Learning by Competing and Competing by Learning:

Experience from the e-Yantra Robotics Competition

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***Abstract*—e-Yantra Robotics Competition (eYRC) is an initiative of the e-Yantra project to bring the experience of Project Based Learning to engineering students by using a competition to deliver hands-on training on-line. Five hundred students forming 131 teams were selected from across India to participate in the pilot run of the competition, eYRC-2012 that consists of a set of tasks through which students are evaluated. We map the tasks such as theme analysis, implementation analysis, and video demonstration to outcomes such as acquiring basic knowledge, application of knowledge, and critical analysis. Results show that over 95% of the teams participated imbibed basic knowledge of embedded systems and robotics, 60% of the teams applied their knowledge to develop a solution to a given problem, while over 30% of the teams could critically analyze the problem and come up with an effective solution. These results are confirmed by similar effectiveness studies of the eYRC-2013 competition. This competition was conducted completely on-line and students did not incur any costs, ingredients essential for ensuring scalability and inclusiveness of the project. Students transfer the Robotic kits to their respective colleges at the end of the competition enabling nurturing of future generations of students at the colleges.**

***Index Terms*—Project Based Learning, Embedded systems, Robotics, e-Yantra, Robotics Competition**

I. Introduction

Engineering education is incomplete without hands-on Project Based Learning (PBL) where students apply their mind to solve problems in a systematic manner. In engineering colleges across India, students have limited exposure to hands-on experiments in basic sciences and basic engineering concepts. While students at engineering colleges all over the country are capable of working on challenging and interesting projects, the lack of lab facilities and mentors have kept students away from projects in embedded systems and robotics.

e-Yantra is motivated to bridge the lacunae in engineering education and bring up the quality of engineers graduating from second and third tier engineering colleges. In the pilot phase of e-Yantra, to create awareness and to train students in the basic concepts of embedded systems and robotics, e-Yantra had conducted face-to-face two-day workshops at various venues. Given the geographical distribution of engineering colleges across the country, this was not a scalable proposition. Robotic kits were distributed to colleges to encourage student projects in robotics and embedded systems. This turned out to be ineffective as the robots ended up locked in cabinets and students did not have access to the robots. These experiences prompted e-Yantra to look for other ways to engage with students.

Robotic competitions [1] are popular with students. However, most competitions expect students to build a robot from scratch and typically students invest in the components to build the robots. In such competitions, as with the popular Robocon competition[2] teams build large robots driven around by seated operators in large, expensive arenas. Instead of asking students to build a robot, we devised our competition around a commodity robot (all teams participating in eYRC-2012 were given a FireBird-V[1] robot with sensors and actuators). Participants used these kits to solve scaled down versions of real world problems and demonstrated their prototypes on 6ftx6ft flex-sheet arenas.

Participation in the competition amounts to a Project Based Learning (PBL) exercise which requires (i) training students in basics of embedded systems and micro-controller programming, (ii) providing them with a platform to implement a project and (iii) a methodology imparting PBL at a distance through the Internet. The core challenge that had to be addressed involved training the participants in the requisite skills of programming the robot and building the additional accessories required to solve the given problem.

In the e-Yantra Robotics Competition-2012, (eYRC-2012) the above challenge was met in the following manner: (i) The material covered in the face-to-face two-day workshop was converted into video tutorials. These tutorials were given to students participating in eYRC-2012 to learn concepts at their own pace. Support was provided through an on-line discussion forum where students posted their queries and got answers within 24 hrs. (ii) All teams participating

[1]The FireBird series of robots was designed by the Embedded Real-Time Systems (ERTS) Lab, IIT Bombay as an educational robot for imparting hands-on project component of the embedded systems course taught in the Department of Computer Science and engineering, IIT Bombay.

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in eYRC-2012 were given a FireBird-V Robot along with accessories required to implement the solution to a Theme[2] assigned to them. Students do not incur any cost to participate in the competition. (iii) The interesting part of the competition is the model and methodology used to engage with students from even the remote regions of the country. We discuss this in detail in the next section.

II. Related Work

Several robotic competitions are conducted around the world [1] and competitions are seen as an effective way to impart Project Based Learning (PBL) [3][4]. We consider three different models in which PBL is deployed to impart knowledge of engineering concepts effectively:

(i) PBL through a stand-alone competition: In this model, the competition organizer defines a problem statement that is solved by students in a self-learning mode. Students do not have any feedback or guidance from the organizers during the competition. Given that only a few teams emerge as winners in these competitions, most of the students are left out, not learning much from participating in the competitions. Impact studies in this model are based on either a set of questions, asked to students before and after the competition [5][6] or on improved performance in their college courses after the competition [7]. While most of these studies claim positive impact of PBL through the competition on student performance, most of these analyses are done with a small number of students.

(ii) PBL through a classroom course incorporating the competition as a course project: This model is a mix of traditional classroom lectures and a team-based project. Typically the project component of the course is modeled as a competition. This model covers both theory and practical components [8] such that students apply theoretical concepts learnt to solve practical problems. Challenges in this model include: (i) providing the correct weightage to the theory and practical aspects of the course and (ii) allowing adequate time for implementing an innovative solution to the problem assigned through the competition [9][3]. Several universities use the problem definition of an actual competition as part of their course assignments/projects [10][11][4]. In [12] students in an "Introduction to Engineering" class were engaged in a semester long project through a competition. while the paper reports that the competition fed the excitement of the students and fueled creativity, analysis is based on a small sample size of 12-13 students enrolled in the course. Note that all the cases discussed above are confined to face-to-face classroom courses, restricting the reach of such a PBL model. In fact, our competition paradigm was born out of the project component of the Embedded Systems course taught at IIT Bombay to over 50 postgraduate students every year, in the Department of Computer Science and Engineering.

[2]Each theme comprised of a problem encountered in the environment, specified in the form of a rulebook, posed as a challenging game.

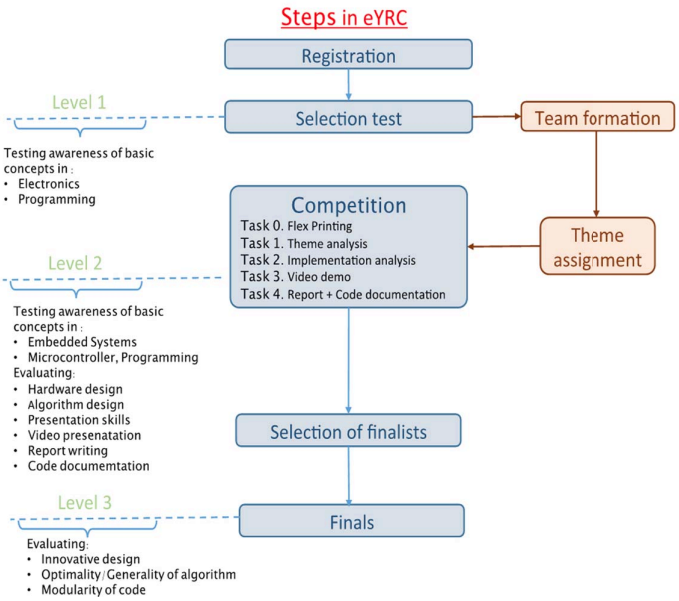

Figure 1: Steps in the e-Yantra Robotics Competition

(iii) PBL through an online course: In [13] the authors show that PBL is imparted effectively when on-line support systems in the form of discussion forums are used by students for interactions. A combination of Web LiveCast and local Voice over IP (VoIP) messaging tools are shown to be effective in improving student engagement in geographically distributed classrooms, in [14]. These examples make a case for reaching out to students by offering PBL in the on-line mode.

Note that in eYRC, we use a model that combines the positive aspects of all the three models discussed above - a **competition** with a **step-by-step methodology** that imparts both theoretical concepts and application of these concepts to problem solving that is conducted completely **on-line**.

III. A Unique Model to impart Project Based Learning

In order to engage students from colleges all over India, e-Yantra launched the e-Yantra Robotics Competition (eYRC-2012) in July-August 2012. Figure 1 provides the steps of the competition along with the details of the filtering process at various stages of the competition. We briefly outline these steps and explain the three levels of evaluation used in this competition.

Given the inter-disciplinary nature of the subject "Embedded systems and Robotics", registration was open to engineering undergraduate students from any discipline of engineering. Over 4000 students registered. As shown in Figure 1, an online selection test was conducted as Level-1 evaluation to test awareness of basic concepts in robotics and programming which is a pre-requisite to participate

in the competition. This test comprised of multiple-choice questions with single correct answer in basic electronics and C-programming. Questions carried negative marks for wrong responses and 45 minutes were given to solve 40 questions. 500 students were chosen based on the selection test. These students then formed 131 teams. One of four themes – Pothole filler, Pick and placer, Line follower, and Room cleaner – was assigned to each team.

To maintain uniformity and spreading knowledge amongst all students, a robotic kit – a Firebird-V robot along with accessories, video tutorials, detailed hardware and software manuals, instruction sheets, and necessary software – is given to each team. This robot, shown in Figure 2, is a general-purpose robot enabling beginner students to quickly learn essential concepts and implement their solution to the assigned theme by modifying the robot.

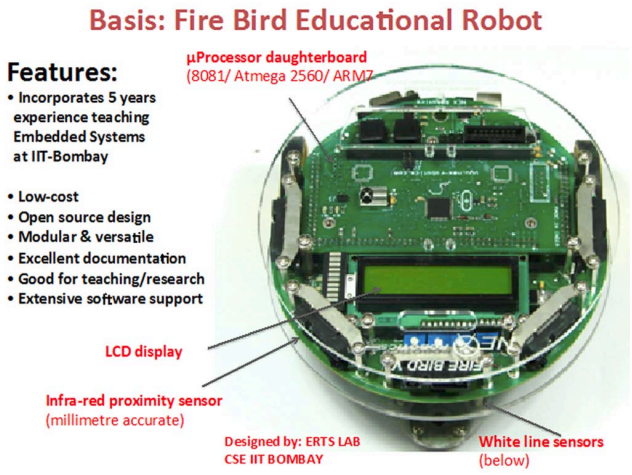

Figure 2: FirebireV: Our Educational Robot

The Competition is designed to run in a time span of three months. As listed in the box named "Competition" in Figure 1, several tasks were assigned to the teams during the course of the competition. Note that each of these tasks – theme analysis, implementation analysis, etc. – is a step in the project life cycle.

Each task is evaluated and the total scores of the teams are used to select the finalists. Five teams from each theme were selected as finalists. With reference to Figure 1, Level-2 evaluation consists of a set of tasks designed to impart PBL. Along with awareness of basic concepts in embedded systems and micro-controller programming several other skills that are honed through PBL were also evaluated, completely on-line. These include: (i) hardware design (ii) algorithm design (iii) report writing and (iv) code documentation, in addition to soft skills such as presentation skills and video recording skills. The innovative methodology used in the competition is explained in the next section in detail. Twenty finalist teams - 5 teams from each of the 4 themes - travelled to IIT Bombay to participate in the grand finals. Note that this was the only time we had face-to-face interactions with the student teams. This event provided the Level-3 evaluation which authenticates the project implemented by the students in (i) design quality (ii) generality/optimality of the algorithm implemented, (iii) modularity of the code written and (iv) validating authorship of the project. Teams were asked to demonstrate their solution in an arena that was slightly modified to ensure the originality of the work done and generality of the algorithm used. Expert (faculty) judges conducted an oral questioning during the demonstration, to evaluate the contribution from each of the team members and their understanding of the solution provided. Design aspects of the solution provided were also given due consideration.

IV. An innovative Methodology to impart Project Based Learning

In eYRC the methodology used is derived from the experiences of Prof. Kavi Arya and Prof. Krithi Ramamritham in teaching the "Embedded systems" course at IIT Bombay.

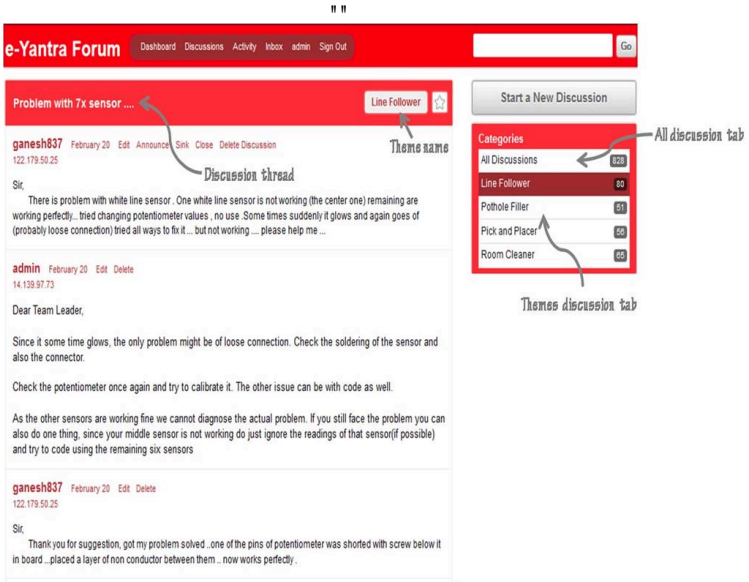

Figure 3: Discussion Forum

This methodology involves several steps to guide the students to understand, think, and then implement a solution based on their analysis of alternative solutions. During the course of the competition, students are taken through the various steps of project implementation, gradually exposing them to solve a real world problem in an effective way.

Thus, PBL through eYRC is divided into several tasks each with specific goal/s as explained in Table I. This table also lists the responsibilities of the e-Yantra team and the student teams.

Support mechanisms to achieve effective knowledge dissemination

An online discussion forum as shown in Figure 3, was

Table I: Details of Tasks assigned in e-Yantra Robotics Competition

Assigned Task:	**Outcomes Imparted/Tested:**	**e-Yantra provides:**	**Responsibility of Student Team**
Task 0: Flex Printing	• Following given Instructions	• Flex-design Instructions	• Printing Flex Design • Uploading an image of the flex design.
Task 1: Theme Analysis	Understanding of • Concepts • Working of Robot • Theme Assigned	• Video Tutorials • Robotic kit with accessories • Manuals • Rule Book with the Problem Specification • Template for Theme Analysis	• Critically Examining the Problem. • Answering Questions Based on the Concepts Learnt.
Task 2: Implementation Analysis	• Design Analysis • Algorithm Analysis	• Template to test Design Analysis and Algorithm Analysis	• Designing mechanical structure on the Robot. • Placement of Sensors, Actuators. • Considering different options for solving the problem, listing the pros and cons of each option, justifying selection of a particular.
Task 3: Video Demonstration	• Working Prototype for the Theme Assigned • Video Shooting • Presentation Skills	• Instructions	• Setting up the Demonstration. • Video Recording as per Specifications. • Providing an introductory presentation.
Task 4: Report and Code documentation	• Report Writing • Following Software Documentation Standards	• Instructions to follow Software Engineering Principles • Template for Report	• Specifying Implementation Idea, Design Constraints, Challenges faced. • Modular design of code for reuse by providing: Comments in code, "read me" file with versions of software used and instructions for execution of code.

available to students to post their queries. The forum had provisions for participating in a general discussion through the "all discussions" tab or in a theme-specific discussion through one of the tabs with the theme names. Figure 4 provides count of discussions posted in each of the four themes. Note that count of discussions posted in each theme was almost the same, indicative of similar difficulty levels across all the themes.

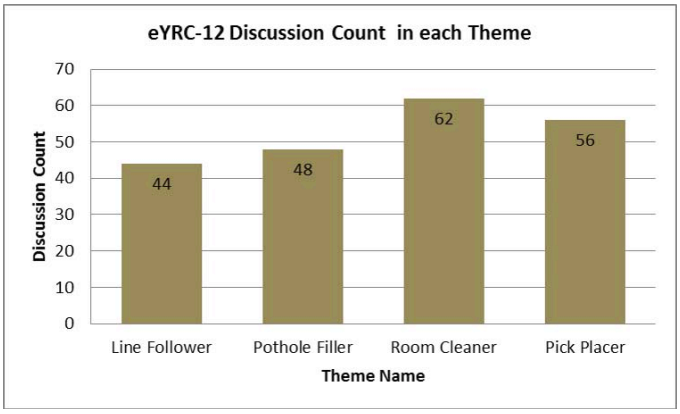

Figure 4: Discussion per Theme

V. Impact Analysis

In this section, we study the effectiveness of our approach using the following level of achievement metrics [15] that can be mapped to the tasks assigned in the competition. We provide the metrics and mapping of these metrics to the tasks in Table II.

In Figure 5, we present the statistics on the number of teams that completed the various tasks. We have given the percentage break-up as a pie chart with the actual number of teams given as legend. Out of 131 teams, 127 teams submitted at least one task - i.e. 97% of the teams acquired at least the basic knowledge. 79 teams out of the 127, submitted all tasks - i.e., 62% of these teams were exposed to all the tasks through the PBL mode. Out of the 79 teams that submitted all the tasks, 41 had completed all the tasks, i.e., 52% of these teams were successfully trained to implement a project independently. Out of these 41 teams 20 teams were chosen as finalists to compete in the grand finals of the competition, i.e., 49% of these teams not only successfully completed all the tasks but also have shown the potential to be innovators.

Table II: Mapping of Level of Achievement Metrics to Tasks

Level *	Level Description *	Task	Task Description
Basic Knowledge	Recognition and understanding of facts, terms, definitions, etc.	Task 1: Theme Analysis	Critically examining the problem. Answering questions based on the material learnt.
Application of Knowledge	Use of knowledge in ways that demonstrate understanding of concepts,their proper use, and limitations of their applicability	Task 2: Implementation Analysis	Considering different options for solving the problem, listing the pros and cons of each option,justifying selection of a particular algorithm.
Critical Analysis	Examination and evaluation of information as required to judge its value to a solution and to make decisions	Task 3: Video demonstration	Making a working prototype.Evaluating the prototype to make the solution more efficient.
Extension of Knowledge	Extending knowledge beyond what was received, creating new knowledge,making inferences, transferring knowledge to usefulness in new areas of application	Task 4: Report and Code Documentation	Specifying implementation idea, design constraints, challenges faced.Coming up with a sleek design and/or an efficient algorithm.

*Levels and Description of levels are taken from [15]

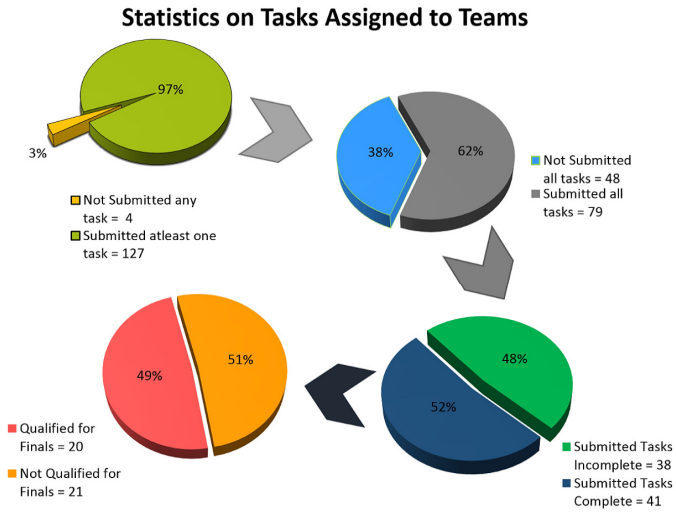

Figure 5: Task-wise break-up of performance of teams

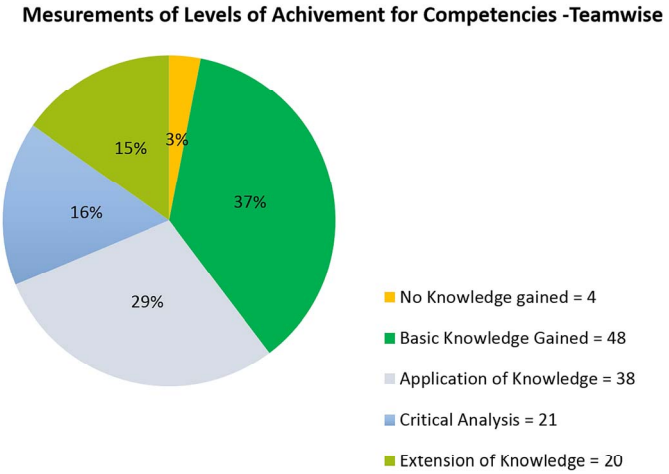

Figure 6: Outcomes of the e-Yantra Robotics Competition -2012

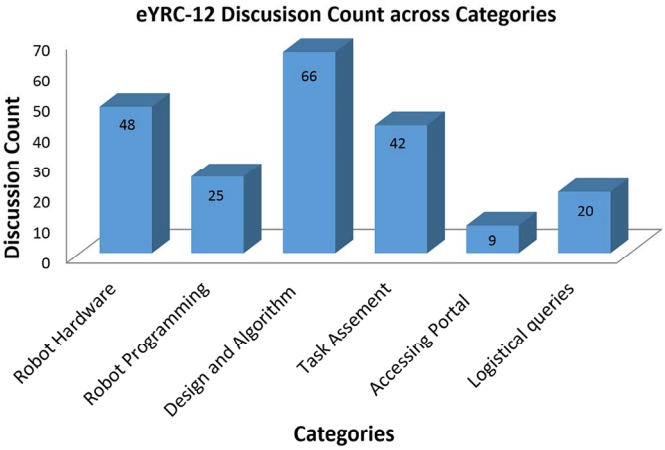

Figure 7: Discussions across Categories

Based on the statistics, we map the outcomes to the level of achievement metrics discussed in Table II:

i. No Knowledge Gained: Students who did not complete even one task. These students did not learn anything from the e-Yantra Robotics Competition.

ii. Basic Knowledge Gained: Students who submitted at least one task but could not solve the assigned problem and dropped out of the competition. These students learnt the basic concepts related to robots through video tutorials and completed the first or second task.

iii. Application of Knowledge: Students who tried to solve the assigned theme but could not complete the theme as desired. These students were able to make the robot perform part of the solution but could not integrate all modules required to solve the theme completely.

iv. Incorporated Critical Analysis: Students who successfully completed all the tasks and solved the problem as specified. These teams learnt the basic concepts and applied those to design the robot by understanding and analyzing the problem statements.

v. Showcased Creativity: These students were the members of the top five teams from each theme. These students not only demonstrated a working solution but also showcased their creativity in designing an efficient solution.

Figure 6, illustrates the team-wise outcomes discussed above.

Discussion forum: A crucial component

During the course of the competition 210 queries were posted; these were grouped into six categories. Figure 7 provides the distribution of the queries across these

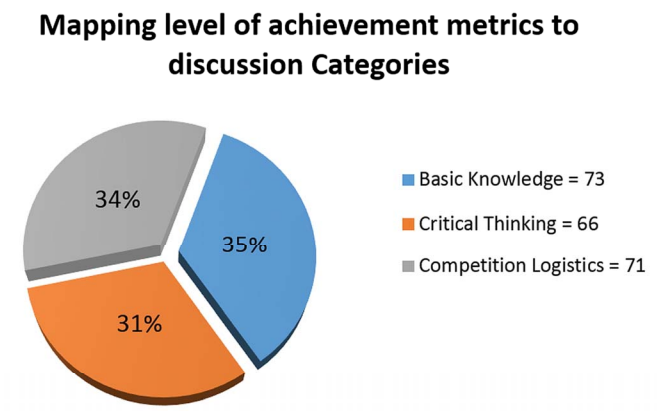

Figure 8: Effective learning discussions

categories. Note that the queries in robot hardware and robot programming were questions in "Basic Knowledge" while the queries in design and algorithm were pertaining to "Critical Analysis". The rest of the queries were general in nature - pertaining to the competition logistics. We present the break-up of queries along these dimensions in Figure 8.

From Figure 8 we find that 66% of the posted queries were from levels of basic knowledge and critical analysis. These queries were related to concepts learnt through video tutorials and implementation of those concepts in designing the robot hardware and algorithms. Thus, these queries were directly related to the learning experience of the students. Other 34% of the queries were related to task submission deadlines, accessing online portal, and other logistics.

Another interesting aspect of the discussion forum was that it enabled students to discuss technical queries with both e-Yantra technical team and other participating teams. The forum served as a platform for peer-to-peer interaction where from among 210 posted queries, 58 queries (approx. 26%) involved students from different teams discussing the problem amongst themselves. 10 queries (approx. 5%) were answered by students from other teams who faced similar problems, but found ways to overcome them. Given that most of the students who participated in the competition were novices, with little or no experience with robots. These numbers, even though small, show the power of open discussion forums amongst peers in providing the necessary support.

VI. Current Status: Results of e-Yantra Robotics Competition 2013

The second edition of e-Yantra Robotics Competition (eYRC-2013) was conducted over the period November 2013 - February 2014. In this competition students registered as a team of 4 and each team appeared for randomly created selection tests online, concurrently. Out of 1581 teams (6324 students), 160 teams (640 students) were selected to participate in the competition. Four themes from "urban agriculture" domain, namely: seed sowing robot, weeding robot, fertilizing robot, and fruit plucking robot, were each assigned to 40 teams. Finals of eYRC-2013 were held on March 28, 2014 where 20 teams selected as finalists from the 4 themes, competed for Internship awards at IIT Bombay and other prizes.The model and methodology as explained in Section IV were used for the competition. We present the Task-wise break-up of performance of the teams in Figure 9.

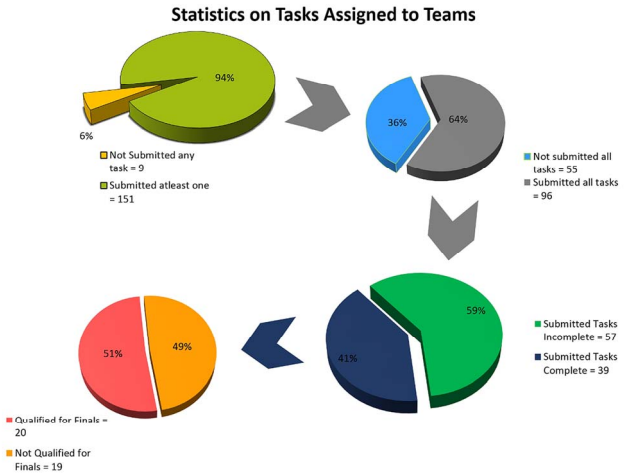

Figure 9: eYRC-2013: Task-wise break-up of performance of teams

In Figure 9, we present the statistics on the number of teams that completed the various tasks. Note that we have given the percentage break-up as a pie chart with the actual number of teams given as legend. Out of 160 teams, 151 teams submitted at least one task - i.e. 94% of the teams acquired at least the basic knowledge. 96 teams out of the 151, submitted all tasks - i.e., 64% of these teams were exposed to all the tasks through the PBL mode. Out of the 96 teams that submitted all the tasks, 39 had completed all the tasks, i.e., 41% of these teams were successfully trained to implement a project independently. Out of these 39 teams 20 teams were chosen as finalists to compete in the grand finals of the competition, i.e., 51% of these teams not only successfully completed all the tasks but also have shown the potential to be innovators.

Based on the statistics, we map the outcomes to the level of achievement metrics discussed in Table II. Note that we have used the same format as in Section V, to facilitate comparison of results of the two competitions :

i. No Knowledge Gained: Students who did not complete even one task. These students did not learn anything from the e-Yantra Robotics Competition.

ii. Basic Knowledge Gained: Students who submitted at least one task but could not solve the assigned problem and dropped out of the competition. These students learnt the basic concepts related to robots through video

tutorials and completed the first or second task.

iii. Application of Knowledge: Students who tried to solve the assigned theme but could not complete the theme as desired. These students were able to make the robot perform part of the solution but could not integrate all modules required to solve the theme completely.

iv. Incorporated Critical Analysis: Students who successfully completed all the tasks and solved the problem as specified. These teams learnt the basic concepts and applied those to design the robot by understanding and analyzing the problem statements.

v. Showcased Creativity: These students were the members of the top five teams from each theme. These students not only demonstrated a working solution but also showcased their creativity in designing an efficient solution.

Figure 10, illustrates the team-wise outcomes discussed above.

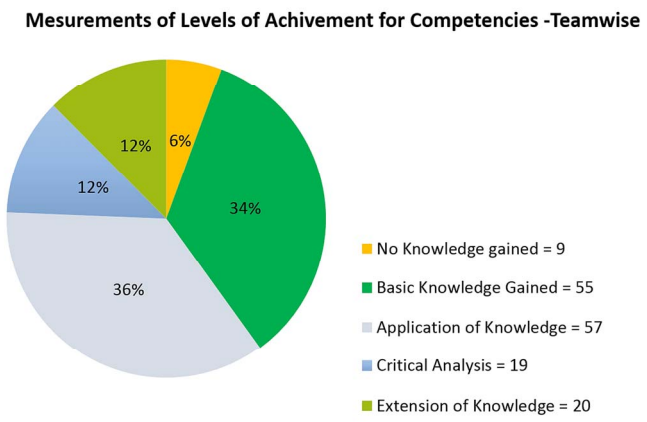

Figure 10: Outcomes of the e-Yantra Robotics Competition -2013

VII. Conclusion

As discussed in Section V, our experience from eYRC-2012 shows over 95% of the students who participated in the competition gained basic knowledge of embedded systems and robotics. Out of these about $2/3^{rd}$ of the teams could apply their knowledge and implement solutions using the robot. Approximately $1/3^{rd}$ of the teams that participated, exhibited creativity and critical thinking skills; they not only devised a solution but also worked on efficient ways to design and implement their solution. These results are further supported by our preliminary analysis of outcomes in eYRC-2013 second edition of the competition, where we had increased the number of teams by over 20% and included teams from states that were under represented. Having run the competition again using the same model and methodology tested during eYRC-2012, we have proven the scalability of the competition. In addition to the statistics we have presented in this paper, the feedback we received from students who participated in the competition from the remotest parts of the country provide testimonials [16] to the effectiveness of this project in identifying and nurturing talented students who otherwise lack the opportunity to experiment and innovate.

To summarize, unique features of the model and methodology used in the e-Yantra Robotics Competition include:

(i) Achieves Project Based Learning through a competition conducted completely on-line.
(ii) Provides opportunities to talented students to work hands on with a robot without incurring any cost.
(iii) Incorporates features deemed essential for effective on-line learning such as: (a) self-paced video tutorials (b) evaluations in the form of tasks to be completed along the way (c) peer-to-peer interaction - both with the team members and with other participants and e-Yantra team through the forums
(iv) Leverages the competition to identify colleges with motivated students to seed Robotics labs at these colleges - the robotics kit given to the student team were retained by the college at the end of the competition.

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