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Augmenting High School Student Interest in STEM Education Using Advanced Manufacturing Technology

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AUGMENTING HIGH SCHOOL STUDENT INTEREST IN STEM EDUCATION USING ADVANCED MANUFACTURING TECHNOLOGY

Engineering effective education is gaining a huge interest for harvesting and improving higher education on a global basis for increasing student engagement in Science, Technology, Engineering and Mathematics (STEM). As a part of this effort, this paper is based on introducing high school students towards Additive Manufacturing technologies for improving their interest in Science, Technology, and Engineering and Mathematics (STEM) fields. The instructional set up involved using of Solid Works® software by high school students to develop computer aided design models which were then visualized and printed using 3D Printers. Design of Experiments (DOE) based statistical techniques were then used to identify the best-built conditions for the parts developed by the students. The approach for creating an effective learning environment for high school students in a university setting along with the course structure used and project findings are presented in this paper. It is found that the students involved showed a basic level of understanding on how engineering problems are tackled using the tools available at their disposal at the concluding phases of this project.

Keywords: Additive Manufacturing; CAD; Design of Experiments; STEM.

INTRODUCTION

Science, Technology, Engineering and Mathematics (STEM), plays a vital role in shaping the future of emerging workforce in United States. According to department of Labor, STEM careers are projected to be among the 10 fastest growing jobs in United States from 2008-2018[1]. Mentioned below are some of the skills acquired by STEM students that prepare them to succeed in education and industries [2]:

- Increased Research Competency.
- Understanding how a system works based on analyzing a system and its sub system relationships.
- Recognizing issues that can be described from a STEM perspective.
- Identification of appropriate explanations, solution and conclusion to a given problem.
- Identifying appropriate explanations based on evidence based conclusions.
- Engaging STEM related issues with emerging Science, Technology and Engineering driven solutions.

Information sensitive, continually evolving, technology flexibility and competency to meet changing customer demands are some of the mostly dominant attributes required for current working environments[3]. Traditional instructional settings fail to impart these competency skills required in students for preparing them to be involved in real world technology driven problems[4]. This implies that there is a need for educators to make the required changes in either their curriculum or the approach taken towards students for them to acquire emerging technical skills for successful employment in complex conglomerative working environments [3].

While STEM plays an important role in student education, it is to be noted that at the college level, many students are dropping out of STEM majors, implying that there is a need to increase student retention. According to AT&T Aspire, many high-paying STEM jobs are going unfilled because the candidates lack the necessary technical skills and also, around 64 percent of organizations have vacancies for STEM positions due to lack of qualified applicants. This will make it difficult for industries to recruit the new stream of engineers, technicians and manufacturers [5].

To educate and focus on improving student participation in STEM, many Organizations, Science and Engineering societies, and Universities are leading initiatives to change the current equation for improving student competitiveness. As a part of this initiative to improve student technology readiness levels in the emerging field of additive manufacturing, a project based learning course was initiated by Industrial, Manufacturing and Systems Engineering Department at *XXXXXXX*. This course was geared towards introducing high school students to the concepts of Additive Manufacturing for increasing technology competency for meeting current industrial need along with trying to increase their personal interest towards STEM. In the later sections of this paper, the course structure developed along with the details on successfully completed student projects is explained.

OVERVIEW OF COURSE STRUCTURE DEVELOPED

In order to increase and stimulate the knowledge and motivation of High school students towards STEM, a course structure based on the concepts of *Additive Manufacturing*, *SolidWorks*, and *Design of Experiments* was developed. The main objectives for the students were to: *Design* a product using virtual modelling environments (Solid Works®), *3D print* the developed design by considering its various related layer properties, *Analyze* the product based on the factors used and to be able to obtain *Results* based on real time data. To meet this objective, interactive hands on sessions were used with the help of three graduate research assistants at *XXXXXX*. The steps followed to achieve the said objective are illustrated in Figure 1. The information content provided to the students was designed to make them acquainted in the fields of Computer Aided modelling, Additive Manufacturing and Statistical Analysis. The main intention here was increase their interest in the field of STEM by providing them with sufficient technical knowledge to successfully complete their assigned project.

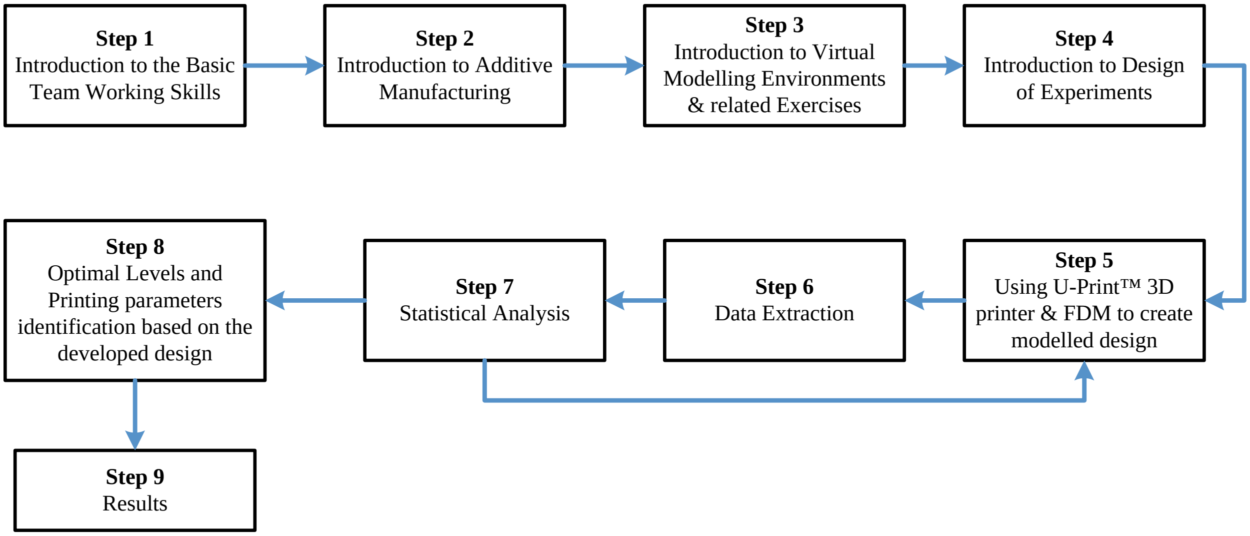

Figure 1: Course Structure Illustration

Additive Manufacturing Technology

Additive manufacturing currently believed to be on a huge trend towards changing the face of current manufacturing technologies [6]. The foreseen rise of global 3-Dimensional (3D) printing market is estimated to be around 2.99 Billion USD by the year 2018 according to a global strategic business report [6] complied by Global Industry Analysts Inc., a source of Worldwide Strategy and Market Intelligence.

As a flipside to Subtractive Manufacturing process where a solid block of material is used to manufacture products, Additive Manufacturing (AM) is an advanced manufacturing technology process used since 1980's where parts are built by selectively adding materials as layers along with reducing waste. It is an automated technique for direct conversion of 3D Computer Aided Design (CAD) (digital) data into physical objects using different layer-based additive approaches. Manufacturers have been using these technologies to reduce development cycle times and introduce products into the market quicker, more cost effectively, and with added value based on its ability for customization. Realizing the potential of AM in product design and manufacturing, a large number of processes have been developed that allow direct fabrication of parts from a variety of materials ranging from plastics to metals [7].

AM also commonly known as 3D printing, is a manufacturing process that creates a 3-Dimensional object. Fuse Deposition Modeling (FDM) is a common 3D printing process that consists of laying down layers of material to create a desired model or a part [8].

3-D printers based on FDM technology were incorporated into the course structure. The FDM process consists of feeding a build material and a support material thru two separate nozzles. Both materials are laid down layer by layer in order to construct the model or part designed in CAD software. Support material layers are used in order to create a firm base for the model material to lie down and cure. Once the part is printed the support material can be removed or cleaned, allowing the user to have a customized part. The nozzles contain resistance heaters that allow the material (*based on the type of printer used*) to be deposited on the building base. As each layer is created, the building base lowered by a level in order to set next level of material[9]. Students were introduced to the concepts of different Additive Manufacturing technologies with an increased focus on Fused Deposition Modelling. Figure 2 illustrates a brief summary on different AM technologies students were introduced to along the course.

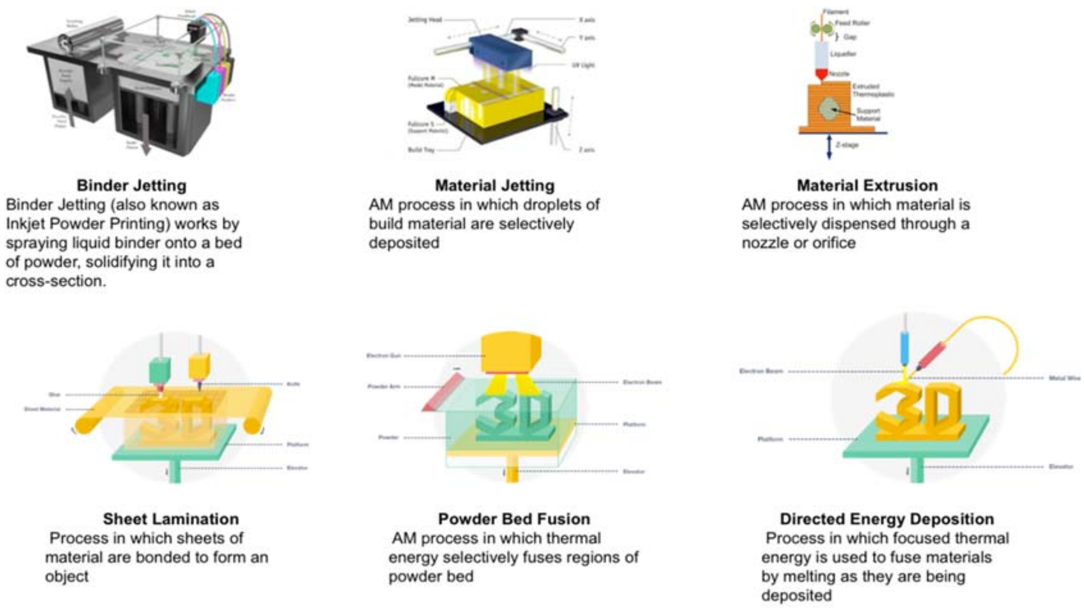

Figure 2: Additive Manufacturing Processes [10, 11, 12, 13, 14, 15]

Virtual Modelling Environment Used (SolidWorks®)

SolidWorks® is a computer aided modelling tool that uses a parametric feature based approach enabling a user to create and design 3 Dimensional models, parts, assemblies and drawings. It has a set of library tools that help to create exactly what is desired such as fillets, round-off corners, holes, and even text. Once a 2D sketch or a cross section is developed, it can be translated to 3 dimensional figure using inherent features. These are completely dimensional driven and use geometric relationships to reflect reality as close as possible based on the design intent [16].Students were given hands-on live tutorials on how to use SolidWorks® software to create and model the design of their intent. Figure 3 illustrates a sample 3D LEGO® part model created by students.

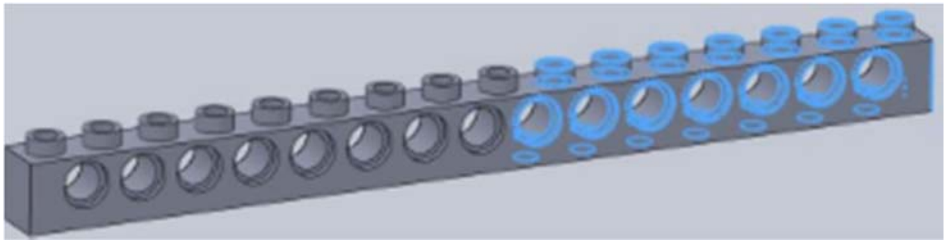

Figure 3: 3D LEGO® Part Model Created in SolidWorks®

Using uPrint® SE Plus 3D Printer

uPrint® SE Plus 3-D printer manufactured by Stratasys technologies was used to bring the student designed parts to life. This printer uses FDM technology to build and create models and prototypes to the highest possible accuracy using ABS*plus* thermoplastics. CatalystEX software was used to translate the designs to be able to print [17]. CatalystEX software enables a user to choose various Dimensional, Layer and Feature aspects such as *Model Interior*, *Support Fill*, *Layer Resolution* and *Orientation* to print a part.

- *Model Interior*: This attribute helps to establish the type of fill used for interior solid areas of a part. It has 3 levels associated, where, *Solid* is used to build and stronger part with more material and built time associated, *Sparse High Density* is used as default level with shorter built times and less comparative material, and, *Sparse Low Density* for a honey combed interior with shortest associated built time and lowest material used [18].

- *Support Fill*: Support material is usually used to build a part for bracing the model material during a built process. It affects strength and built time along with the strength of the original part itself. It has 3 associated levels, where, *Basic* uses a consistent narrow spacing between support raster paths, *SMART* helps to minimize the support material used with wide spacing of toolpath raster's and, *Surround* encloses the entire model with support material [18].

- *Layer Resolution*: Enables a user to choose the height of each layer while printing a part. There are 2 available levels *(0.010 inches & 0.013 inches)* depending upon the type of printer being used. Resolution of a part effects the build time along with its surface finish [18].

- *Orientation*: Helps to choose how a part is positioned for build based on surface contact of the support platform. Orientation of a part effect Speed, Strength and Material consumption while printing a part. A given part can be oriented along all the possible combinations of X, Y and Z [18].

Various Hands on sessions to each and every student individually were given on how to use the 3D printer. These sessions incorporated on how to use CatalystEX software for transferring a file to the machine using different factors mention above. Later, Machine Setup, Build Process, Part

Removal, Post Processing and Safety procedures to be followed were elaborated upon. Figure 4 illustrates side by side visualization of original and student developed LEGO® based parts designs.

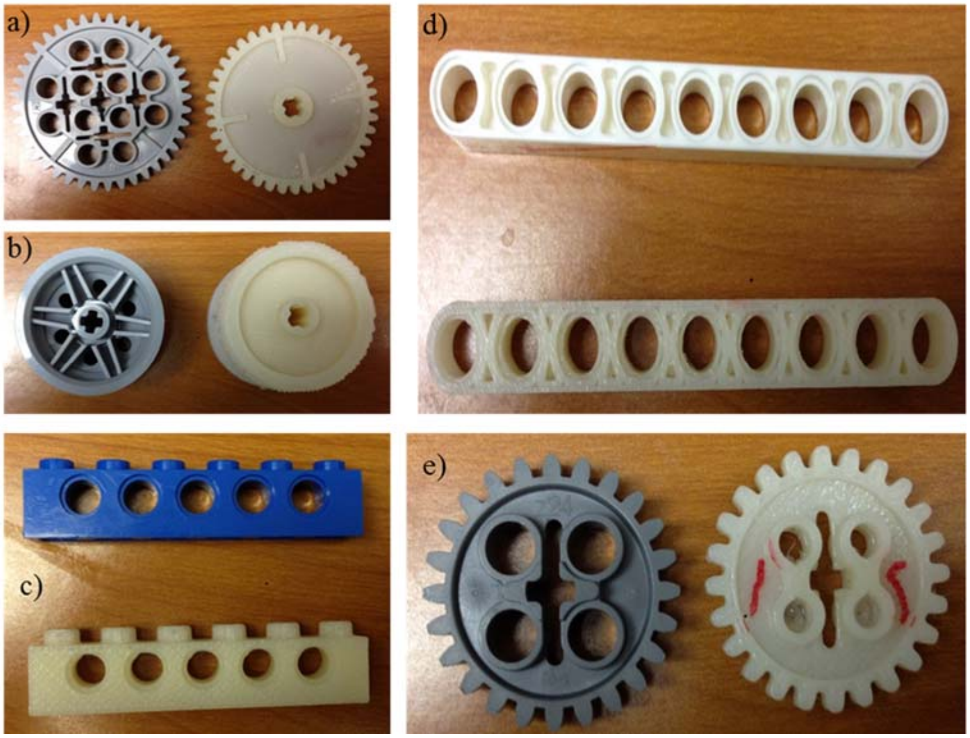

Figure 4: Side by Side illustration of original LEGO® parts and 3D printed (Ivory Color) LEGO® parts [(4a) LEGO® Gears, (4b) LEGO® Tire Rim, (4c) LEGO® Shaft, (4d) LEGO® Shaft, (4e) LEGO® Gear]

Design of Experiments

Design of Experiments (DOE) is used to discover and/or explain a considered attribute of a specific process or a system. One of the most common experiments used to evaluate how different factors affect a manufacturing process or a product is a 2k Factorial Design. This design is used for experiments that involve several factors in order to understand the joint effects of each factor on a process as a synergy[19]. The 2k Factorial Design refers K different factors that affect a process, and the number two refers to 2 levels for each factor (high and low). In order for an experiment to be statistically valid, the following are the assumptions to be satisfied (1) factors are fixed, (2) the design is complete randomized and (3) the data is normally distributed. A step-by-step analysis procedure for a 2k Factorial Design is to [19]:

- Estimate factor effects
- Formulate a model
    - Use full model with replicated design
    - With an un-replicated design, use normal probability distribution plaits
- Perform statistical testing (using ANOVA)

- Refine the model
- Analyzing residual graphs
- Interpret the Results

For complex designs, a full factorial design elicited from Design of Experiment concepts can be used. It is helpful when considered feasible to test all the possible combination of the factors and levels in the experiment. Such a method analyzes all the discrete possible combinations of the levels to interpret the possible interactions[20]. A commonly used statistical analysis on full factorial experiments is the analysis of variances (ANOVA). It is used to identify the variation between a given set of groups along with testing the mean of the groups of data to check for their statistical difference[19].

To understand and use the concept of DOE, students were initially exposed on how to use a full factorial design experiment using Statapult®. Statapult® was used to teach the concepts on basic statistics and design of experiments along with also using it as a tool for team based exercises for applying statistical methods towards a real world problem. Students were tasked to do a 4 factors-2 level DOE using *Pullback angle, Stop angle, Type of ball*, and *Cup position*. This helped them to see how a full factorial experiment can be run using real time data.

Student Projects

Armed with all the mentioned concepts, student were divided into 3 teams with a given choice of choosing their projects from a LEGO® based Solar Car, LEGO® based Battery Operated Car and a LEGO® based Wind turbine. Flexibility was allowed among the teams to identify an Objective and a Methodology to get Results and Conclusions upon a considered problem statement based on their collective interest. Given below are the details on the Objective, Methodology used, obtained results and student team conclusions for each project individually.

LEGO® based Battery Operated Car

Objective: The main objective was to improve the 3D parts used for a Lego battery car in terms of increasing strength of the parts printed along with reducing their weight. Concepts of DOE and ANOVA will be used to identify the best factor levels to achieve the said objective.

Methodology: The following steps were used to achieve the objective: CAD file creation, File conversion to STL, File transfer to 3D printer, Part building process, Removal of part, and Post-processing (cleaning). After gathering the data based on the above concepts, the next step was to use DOE. This involved: Setting objectives, measuring quantitative responses, Perform replications based on Orientation, Model Interior and Layer resolution, randomize order run, and confirm Critical Findings. The final step incorporated Tensile testing and weighing of the printed parts.

Results:

- ***Strength*****:** Using a significance level of 0.05, it was concluded that the data is normally distributed and there is randomness. Model interior was found to the significant factor and the highly influent interaction was among Orientation and Model Interior factors.

- *Weight*: Using a significance level of 0.05, it was concluded that the data is normally distributed and there is randomness. All factors were found to be significant to achieve this objective.
-

Conclusion: It was found that model interior was the only factor that affected the strength of a part and on the flipside; all the considered factors were significantly influencing the weight of a part. The optimal combination of achieving the objective of the parts having high strength and low weight is illustrated in the figure below.

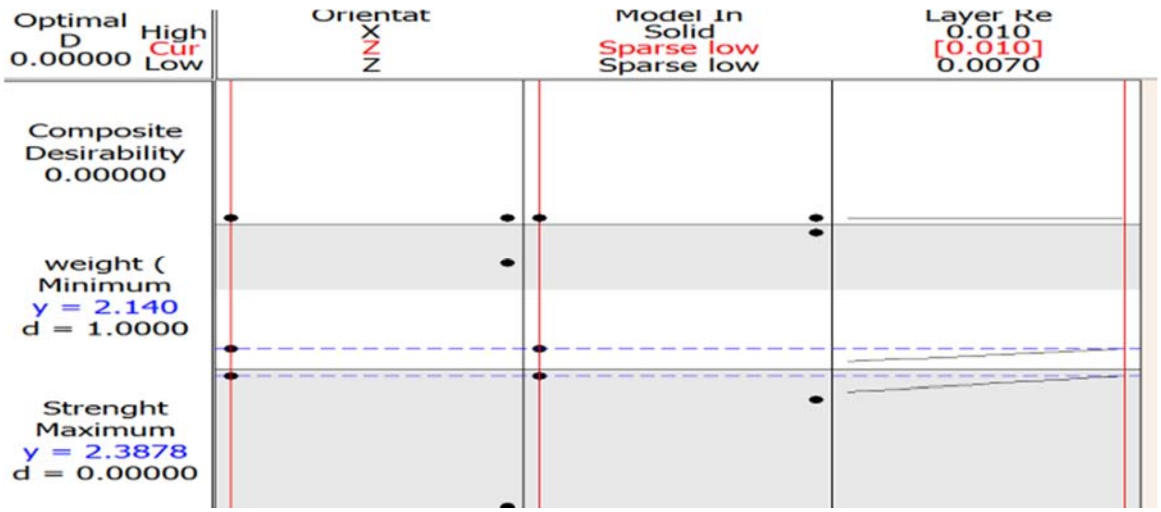

Figure 5: Representation of the Optimal Combination of factors considered

LEGO® based Solar Car

Objective: Main aim of this team was to create a more efficient design in terms of time to build and strength of the solar car. To be specific, the objective was to find the best combination of factors to create a LEGO® based Solar Car with increased strength, minimum amount of material used and less time to print.

Methodology: Lego pieces are first designed in SolidWorks®. A design matrix of 2^3 factorial design was created to be used for the experiment. The factors used for the factorial design were: Model interior, Support fill and Layer resolution. Table 1 below illustrates the factors and levels used for the project based on which parts were printed with the illustrated factor levels. Finally tensile test was used to test the strength of the printed parts.

Results: The following are the results obtained in relation to the mentioned objectives:

- ***Strength:*** The factors that made the strongest piece were: Model Interior – Solid (high level), Support Fill – Surround (high level), and Layer Resolution – 0.330 (high level).

StdOrder	RunOrder	CenterPt	Blocks	Support Fill	Model Interior	Layer Resolution
8	7	1	1	Surround	Soild	0.330
1	8	1	1	Basic	Sparse Low Density	0.254
7	9	1	1	Basic	Soild	0.330
16	10	1	1	Surround	Soild	0.330
11	11	1	1	Basic	Soild	0.254
3	12	1	1	Basic	Soild	0.254
4	13	1	1	Surround	Soild	0.254
15	14	1	1	Basic	Soild	0.330
2	15	1	1	Surround	Sparse Low Density	0.254
9	16	1	1	Basic	Sparse Low Density	0.254

Table 1: Factors and Levels used for the project

- ***Printing time:*** The factors that effected in minimizing the time to print were: Model Interior – Solid (high level), Support Fill – Surround (high level), and Layer Resolution – 0.330 (high level).
- ***Material Used:*** The minimum amount of material was used with the following factors and corresponding levels:
  Model Interior – Solid (high level), Support Fill – Basic (low level), and Layer Resolution – 0.254 (low level).

Conclusion: Performing 2 replications of the full factorial experiment to achieve the objectives mentioned, the following were recommended:

- Model interior: Solid (high level)
- Support Fill: Surround (high level)
- Layer resolution: 0.330 (high level)

<u>LEGO® based Wind Turbine</u>

Objective: The objective of this study was: to identify the inputs that have a significant impact on the overall output of the product.

Methodology: The methodology included establishing the factors to be used during the experiment, which were: Layer Resolution (Refers to the thickness of each printed layer), Model Interior (Refers to how the material inside each part is laid down), and Support Fill (Refers to what hold the model during the printing process). Reference Lego parts were measured, 3Dmodels of these parts were created using solid works®, and the parts were printed and cleaned according to the factors and levels established for the experiment. Finally parts were tested to gather data on strength of each part.

Results: Using a significance level of 0.05, it was concluded that the data is normally distributed and there is randomness. The significant factors were: Model interior and Layer resolution; as illustrated in figure6.

Conclusion: It was concluded that the optimal combination to achieve the objective of high strength and low cost parts was: Model interior: Sparse Low Density, Support Fill: Surround, and Layer resolution: 0.330. Figure 7 illustrates the results.

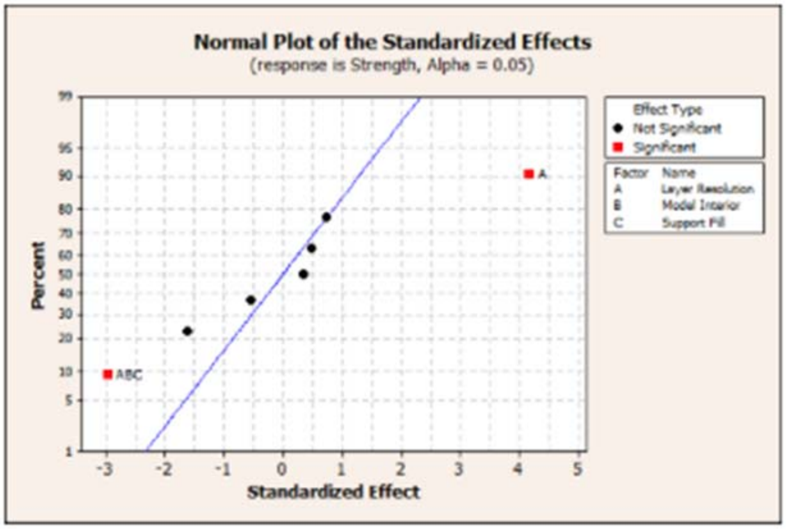

Figure 6: Identification of Significant Factors

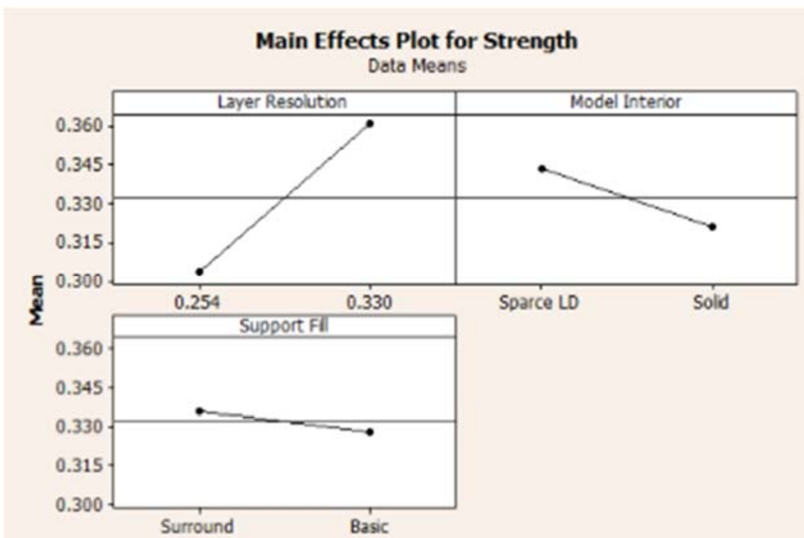

Figure 7: Team results illustration

CONCLUSION

This paper elaborates on the course structure that integrates CAD, design of experiments, and 3D printing, developed for high school students to expose them to current emerging additive manufacturing technologies. Hand on sessions incorporating basic engineering skill with current emerging technologies proved effective in motivating high school students. Student teams under the guidance of graduate mentors were able to design, fabricate, analyze and successfully identify an optimal design reflecting their intent. Design fabrication was based on using 3D printers available to the high school students at their designated facility. Educational materials such as student handouts, power point presentation and hands on exercises were developed along with providing students with access to required software tools for designing and 3D printing. It was found that the students were comfortable and more inclined towards the skills they were introduced to by the end of their session. A student-centered survey was disseminated at the concluding phase of this project to gather feedback on their experience. The students graded the overall experience of the program with a 4.5 average on a scale of 5.0. Also, 66% of the students found 3D Printing and Design Of Experiments to be more appealing. Based on their hands-on experience with Design of Experiments, SolidWorks and 3D printing and the comments received by the program participants it was found that: (a) All the students demonstrated basic level of understanding (through their assigned project) on how to use basic engineering skills to tackle a real world problem based on the tools available to their disposal; (b) Educational environment provided to them in university setting motivated 45% of the participants with a positive impact on their career choices towards STEM.

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