Enhancing First Year Engineering Students Trigonometry Learning Experience

Dr. Liya Ni, California Baptist University

Associate Professor of Electrical and Computer Engineering, Gordon & Jill Bourns College of Engineering, California Baptist University, gni@calbaptist.edu.

Dr. Helen Yoonhee Jung P.E., California Baptist University

Licensed Professional Engineer

University of California, Los Angeles Ph.D. Candidate, Civil Engineering (specialty in Water Resources), June 2009 M.S. Civil Engineering (specialty in Water Resources), June 2005 B.S. Civil Engineering (specialty in Structural), March 2002

Work Experience California Baptist University July 2011-Present: Civil Engineering Department Chair July 2010-June 2011: Civil Engineering Interim Department Chair August 2009-Present Assistant Professor of Civil Engineering Topics taught: Chemistry, Statistics, Statics, Mathematics, Environmental Engineering, Leadership Cohort, Internship Prep, FE Review, Fluid Mechanics, Water Resources Engineering, and Hydrology.

University of California, Los Angeles Mar.2008-June2008 Teaching Fellow Engineering Ethics Sept.2007-Mar.2008 Teaching Associate: Engineering Ethics (2 quarters) July 2004-June 2007 Teaching Assistant: Introduction to Water Resources Engineering (2 quarters) Hydrologic Analysis and Design (2 quarters) trips, preparation of lab and graded assignments. July 2004-May 2009 Research Assistant: Investigating the Effects of Wildfire on Southern California Watersheds.

AKM Consulting Engineers August 2002 – July 2004 Assistant Engineer -Complete knowledge of GIS, H2ONET, Microstation, HEC-RAS, HEC-HMS -Projects-Master plan of City of Garden Grove, Master plan of City of Corona, Storm drain design, Pump station design, City of Newport Highway Improvement project, and City of Long Beach water routing design.

Intel Corporation May 1997 Sept. 1997 Intel's Honor Internship Program -Conducted electrical tests on wafers -Repaired and maintained electrical test devices -Experienced in clean room environment procedures

Research Interests My research interest includes hydrologic modeling/ forecasting, water distribution, and water education/curriculum development.

Dr. Ziliang Zhou, California Baptist University

Ziliang Zhou is a professor of Mechanical Engineering at California Baptist University

Enhancing First Year Engineering Students' Trigonometry Learning Experience

Abstract

The College of Engineering at our institute has been part of the NSF sponsored consortium of *A National Model for Engineering Mathematics Education* for the last 6 years and saw significant retention improvement in all three majors: Civil Engineering, Electrical & Computer Engineering, and Mechanical Engineering programs. Students in those three majors came from a diversified high school math background, ranging from AP calculus to basic Algebra. Students with weak math background have one thing in common: they all struggle with trigonometry, a key engineering skill for success in all three majors. To equip students with necessary trig skills in our first engineering math course taught by engineering professors, we implemented a three step approach in our class:

(1) Made a connection between the classroom trigonometry calculations with the robotic welding operations on the automobile assembly line, so that students can actually see real life applications of the mathematic model of a two-link robot they learned in class . This is largely done by showing class the automobile assembly process videos followed by math model analysis of the robot arm movement. This approach draws attention from all students, particularly the mechanical engineering inclined students.

(2) Added a new NAO robot (an autonomous, programmable humanoid robot developed by Aldebaran Robotics, a French robotics company) based trigonometry experiment to provide students hands-on experience of interaction with a humanoid robot. During the experiment, students specify joint angles (or hand location coordinates for inverse kinematics) via a user-friendly computer interface, watch the robot move its arm accordingly, and then hear the robot report verbally the final location coordinates of its hand (or joint angles for inverse kinematics). Students also create MATLAB function and script files to cross-check and validate the measurements. All students loved to play with the NAO robot, especially the electrical and computer engineering inclined students.

(3) Developing a new surveying experiment to further enhance the trigonometry learning experience. This particular experiment aims to enhance understanding trigonometry applications in civil engineering and construction management field. The students use two equipment set-ups: Leveling and Theodolite. They use leveler to measure slopes and theodolite to measure angles in the horizontal and vertical planes to calculate the building height and/or width.

Students enthusiastically embraced the new approach with active classroom participation. The student performance data also showed improvement related to the trigonometry skills. Our next step is to expand this approach to other areas where students showed weakness.

1. The issue with trigonometry and the work done at our institution

Trigonometry can be easily one of the least favorable math topics among high school and college freshman students due to its complexity and the numerous formulas the students need to memorize. The issue is compounded by the lack of adequate connection between classroom learning and the engineering applications in the real world. This not only causes anxiety among part of the student body but also ill-prepared them for subsequent courses requiring such knowledge. A student can barely pass calculus I and still be lacking some critical skills in handling trigonometry problems in statics and circuits [1].

The engineering application of trigonometry is everywhere, such as in automobile engine crankshaft design, in robotic arm movement programming for assembly line operation, and in land survey result calculation. To promote the study of trigonometry and to acquaint the students with the use and practical application of trigonometry in the surveying profession, California Professional Land Surveyors Association organizes the Trig-Star [2] annual high school mathematics competition based on the practical application of Trigonometry. At our institution, to enhance our first year engineering math education, we joined several years ago a consortium led by Klingbeil [3-4] to equip the engineering freshmen with the required math skills during their first semester by the engineering faculty. All incoming freshmen are required to take this course, which also has a lab component where students have a chance to build circuits, play with air track, operate oscilloscope, and learn to program with MATLAB. This NSF funded project contributed to the significant improvement on student retention rate in our college over the past several years[5]. In the meantime, we also noticed that the student performances among different subjects are not balanced. This is typically not an issue for students getting B or better who have a good understanding on all subjects. However, a barely passing grade of C does not provide the detailed information on their understanding of the subject required to be successful in completing the subsequent courses. For example, a student performing poorly in trigonometry and complex analysis but did reasonably well in the rest of engineering mathematics may still be ill-prepared for Circuit Theory. Among all subjects, trigonometry stands out as a subject many students struggle with.

To improve the situation, we implemented a three-step approach:

1. Made a connection between the classroom trigonometry calculations with the robotic welding operations on the automobile assembly line so that they can actually see how the two-link robot classroom math model in real life applications.

2. Added a new NAO robot based trigonometry experiment to provide students hands-on experience of interaction with a humanoid robot.

3. Developing a new surveying experiment to further enhance the trigonometry learning experience.

To see the impact of this approach, we analyzed student exam performance in trigonometry before and after the implementation of the first two steps. The exam data showed noticeable improvement on student's trigonometry skills. We will implement the last step next year and report its result in future publications.

2. Introducing trigonometry with exciting real life applications

Introduction to Engineering Mathematics is the first math course each engineering student takes during their first semester in our engineering program. Content-wise, it contains pre-calculus and calculus. Most of our students had different topics and ranges of high school math courses, however, most of them are familiar with the topics in pre-calculus. Therefore, the instructors treated those topics as review sessions with an engineering application spin and progress rather quickly, having trigonometry started early as 3rd week of class.

Our adopted textbook introduced trigonometry with the following example of one and two link robot. It is obviously hard to make a direct connection between the example and the actual robot in most students' mind.

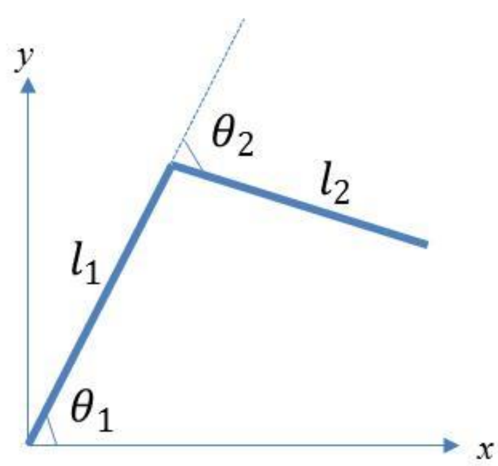

Figure 1. Two link robot model

To get students excited about the subject of trigonometry, we introduced two video clips at the beginning of the class, first with a Star Wars movie clip showing Padmé Amidala and Anakin Skywalker's adventure in droid factory on alien planet Geonosis where the battle droids being assembled by robots on an assembly line. We then show another video of modern day automobile assembly line where the car body parts being welded together by robots on the assembly line. During the process, we emphasize the connection among the three items and conveyed a clear message to each student: trigonometry is an exciting subject and you will use it in your future engineering career.

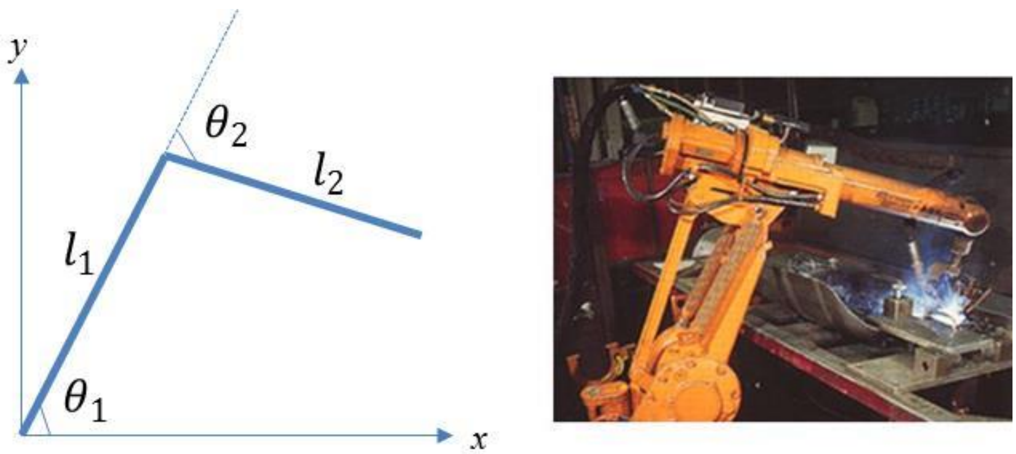

Figure 2. Two link robot model used in auto assembly line

Students received this introduction enthusiastically based on the amount of questions and interaction. From instructor point of view, the introduction provided a convenient reference point in subsequent lecturing on all trigonometry topics. For example, when the Law of Sine and Law of Cosine were discussed, instead of describing it as a method of calculation involving triangle, the instructor would say that in order for the robot to deliver the weld at the precise location on the car body in an auto assembly line, the automation engineer needs to know the angles of the robot arms so he or she can program the robot movement to accomplish the welding task on the auto assembly line. Most of students, especially those mechanical engineering inclined students, who were car enthusiasts and repaired cars themselves, easily made the connection and received this approach positively.

3. A new NAO robot based trigonometry experiment

A new lab component which employed a humanoid robot was developed in the summer of 2013 and was integrated into the existing lab project on trigonometry. The current lab project runs for two lab sessions. In the first session, students focus on taking angle-versus-length measurements with a sun-dial-like instrument and calipers. The simple Plexiglas "sun-dial", shown in Figure 3, simulates a two-link planar robotic arm similar to that shown in Figure 1. Given an angle, students dial it onto the instrument, then measure the *x* and *y* lengths; or vice versa. They also create MATLAB function and script files to cross-check and validate the measurements. In session two, a computer-controlled humanoid robot called NAO replaces the "sun-dial". A NAO T-14 torso model is shown in Figure 4. The T14 model has fourteen Degrees of Freedom including two for the head, five for each arm and one (open/close) for each hand. The robots were purchased with a grant provided by the W. M. Keck Foundation.

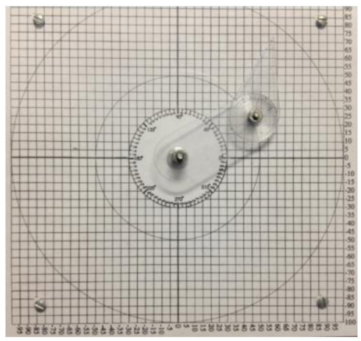

Figure 3. The Sun-dial like instrument

Figure 4. The NAO T-14 model

This part of the lab project was focused on the forward and inverse kinematics of NAO's left arm. In order to resemble the configuration of the "sun-dial", we only allowed the shoulder roll and elbow roll angles of NAO's left arm to be varied but set all the other angles to zeros. The left arm motion was constrained in a 2D plane located at the same height as the center of shoulder. Figure 5 shows the overhead view of the NAO left arm and the valid ranges of the LShoulderRoll and LElbowRoll angles.

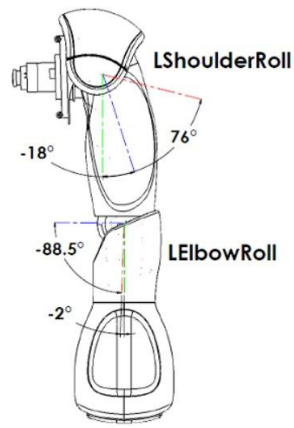

Figure 5. Overhead view of NAO's left arm

A user-friendly computer interface was developed so that for the forward kinematics experiment, students type in shoulder and elbow joint angles, watch the robot move its arm accordingly, then hear the robot report verbally the final location coordinates of its hand. For the inverse kinematics experiment, students can specify the coordinates of the robot hand, watch the robot move its arm, and hear the corresponding joint angles reported by the robot. In addition, students edit their MATLAB files to create equivalent files tailored to the robot (which includes real-world elbow offsets not found in the "sun-dial"). Very little programming or knowledge of the robot is required, but a pre-lab assignment requires students to watch a short introductory video, read the lab assignment, and take a short on-line quiz.

The user interface was designed using the NAOqi API and the software called Choregraphe[6]. Both were provided by Aldebaran Robotics with the purchase of NAO robots. Choregraphe has a user-friendly graphical interface which allows a user to pick functional blocks called "Boxes" and place them in a Flow Diagram. Behaviors such as listen, talk, move, walk, etc. can be composed with proper selection of Boxes and wiring them accordingly. The programs in Flow Diagram format can be directly sent to the NAO robot via WiFi. Figure 6 shows the Flow Diagram we developed for the forward kinematics experiment.

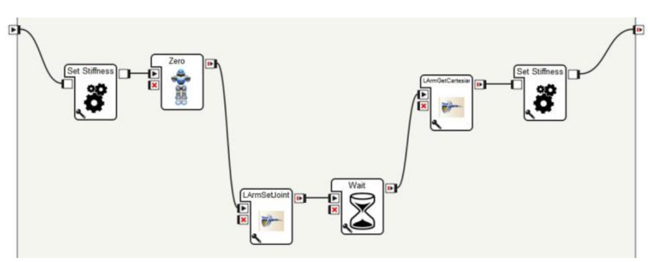

Figure 6. Flow diagram in ChoreGraphe for forward kinematics.

We developed a small library in the ChoreGraphe environment with four Boxes that perform the desired robot motion and retrieve the joint angles or end effector coordinates: LArmSetJoint, LArmGetJoint, LArmSetCartesian, and LArmGetCartesian.

As shown in Figure 6, the Boxes LArmSetJoint and LArmGetCartesian are connected with other Boxes provided by the ChoreGraphe libraries to form the Flow Diagram for the forward kinematics experiment. By using the “Set Stiffness” Box, we enable the motors in the beginning of the experiment and disable them in the end. The Box “Zero” makes the NAO robot position itself to zero configuration with all the joint angles automatically set to zeros. We inserted a “Wait” Box with 10 seconds delay to ensure that the NAO robot has plenty of time to move its left arm joints to desired angles before the sensor measurements are retrieved. The Flow Diagram for the inverse kinematics experiment was developed similarly.

The humanoid robots are expensive, but our impression is that they are powerfully effective in helping students connect math and engineering to the real world. One student, after being exposed to the robots, has already become our “student outreach assistant”—and NAO robot “expert”—in sharing our engineering program with local high schools.

4. A New surveying experiment

Surveying is the process of measuring lengths, height differences, and angles on site to locate and build the designed projects on the ground. The students learn surveying used in civil engineering and construction management field with extensive use of trigonometry. We developed this particular experiment with the following two pieces of equipment: Leveler and Theodolite.

Leveling is the name given to process of measuring the differences in elevation between two or more points. In engineering surveying, leveling has many applications and is used at all stages in construction projects. The students will be using a leveler to calculate the slope of a hill. They first have to measure the elevations at two given points, reference to pre-defined datum. They will have to consider the height of the instrument to calculate the elevation difference. Lastly they will measure the horizontal distance from point one to point two and calculate the slope of the hill. They will measure the slopes of four different sections on a hill and draw the profile to document their measurements and calculations with a diagram.

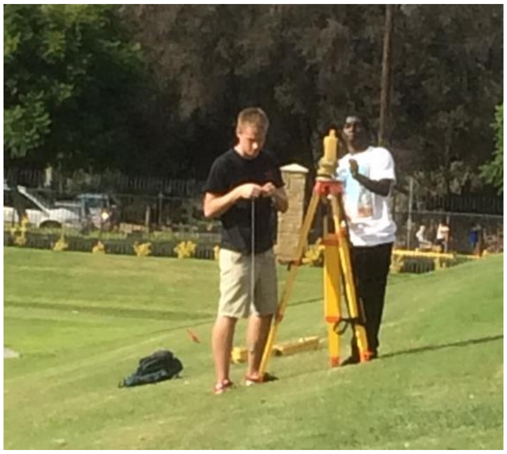

Figure 7: Testing the ‘Surveying Exercise’ with the first group of students

The second instrument that the students will be using to practice trigonometry is Theodolite. Theodolites are precision instruments for measuring angles in the horizontal and vertical planes. The main objective of this exercise is to determine the length of a building (in horizontal plane) without direct measurement of the dimension due to an obstruction in the way of measurement.

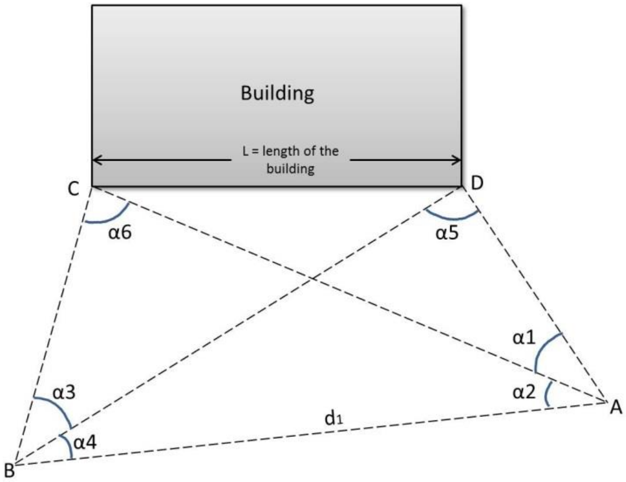

Figure 8: Explanation of measured and calculated variables and angles using Theodolite.

They will be measuring first four angles labeled in the figure above and the distance between the two points, (labeled as points A and B in figure 8), d_1. Using these angle measurements, the other angles (α5 and α6) can be calculated.

The distance between C and D ($\overline{CD}$) can now be calculated using the *Law of Cosine* as shown below.

$$\overline{CD}^2 = \overline{AC}^2 + \overline{AD}^2 - 2(\overline{AC})(\overline{AD})\cos(\propto_1)$$

$$\overline{CD} = \sqrt{\overline{AC}^2 + \overline{AD}^2 - 2(\overline{AC})(\overline{AD})\cos(\propto_1)}$$

Where

$$\overline{AD} = \overline{AB}\,\frac{\sin(\propto_4)}{\sin(\propto_5)}$$

From the *Law of Sine* :

$$\frac{\overline{AD}}{\sin(\propto_4)} = \frac{\overline{AB}}{\sin(\propto_5)}$$

Where $\overline{AC}$ can be calculated using $\overline{AB}$, the measured distance (d_1), and the angles.

$$\overline{AC} = \overline{AB}\,\frac{\sin(\propto_3+\propto_4)}{\sin(\propto_6)}$$

$$\frac{\overline{AC}}{\sin(\propto_3+\propto_4)} = \frac{\overline{AB}}{\sin(\propto_6)}$$

This lab will provide a 'hands-on' and 'outdoor lab' experience to all engineering students, especially the students with civil and construction management interest. They will also learn to relate the 2-D mathematical concept to the 3-D, 'real world' experience.

5. Initial improvement

To assess the student performance improvement related to our effort, we gave the same trig exam problem during two consecutive years to obviously two different groups of freshman engineering students taking the same course, one before implementing the first two steps and one after implementing the first two steps. The result shows 22% improvement on class average performance on this particular trig problem, as illustrated in the following figure.

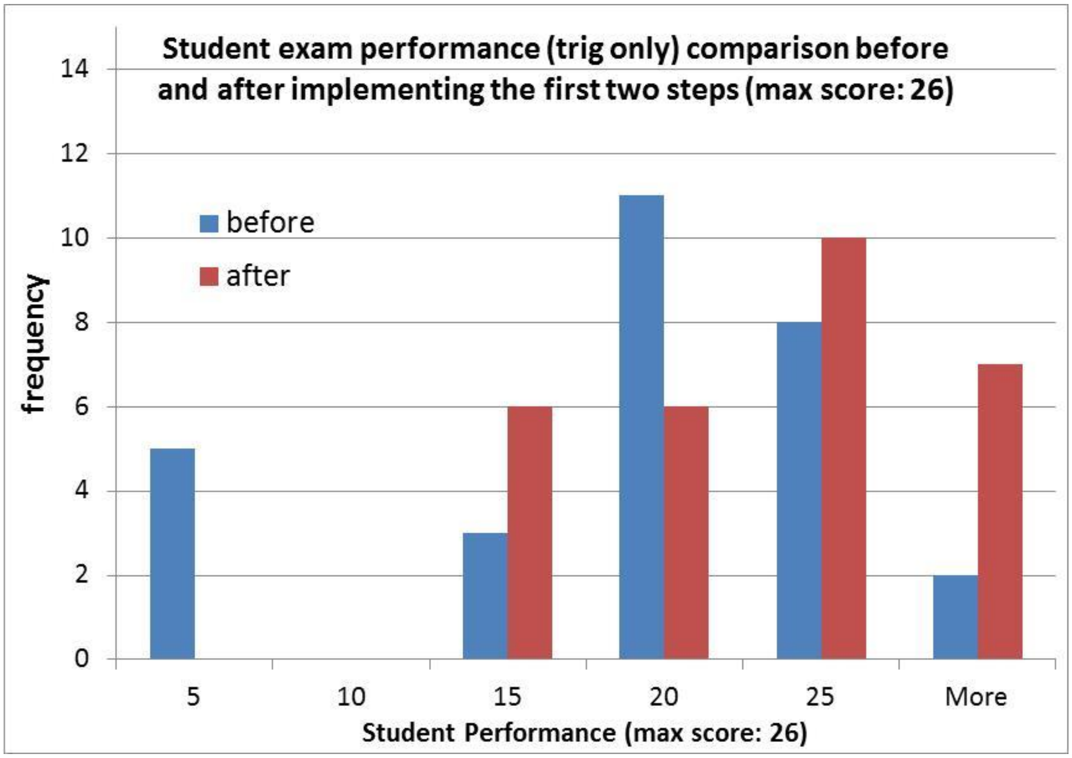

Figure 9. Student exam performance comparison (trig only)

The data were taken from two consecutive years with the exactly same exam problem, and coincidently with the same number of students taking the exam (30 for both years came from similar background and academic preparation). The problem asks students to calculate the two link robot position for the given angles and its inverse problem applying the law of cosine. The problem was graded in both years with the same rubric. Before implementing the first two steps, the trig chapter was taught the usual way directed by the textbook. After implementing the first two steps, the short video was added to the lecture and the new NAO robot experiment was added as a new lab session. Students taking the course have no access to the exam problem prior to the exam. When ranked from high to low performance, the entire class showed significant improvement on students' concept understanding and application skills in trigonometry. Using 70% as the passing grade, the after data shows 67% of the students earned C or better grades while the before data shows only 50% earning C or better grades on this particular problem, a 17% increase.

In addition, we also conducted an informal survey about the new NAO Robot lab component with the question: "How did you feel about the Robotics Lab?" Student responses reveal a high level of popularity with it. They felt that this lab showed a good real-world application of math concepts and it was a "cool way" to introduce robotics. Negative comments were mainly tied to some robot malfunctions and difficulties of the MATLAB work—problems which we are addressing.

To complete our work, we are planning to implement the 3rd step of a new surveying lab in fall of 2015. More data will be collected for validating the statistical significance of the improvement.

6. Conclusions

The two steps implemented in our Introduction to Engineering Mathematics class showed promising potential in improving student learning related to trigonometry. While the improvement is substantial, a 67% passing rate is still low for a concept students should have mastered before coming to college. We plan to implement our 3rd step with a new surveying experiment next year and report our findings in our future publications.

Bibliography

[1] Zhou, Z., "Enhancing Communications among Courses Linked with Prerequisites", Proceedings of the 2011 Frontier in Education Annual Conference, 2011.

[2] https://californiasurveyors.org/trigstar.html

[3] Klingbeil, N.W., Mercer, R.E., Rattan, K.S., Raymer, M.L. and Reynolds, D.B., "The WSU Model for Engineering Mathematics Education", Proceedings 2005 ASEE Annual Conference & Exposition, 2005.

[4] Klingbeil, N.W., Mercer, R.E., Rattan, K.S., Raymer, M.L. and Reynolds, D.B., "The WSU Model for Engineering Mathematics Education: Student Performance, Perception and Retention in Year One", American Society for Engineering Education 2006 Illinois-Indiana and North Central Joint Section Conference, 2006

[5] Zhou, Z., "Enhancing Broader Communication among Courses Linked with Prerequisites", Proceedings of the 2012 Frontier in Education Annual Conference, 2012.

[6] Aldebaran Robotics, "NAO Software 1.14.3 Documentation".