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Using LEGO® Mindstorms and MATLAB in Curriculum Design of Active Learning Activities for a First-year Engineering Computing Course

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Background: ENCP 100

- Engineering, Computer 100 (ENCP 100)
  - Mandatory to all first-year engineering students

- 13-week introductory programming course in MATLAB, with problem-solving methodology

- Teaches students the fundamentals of computer programming [1]

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Background: MATLAB

- “A programming platform designed specifically for engineers and scientists… a matrix-based language allowing the most natural expression of computational mathematics.” [2]

- Analyze, format, graph, and manipulate data
- Develop algorithms
- Create models and applications

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Research Project Goals

1. Investigate literature to explore the use of active learning tools in first-year engineering education
2. Determine the capabilities of the LEGO® Mindstorms platform as an “active learning” tool
3. Use the information gained to propose and test active learning lab activities

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Literature Review: Behrens et al.

- Inspiration for this research project came from two papers by Behrens et al [3], [4]
- Freshman engineering introduction course at RWTH Aachen University, Germany
- 309 students given 100 LEGO Mindstorms robots
- “Encouraged [students] to transfer known mathematical basics to program algorithms and real-world applications”

Literature Review : Behrens et al.

- Conclusion:
  - “Successfully boosts students’ motivation, advances their programming skills, and encourages the peer learning process”

Literature Review

- Traditional teaching methodologies focussed on knowledge transfer are becoming obsolete; "knowledge acquisition must be linked to their application" [5]
- "This study has found support for all forms of active learning examined… benefits of student engagement…likely to positively influence student attitudes and study habits… students will retain information longer and develop enhanced critical thinking and problem-solving skills" [6]

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Literature Review

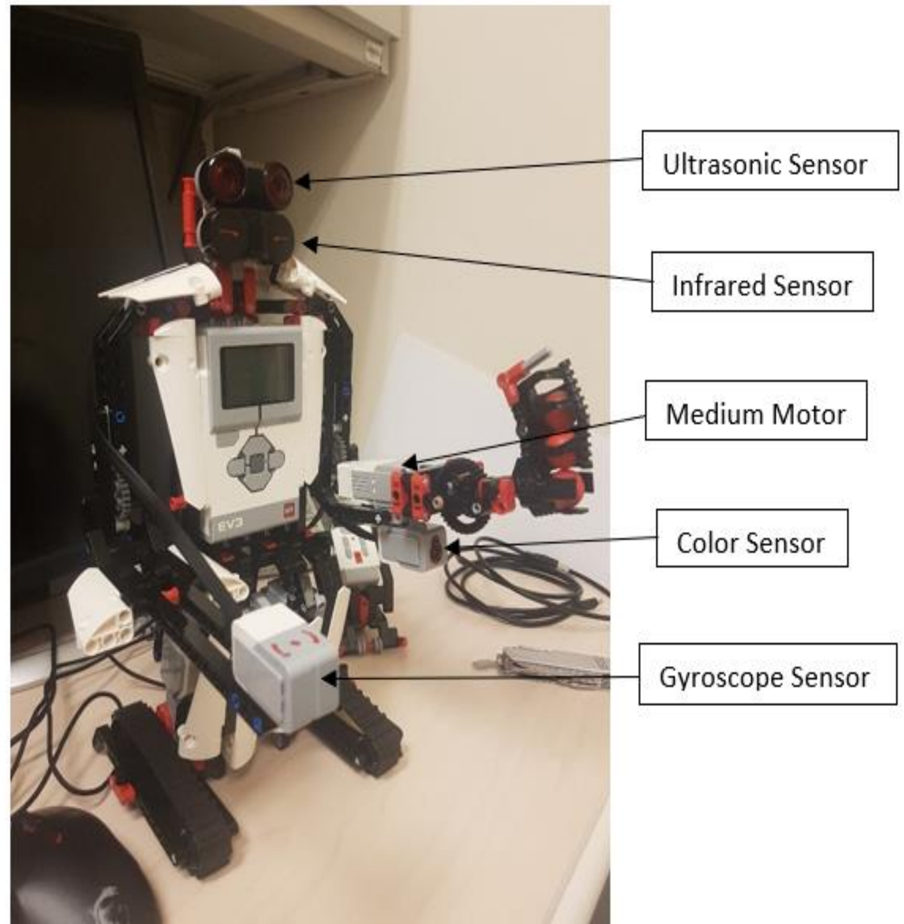
- Reviewed over 100 research papers
- 89 applicable research papers

- The problem: very few specifics on the activities and assignments
- Nearly all was qualitative research

LEGO® Mindstorms

- A programmable robotics construction set
- ~$400 CAD per set
- 2 large motors
- 1 medium motor
- 5 sensors

Beacon Remote



Fred Version 1.5

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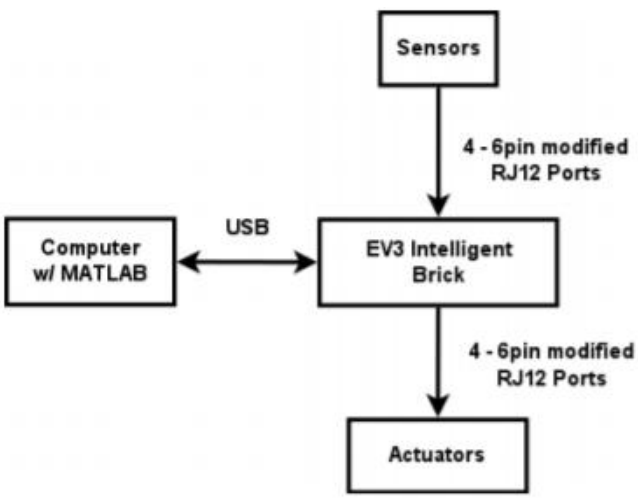
Mindstorms and MATLAB

- Connect the EV3 Intelligent Brick to a computer via USB, wi-fi, or Bluetooth connection
- Free MATLAB add-on, “MATLAB Support Package for LEGO MINDSTORMS EV3 Hardware” is needed



Sensor/Motor Evaluation for LEGO® Mindstorms EV3

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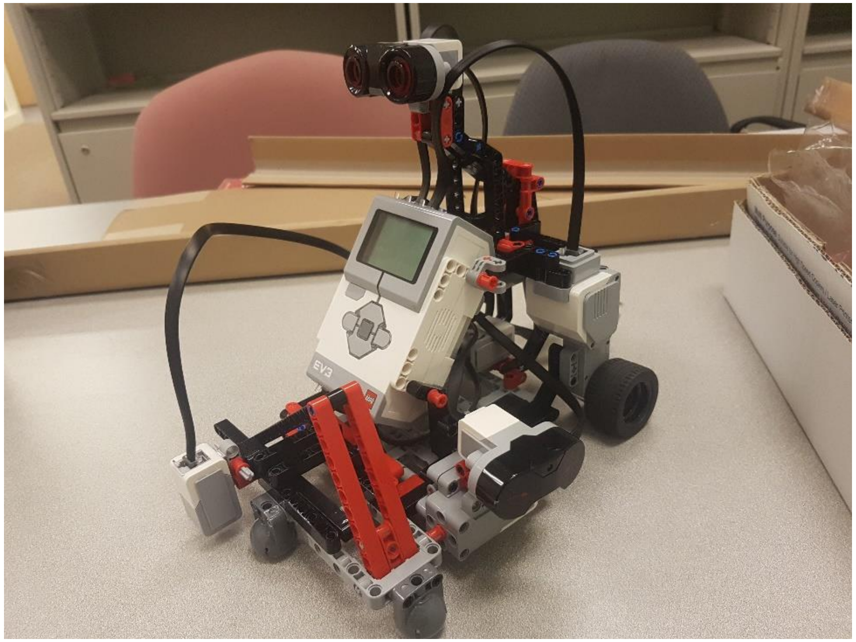
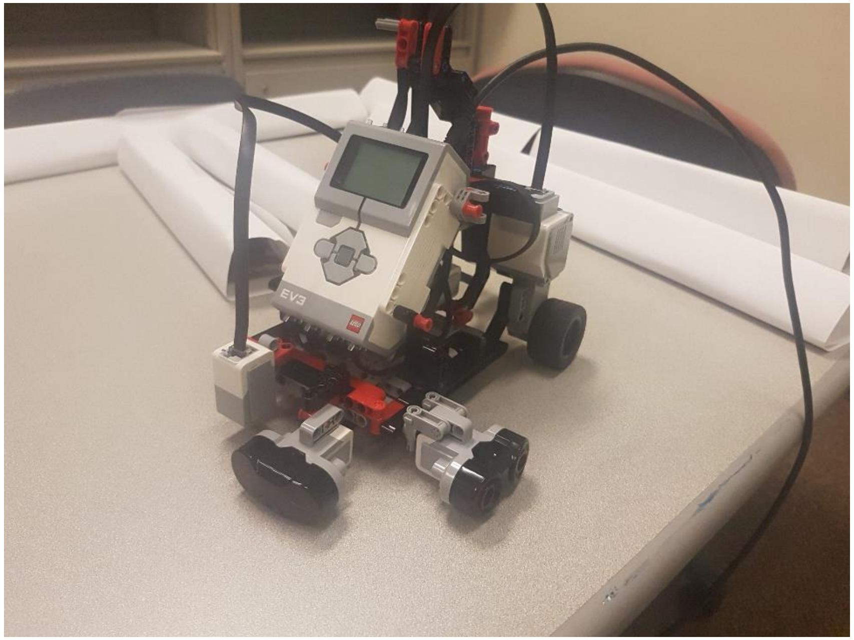
Fred

Linear Actuator Scanner Version



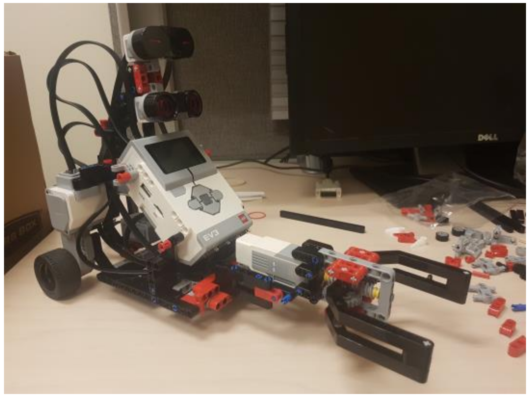
“Maze Solver” Version



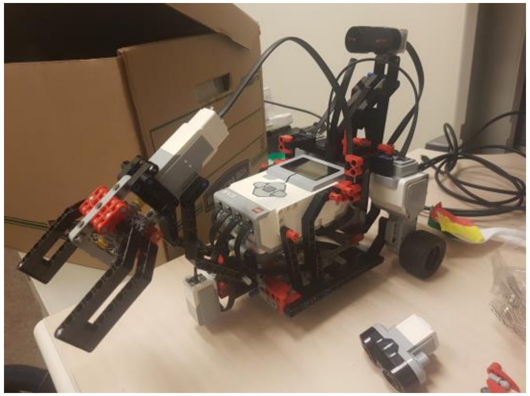
Barney

Ev3meg Design

Claw Version 1



Claw Version 2



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Coding Mindstorms: Simple Tasks

Moving Forward

```
Fred = legoev3('usb')

myLeg1 = motor(Fred,'B')
myLeg2 = motor(Fred,'C')
```

Create handles

```
myLeg1.Speed = 50
myLeg2.Speed = 50
```

Set speed

```
start(myLeg1)
start(myLeg2)
```

Start motors

```
pause(3)
```

Continue motion for 3 seconds

```
stop(myLeg1)
stop(myLeg2)
```

Stop motors

Motion Alarm

```
Fred = legoev3('usb')

mysensor = sonicSensor(Fred)

while ~readButton(Fred, 'up')
    d = readDistance(mysensor);
    if d < 1
        freq = 500*(1-d)
        volume = 100*(1-d)
        playTone(Fred, freq, 1, volume)
    end
end
```

Coding Mindstorms: Sounds

Frequencies

```
c = 261;
d = 294;
e = 329;
f = 349;
g = 391;
gS = 415;
a = 440;
aS = 455;
b = 466;
cH = 523;
cSH = 554;
dH = 587;
dSH = 622;
eH = 659;
fH = 698;
fSH = 740;
gH = 784;
gSH = 830;
aH = 880;
```

Tone

```
playTone(Fred,a,.5,5)
pause(.5)
playTone(Fred,a,.5,5)
pause(.5)
playTone(Fred,a,.5,5)
pause(.5)
playTone(Fred,f,.35,5)
pause(.35)
playTone(Fred,cH,.15,5)
pause(.15)
playTone(Fred,a,.5,5)
pause(.5)
playTone(Fred,f,.35,5)
pause(.35)
playTone(Fred,cH,.15,5)
pause(.15)
playTone(Fred,a,.65,5)

pause(1.15)

playTone(Fred,eH,.5,5)
pause(.5)
playTone(Fred,eH,.5,5)
pause(.5)
playTone(Fred,eH,.5,5)
pause(.5)
playTone(Fred,fH,.35,5)
pause(.35)
playTone(Fred,cH,.15,5)
pause(.15)
playTone(Fred,gS,.5,5)
pause(.5)
playTone(Fred,f,.35,5)
pause(.35)
playTone(Fred,cH,.15,5)
pause(.15)
playTone(Fred,a,.65,5)
pause(.65)
```

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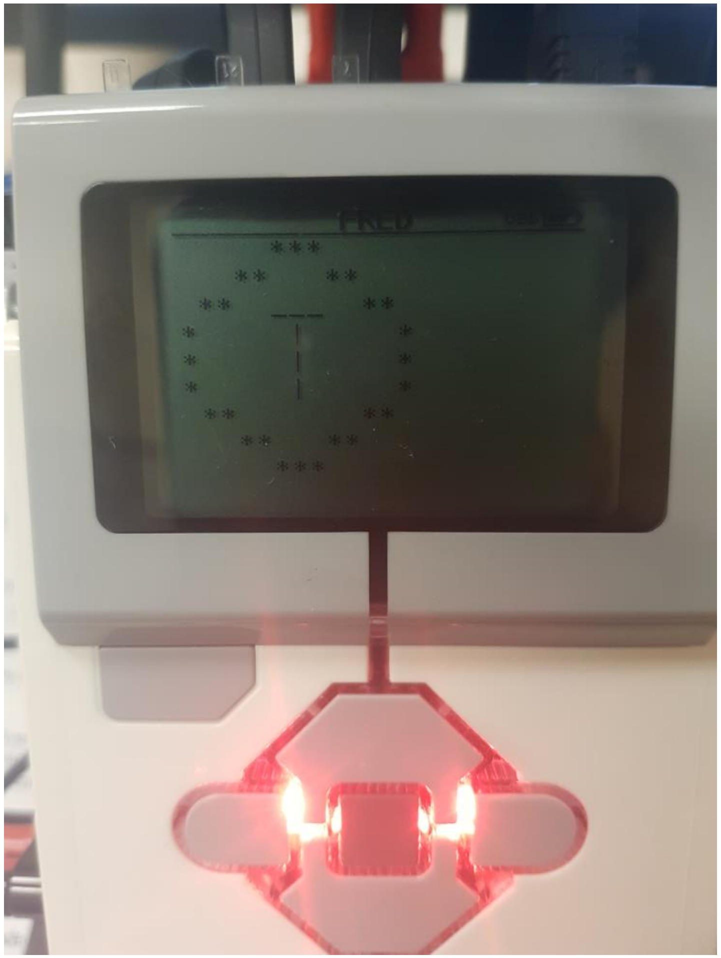
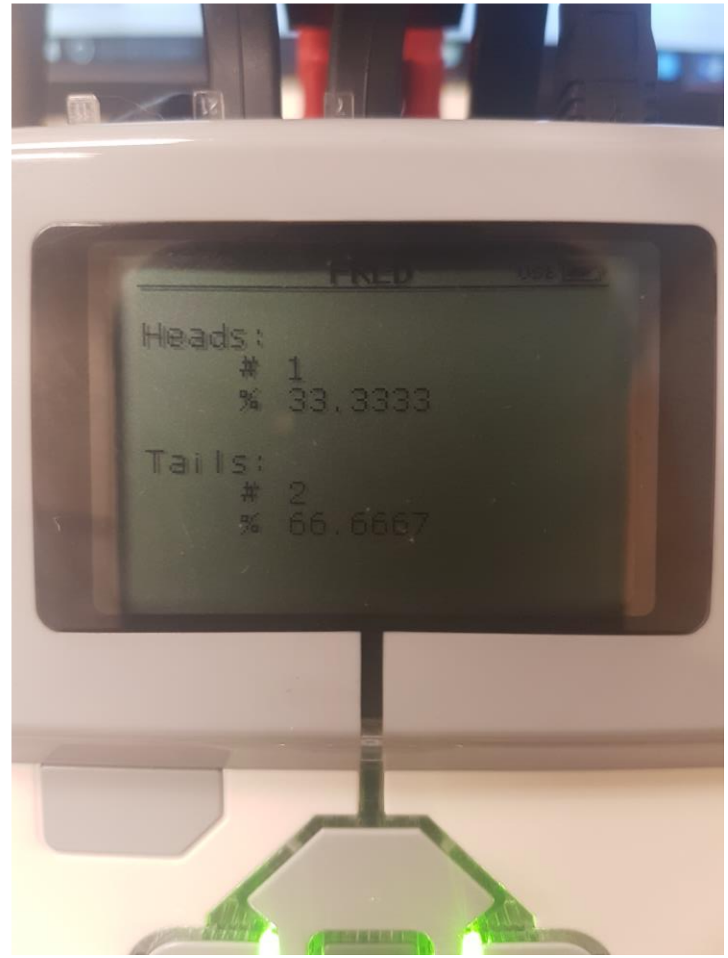
Coding Mindstorms: Display





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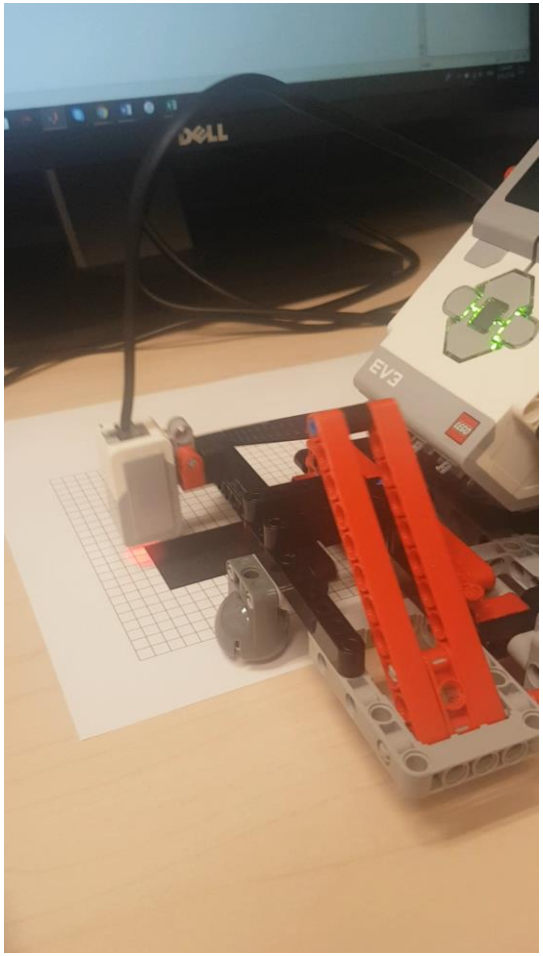
Coding Mindstorms: Scanner



Page 1

```
Fred = legoev3('usb')

scan = motor(Fred,'A');
myLeg1 = motor(Fred,'B');
myLeg2 = motor(Fred,'C');

mycolor = colorSensor(Fred,4);

gather = true;
j = 0;

while gather

    j = j + 1;
    i = 0;
    forward = true;
    scan.Speed = -15;
    start(scan);
    tic

    while forward

        time = toc;

        if time >= 0.4
            scan.Speed = 0;
            start(scan);
            forward = false;
        end

        i = i + 1;
        scan_value(j,i) =
readLightIntensity(mycolor,'reflected');

    end

    back = true;
    tic;
```

Page 2

```
while back
    scan.Speed = 10;
    start(scan);
    time = toc;
    if time >= 0.7
        scan.Speed = 0;
        start(scan);
        back = false;
    end
end

move = true;
tic;

while move
    myLeg1.Speed = -30;
    myLeg2.Speed = -30;
    start(myLeg1);
    start(myLeg2);
    time = toc;
    if time>=0.05
        myLeg1.Speed = 0;
        myLeg2.Speed = 0;
        start(myLeg1);
        start(myLeg2);
        move = false;
    end

end

pause(0.3)

if j == 20
    gather = false;
end
end
```

Page 3

```
y = nan(nr, size(scan_value,2)+10);

for j = 1:nr

    for i = 1 : 5

        x(j,i) = nan;

    end

    for i = 6 : size(color,2)+5
        if scan_value(j,i-5) < 50
            x(j,i) = i;
        else
            x(j,i) = nan;
        end
    end

    for i = length(scan_value)+6:length(scan_value)+10

        x(j,i) = nan;

    end

    y(j , 6:length (x)-5) = j;

end

plot(x, y, 'sk','markers',17,'MarkerFaceColor',[0 0 0])
axis([0, length(x), 0, j])
xticks(0:2:length(x))
grid on
```

Analyzing 2018 Lab Assignments

Asgn. #	Main Topic	Subtopics
1	Course outline and introduction	Introduction to computers and MATLAB environment
2	Problem solving and expression assignment	Pseudo-code, flow charts, program structure, variable assignment, math operators, precedence, built-in functions
3	Arrays and plotting	Array initialization, indexing, operations, plotting
4	Logical data types and selection flow control	Logical data types, ifelse, select
5	Repetition flow control	Control mechanisms: for, while, convergence
6	Functions	M-file, anonymous, and recursive functions
7	Numeric data types	Integers, floating point, precision vs. round-off error
8	Data types: Character and heterogeneous	Characters, structures, cell arrays
9	Input / Output	Standard and file I/O
10	Validation and verification	Testing and debugging, variable checking
11	Engineering problems	Various possible topics
12	Review	

Creating New Assignments

- Review tasks from previous 2018 assignments
- Achieve the same learning objectives while incorporating LEGO Mindstorms
- Test and develop code for all proposed tasks to validate the proposed assignments

Proposed Lab Assignments

Asgn. #	Goal	Assignment Task
1	Introduction to MATLAB	Interfacing robot with MATLAB – output to screen
2	Exploring MATLAB features	Interfacing robot with MATLAB – exploring use of motors and sensors (syntax, built-in functions, operators, and data types)
3	Solution procedure – simple programs	Creating simple programs using robot's motors and sensors, and creating flow charts and pseudo code
4	Using arrays and plotting	Gather data using a sensor, plot data
5	Logic – decisions, conditional statements	Object detection and avoidance Braitenberg Vehicles – complex behaviors using simple sensors
6	Repetition	Automatic Motion with Object avoidance (Random Walk)
7	Functions	Dead Reckoning or other applications using functionality of robot
8	Numeric Data types	I2C communication – understanding digital data transfer
9	Character	Send string instructions to robot to execute various tasks
10	Standard and File I/O	Collect data and periodically sync with computer to download
11	Engineering Application	Building advanced robot functionality through structures
12	Advanced	Students develop complex programming project to encompass all learning outcomes – i.e. maze solving algorithms, color tracking

Missing Elements

- Assignment 2 fails to incorporate the robot for: rewriting expressions in MATLAB, use regular built-in MATLAB functions, learn syntax
- Assignment 8 fails to incorporate the robot for: general base conversions – previously given as a hand-written task

Difficulties

- Battery-powered, bad battery life (3-4 days)
- Couldn’t connect to school wi-fi due to log-in screens

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Conclusion

- The functionalities of the sensors and motors offer many opportunities to demonstrate programming concepts and create different assignments from year to year
- The LEGO® Mindstorms EV3 robot combined with MATLAB programming language would be feasible for implementing in a first-year programming course
- The proposed activities satisfy the learning outcomes and show potential for improving student outcomes

Thank you

Questions?

References

[1] Davis, J. (2018) *ENCP 100 – Computer Programming for Engineers Syllabus.* [Class Handout]. Edmonton, AB: MacEwan University.

[2] MATLAB. "What is MATLAB?" https://www.mathworks.com/discovery/what-is-matlab.html [Accessed: April 4, 2019].

[3] A. Behrens, L. Tarof, R. Schwann, J. Ballé, T. Herold and A. Telle, "First Steps into Practical Engineering for Freshman Students Using MATLAB and LEGO® Mindstorms Robots", Acta Polytechnica, Vol. 48, No. 3, pp.44-49, 2008.

[4] A. Behrens, L. Atorf, R. Schwann, B. Neumann, R. Schnitzler, J. Ballé, T. Herold, A. Telle, T.G. Noll, K. Haymeyer and T. Aach, "MATLAB Meets LEGO® Mindstorms – A Freshman Introduction Course into Practical Engineering", IEEE Transactions on Education, vol. 53, no. 2, pp. 306-317, 2010.

[5] M. Aznar, J. Zacarés, J. López, R. Sánchez, J.M. Pastor and J. Llorca, "Interdisciplinary Robotics Project for First-Year Engineering Degree Students", Journal of Technology and Science Education, pp. 151-165, 2015.

[6] M. Prince, "Does Active Learning Work? A Review of the Research", Journal of Engineering Education, vol. 93, pp. 223-231, 2004.