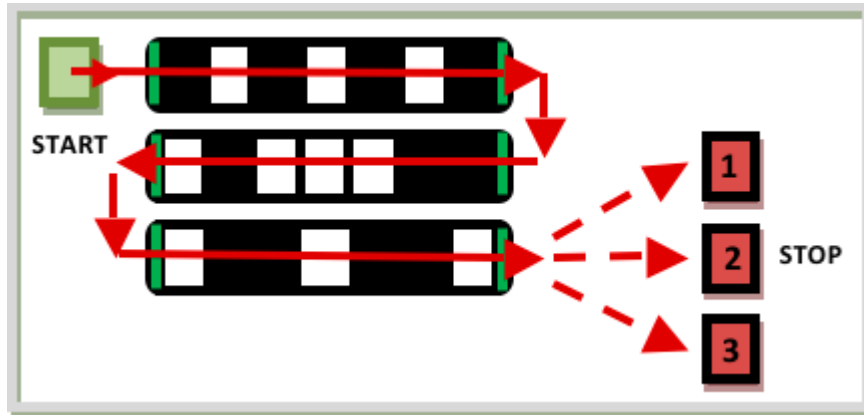


Figure 6. The track of the robotics project

Deliverables		Assessment criteria
1	Initial design proposal	Sub-division of the tasks, feasibility of the plan, fair distribution of tasks.
2	Mid-project robot design	Demonstration of autonomous robot that can moving in straight line and identify black and white squares
3	Robot trial run	Demonstration of autonomous robot capable of completing track with limited intervention
4	Program flowchart	Correctness, logic presented, clarity
5	Robot for competition	Extent to which the robot completes tasks autonomously
6	Matlab code	Correctness, use of functions and loops, use of conditionals
7	Final Report	Writing and presentation style, completeness, content

Table 2. The Deliverables In Project 2

all four programs indicated a strong desire to build the MATLAB skills of the students to better prepare them for their future courses.

3.1 Project 1

In the first project, students developed code in MATLAB, using matrices, arrays, strings, loops and conditionals to implement the encoding and decoding schemes of a simplified 2D format over a 3 week period. The project made them aware of the basics of coding theory including how error detection and correction bits are used in identifying defective barcodes and the trade-off between accuracy and data capacity.

Through this project, students learnt how data is first converted to digital format to be encoded and then stored in 2D barcodes. They were guided on a specific structure to follow that included the use of loops, conditionals and functions to ensure they learnt the fundamentals programming. Students had to develop MATLAB functions to decode correct and incorrect images as well as encode given strings into the corresponding images over a three week period. Part of the code was given to them in the form of reusable functions to help them overcome the out-of-scope coding blocks in building a larger program.

In this project, the students were also taught to use simple engineering design techniques like flowcharts as shown in Figure 4. To



Figure 7. Project 2 – Work Breakdown Structure

introduce them to project management tools, they were asked to prepare a project plan at the start of the project in which they had divide the project into milestones, allocate tasks to individual team members and present a project timeline. At the end of the project, students presented their work in a poster as in Figure 5 to show their work. Table 1 shows the deliverables that the students had to submit as part of their project.

The poster element was added to build the technical presentation skills of the students and they were thus beforehand given a session on how to effectively present technical information in a poster. In the poster the students had to present how successful their encoding and decoding functions were. They also had to provide the barcodes they decoded and the messages that they encoded. They also had to analyze the images they worked with by creating functions in MATLAB to determine the number of white and black squares in

**The ‘Robo-scanner’ Team Project
Group (01)**

Task	H	D	A	B.H.
Robot construction				
1. Robot kit collection	1	2	2	
2. Robot Design	1	1	2	3
3. Robot Creation	2	1	2	
4. Robot Completion	1	1	1	
Loop Programming				
1. Robot Movement	1	1	1	3
2. Robot Scan	1	1	1	
3. Robot Directions	2	1	1	
4. Robot Decoding	1	1	1	
Robot Testing				
1. Playing sounds/ movement	1	1	1	3
2. Straight walking/ color differentiation	1	1	1	3
3. Trail run	1	1	1	3
4. Final testing	1	1	1	3
Report preparation				
1. Initial Design Proposal	1	2		
2. Mid-Project Review	2	2	1	3
3. Project Flowchart	1	2	2	
4. Final Report	1	1	1	
(1) = Primary Responsibility (2) = Support (3) = Must Be Consulted				

Figure 8. Project 2 - Linear Responsibility Chart

the rows and columns of the grids and plot the results. These results also had to be discussed in their poster.

3.2 Project 2

The authors earlier found robotics projects to be an active learning tool for teaching engineering design as it effectively engages the students [4]. The project was thus designed to introduce them to the main components of an engineering design problem and at the same time build some basic programming skills. The project thus involved multiple steps and milestones to be completed over a 4 week period; thus necessitating that the students plan their activities well ahead of time. This project was used to introduce the students to the importance of effective time and project management, both of which are essential skills for their future as engineers.

Percent Complete Matrix (Group 01)

Robot construction				
1. Robot kit collection	1	3%	2	1.0
2. Robot Design	1	3%	2	1.0
3. Robot Creation	3	8%	2	3.0
4. Robot Completion	1	3%	2	1.0
Loop Programming				
1. Robot Movement	2	5%	2	2.0
2. Robot Scan	3	8%	2	3.0
3. Robot Directions	2	5%	2	2.0
4. Robot Decoding	3	8%	1	1.0
Robot Testing				
1. Playing sounds/ movement	1	3%	2	1.0
2. Straight walking/ color differentiation	2	5%	2	2.0
3. Trail run	4	10%	2	4.0
4. Final testing	4	10%	0	0.0
Report preparation				
1. Initial Design Proposal	4	10%	2	4.0
2. Mid-Project Review	2	5%	2	2.0
3. Project Flowchart	2	5%	2	2.0
4. Final Report	4	10%	0	0.0
Total Days	39	100%		74.36%
*(0) = No started “No credit” (1) = In Process “1/3 Credit” (2) = Completed “Full Credit”				

Figure 10. Project 2 - Percent Complete Matrix

In this project, the students were assigned multiple steps and milestones similar to those used in typical of engineering projects over a 4 week period culminating with a competition. To ensure the students completed the projects on time they were given intermediate deadlines and submissions. Table II gives the deliverables that all of the teams had to produce during the course of the project. The overall project grade was divided amongst all these deliverables according to a detailed grading rubric. Through these deliverables, the students were taught how to use standard project management tools to plan their activities ahead of time and the teams produced several engineering documents. Their initial design proposal included a Work Breakdown Structure (Figure 7), Linear Responsibility Chart (Figure 8) and Timeline (Figure 9).

The teams had to report their progress in the project weekly using Percent Complete Matrices (Figure 10). They also had to detail the working of their program logic using flowcharts (Figure 11). At the end of the project, the students had to produce a working autonomous robot that would participate in a final competition open to the whole campus (Figure 12). The competition element was added to motivate the students and add a fun element to the project. For the technical presentation part of the project, the students summarized the work they did in a technical report. In the report the teams had to describe their final robot design including the major components and results of any computations that they have performed to quantify the robot’s performance. They also had to summarize how successful their robot design was in the Robo-Scanner Competition and the limitations of their robot design.

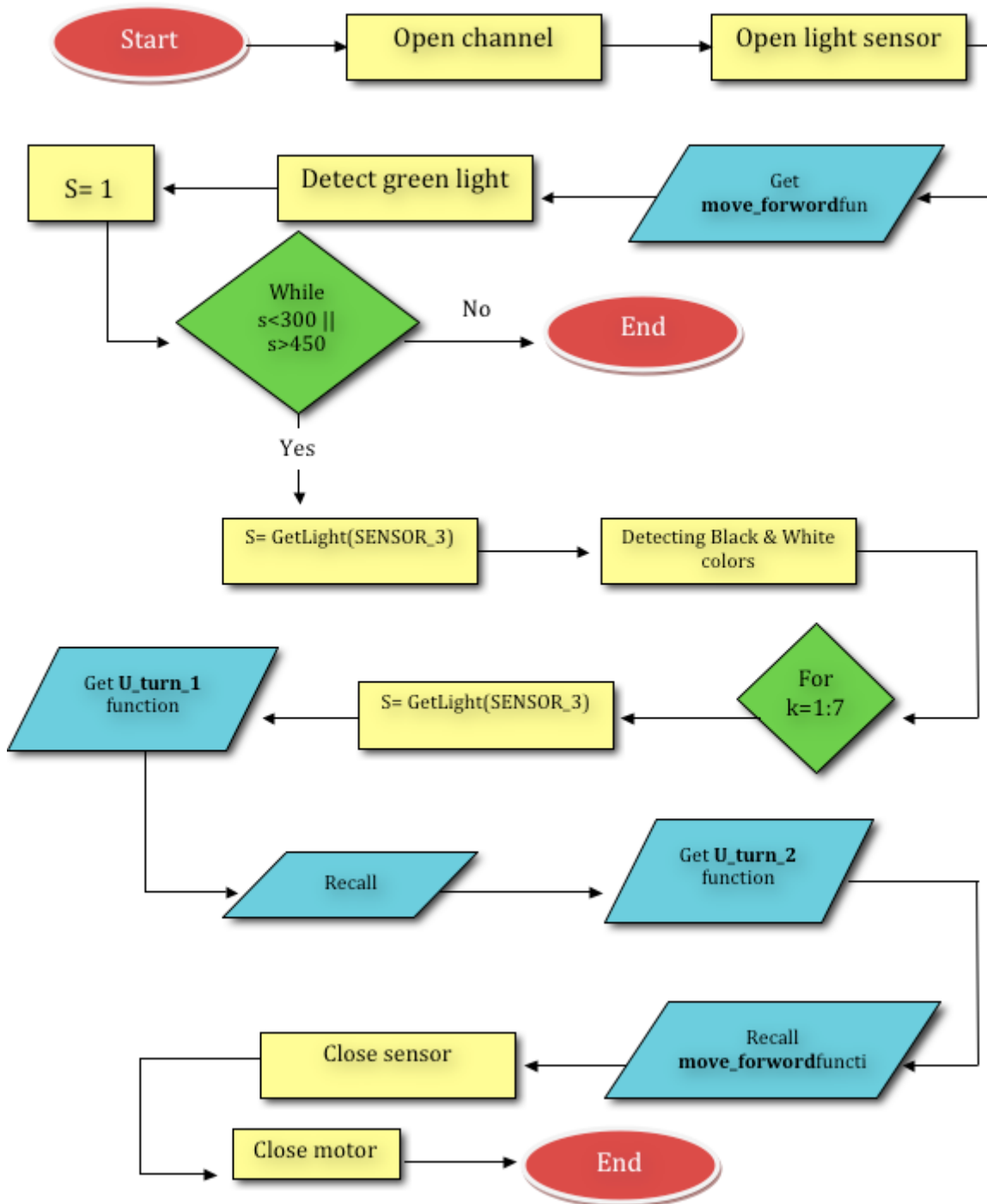


Figure 11. Project 2 - Flowchart

3.3 Teamwork

As in today's world most engineering projects are completed by teams, it was imperative that the students understand what teamwork is at an early stage. Most of our freshmen students were found to have had limited exposure to teamwork in their high school careers, hence it was important to provide the students with the opportunity to develop these skills and provide them with appropriate feedback tools. This is why one of the learning objectives of the course was to teach the students to 'function as a team and complete project team assignments with little supervision'. For the projects, the students were placed in groups chosen by the instructor structured such that the team members had previously not worked with each other in earlier projects.



Figure 12. A robot participating in the competition

Outcome	A	B	C	D
a	0.00%	2.90%	67.70%	29.40%
b	0.00%	5.90%	67.60%	26.50%
c	0.00%	11.80%	38.20%	50.00%
d	0.00%	11.80%	41.20%	47.10%
e	2.90%	20.60%	47.10%	29.40%
f	0.00%	11.80%	55.90%	32.40%
g	0.00%	17.60%	53.00%	29.40%
h	0.00%	17.60%	44.10%	38.30%

Table 3. The ENGR111 learning objectives survey results

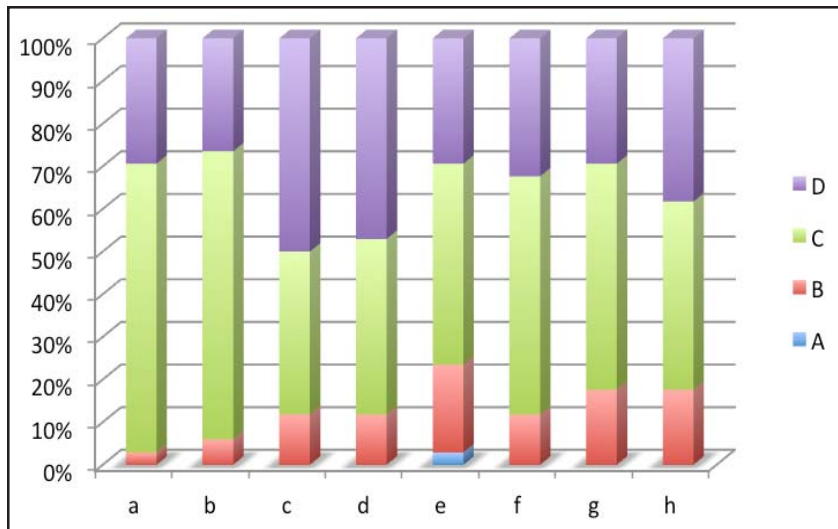


Figure 13. Learning Outcomes chart for the course

As teamwork was a key component of both projects, it was vital that the individual contribution of each member be accurately assessed. This was done by asking the students to provide feedback about their teamwork experience via confidential peer evaluation forms for both projects. In it the students assessed the individual contribution of his/her team members and themselves on a range of criteria such as organization, participation, punctuality, attitude, concern towards others and listening skills. To ensure the validity of the final peer evaluation, brief individual assessments were also conducted randomly during the projects. The feedback obtained from these evaluation forms were then used to adjust the final project grade.

4. Survey Results

Using project based learning together with a coordinated lecture and laboratory structure; it was possible to meet the learning objectives set out for the course. The course was able to provide a truly multidisciplinary introduction to the students about

engineering using a real world example. At the end of the course surveys were conducted to determine how effective the pedagogy used in the course was. Students were asked to assess how well the two projects helped them in developing their programming and engineering design skills. The students were also asked to express their opinion on the experience of having projects based on a central theme. Survey results at the end of the course showed the students found these projects interesting and beneficial in understanding engineering.

The course learning outcomes for ENGR111 are as follows:

- a. Identify the responsibilities and ethical commitments of engineers
- b. Produce effective written and oral Communications
- c. Function as a team and complete project team assignments with little supervision
- d. Demonstrate the ability to do neat work and to be well organized
- e. Use problem solving skills to solve simple engineering problems
- f. Apply the basic tools of engineering design and project management
- g. Develop functions and programs in the provided programming environment
- h. Use arithmetic, relational and logical operators and variables in a program

	Strongly Agree	Slightly Agree	Neutral	Slightly Disagree	Strongly Disagree
1	33.3%	36.4%	15.2%	6.1%	9.0%
2	45.5%	36.4%	12.1%	3.0%	3.0%
3	42.4%	42.4%	9.1%	3.1%	3.0%
4	15.2%	48.5%	21.2%	12.1%	3.0%
5	33.3%	33.3%	18.3%	3.0%	12.1%

Table 4. Project Survey Results

Results of the student survey (Table III and Figure 13) conducted at the end of the term indicated that the course was able to achieve its desired goals. Student feedback was positive, with most students enjoying the course as they felt they had learned a lot about engineering through it. The learning outcomes were assessed using a four point scale of A-D with A corresponding to having no understanding, B having a limited understanding, C having an understanding and D being skilled in the learning outcome.

It is clear from Figure 13 that the feedback was positive for all the learning outcomes with varying percentages. Students identified as having ‘no understanding’ of only one outcome (2.9%) with 20.6% having ‘limited understanding’ of the same outcome. 40%~70% of the students felt they had a ‘good understanding’ of the outcomes and 25%~50% felt they were ‘skilled’ in these outcomes.

The students were also surveyed specifically about the use of project based learning experience to teach them about programming and design. They were asked to assess on a scale of 1 to 5 ranging from Strongly Disagree to Strongly Agree respectively the statements below:

- 1- Project 1 helped me in learning how to program with MATLAB.
- 2- Project 2 helped me in learning how to program with MATLAB.
- 3- Project 2 has been effective in teaching me about the engineering design process.
- 4- I am now comfortable working with MATLAB.
- 5- The peer evaluation process was a good way to give honest feedback about the team work experience.

Table 4 and Figure 14 present the results of the surveys. The results show that the majority of the students (more than 70%) agreed that the projects were useful in teaching them about programming and design. Only 15.1% of the students disagreed that Project 1

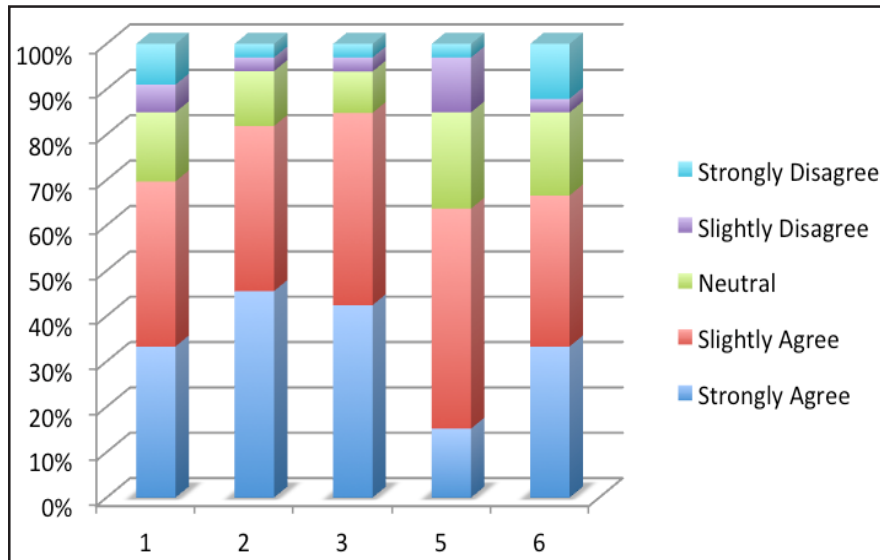


Figure 14. Project 2 survey results

helped in the learning MATLAB. Whereas only 6% of the students disagreed that Project 2 was useful in learning programming and engineering design.

Comments given by the students about the projects include

- *'The projects helped me to learn the real engineering.'*
- *'At the start Project 2 was difficult but after making it and understanding the concepts of it, it became something enjoyable to work on.'*
- *'Team work was a good chance for me to learn to deal with others.'*
- *'I want the main concept of each project to remain the same, but the amount of time must be changed.'*
- *'Ideas of projects were interesting.'*

5. Conclusions

In this paper, we have shown how a freshmen introductory engineering course consisting of multiple projects can be centered around a theme of two dimensional barcodes to introduce students to key engineering skills. The experience was extremely positive with a programming and a robotics project based upon two-dimensional barcodes. The projects provided students with the opportunity to participate in hands-on, project based learning by working teams with their peers from other disciplines to solve real life problems. Survey results show that the projects were successful with students developing a good understanding of all the course learning outcomes. Students also found the project-based learning experience with more than 70% of the survey participants finding the project useful in learning programming and developing engineering design skills.

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