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# The Impact of Authentic Complex Engineering Design Experience for K-12 Students on 21st Century Attributes and Perceptions towards STEM fields (Evaluation, Strand 3)

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## Abstract

Recent studies showed that embedding engineering at K-12 level has a positive impact on stimulating interest in- and improving learning outcomes of science and mathematics, and development of 21st Century skills. Engineering activities are used as a way for displaying an authentic applicability of taught math and science in K-12 students in real applications. In this context, an outreach activity, namely Life is Engineering Program (LIEP) was launched in 2009 by the College of Engineering at Qatar University with particular focus on Qatari male students. In LIEP, K-12 students in the 10$^{th}$ and 11$^{th}$ grade work on assembling racing cars over a period of six months throughout an accompanying program of activities, engineering workshops and seminars, and finally a race is conducted in an international racing circuit located in Qatar.

The methodology of the assessment included analysis of 2 surveys each of 16 questions (including demographics, open-ended, and Likert scale up type of questions). Surveys were delivered to both LIEP participating students (Sample no. N= 57) and LIEP non-participating Qatari students (sample no. N= 51).

Experimental group outcomes against Control group outcomes were analyzed; findings indicate statistical significance in perceptions towards development of significant set of 21st century competencies. Perceptions towards STEM fields were more positive for the experimental group than the control group for the majority of measuring items, however statistical significance was detected in fewer items.

The paper provides further details on the LIEP outreach program, as well as the assessment, its methodology and initial findings and planned actions.



Keywords— Engineering Design, K-12 students, Qatar, Life is Engineering, STEM field


## Introduction

Offering various forms of engineering education at K-12 level can be traced to the early 1990s [1], Malcolm argued that students perception towards engineering was considered more of a technically oriented, they did not understand the socio-economic context and benefits of engineering. Accordingly, preferences of introducing of engineering design to K-12 education programs were emerged to provide a venue and experience demonstrating engineering connections to human needs [2].

STEM is actually an integration of four disciplines in which technology and engineering are layered onto standard science and Mathematics curricula resulting in cohesive curricula in which barriers are removed between the four disciplines.

Although wide spectrum of scientific knowledge and socio-economic advances are based on technological developments, the American Society of Quality 2009 stated that 85% of 8-17 years students are not interested in engineering, they view engineering as a boring profession involving mainly construction operations, repair and installation of equipment rather than innovation and design for the benefit of good or humanity [3].

Approaches whereby engineering was utilized as an integrative interdisciplinary STEM oriented (e.g. through engineering innovation and design) was found better impacting K-12 students than approaches of teaching engineering in K-12 in a traditional didactic way [4]. Classroom are not "Authentic" enough in which most activities and products are not well connected to outside problems 5. Engineering is an applied science and mathematics field that is to a significant extent problem solving and design oriented, hence engineering design connect students to real-world problems [6]; Main steps of Incorporating Engineering Design Challenges into STEM courses are shown in Figure (1) [7]

The paper provides an analysis on the impact of engineering design in K-12 student's perception and attributes towards STEM fields, as well as, impact on 21st century skills development. The paper reports on Quantitative analysis investigating the impact of engineering design based experience "Life is Engineering project" on soft skills enhancement and technical development of K-12 students.

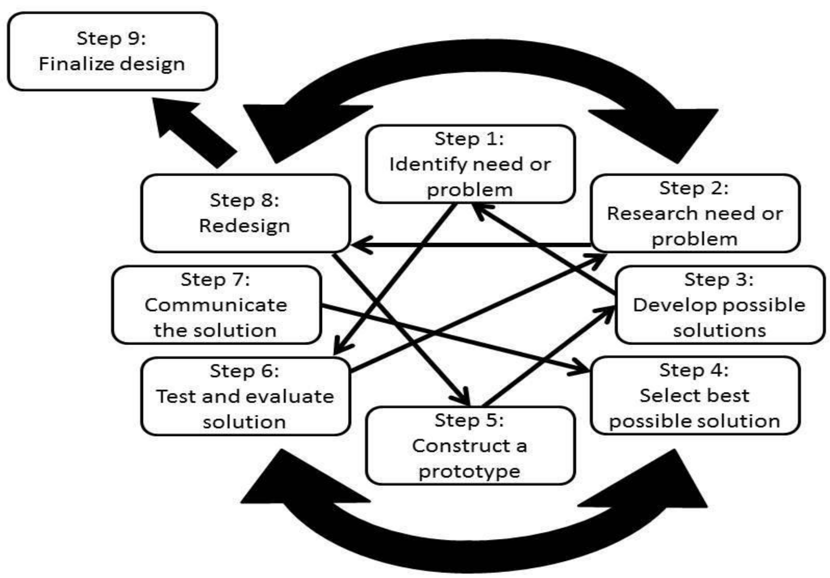



**Figure (1) the main steps of Incorporating Engineering Design Challenges into STEM courses [7]**

## Emerging Needs in Qatar

Qatar government has set a national aim to transform into a Knowledge Based Economy (KBE) by 2030; Engineering and other STEM fields are at the core of realizing such vision [8; 9; 10; 1111]. The current demand of National Engineers is quite high in Qatar; currently a big gap in supply exists. Transformation into a KBE, together with planned mega infrastructure projects in Qatar makes this demand even higher in the near future; this requires emergency and proactive interventions at K-12 level.

Recent statistics have shown that low percentage of Qatari male high school students choose to pursue higher education after finalizing their school [12]. The Programme for International Student Assessment (PISA)[1] ranked Qatari students near bottom of the education index; they are ranked in 2012 as 62 from 65 participating countries although their neighbor UAE is ranked as the 47th. PISA also sought to compare how GDP per capita correlates with test performance means "*When performance differences across the socio-economic spectrum are small and students often perform better (or worse) than expected, given their socio-economic status, one of the main policy goals is to improve performance across the board*"

In Qatar, which has one of the world's wealthiest countries per capita, there was no real correlation which In these cases, universal policies tend to be most effective. These types of policies include changing curricula or instructional systems and/or improving the quality of the teaching staff, providing incentives for high-achieving students to enter the profession, increasing salaries to make the profession more attractive. Other interesting points from the PISA report include outperformance of girls to boys in mathematics in only five countries in which Qatar was one of them [13]. In addition to that, the recruitment of Qatari male students at the College of Engineering (CENG) of Qatar University (QU) has been an issue for a number of years. For all these reasons, the LIEP program was developed, and has focused so far or Qatari males students; The next subsection introduces the Life is Engineering project.

## Life Is Engineering Program

"Life is Engineering Program" is an engineering design teaching method, and is a competition oriented learning experience targeting pre-college K-12 students. "Life is Engineering Project" is an example of a modern design-based teaching method and a community service project. Four rounds (LIEP 1, 2, 3, 4 ) have already been conducted and have been well received by schools, students, teachers, and parents as well as local media. The program focuses on high school students for boys.

It is an opportunity for students to be exposed to the engineering design learning through project-based engineering design intervention. Program starts with workshops, and seminars to provide technical and leadership training to the eventual nominees. Additionally, students will get training on car assembly before going ahead with the second stage which is preparations for the final race. In the second stage, all cars are assembled and are ready technically and professionally before students can drive them in the race as illustrated in Figure 2. Students complete the design phase of their vehicles, including planning the car from scratch, building and testing it in cooperation with the college of engineering in Qatar University. Finally winners will be awarded trips to different countries aiming to visit assembly cars industries to increase their motivation to pursue engineering fields.

[1] PISA: Worldwide study by the Organization for Economic Co-operation and Development (OECD) for 15-year-old school pupils' scholastic performance on mathematics, science, reading and problem solving conducted every 3 years

**Figure (2): LIEP Competition groups**

## Research Questions and Investigation Hypotheses

A number of research questions have been formulated to investigate the impact of Life is Engineering program on K-12 students, these are:

- RQ1: Does LIEP design experience have an impact on students' perceptions towards STEM disciplines (Mathematics, sciences and engineering) as compared with pre-participation and non-participating groups?
- RQ2: Does LIEP design experience have an impact on 21st Century engineering skills as compared with pre- participation and non-participating groups?
- RQ3: What are the main incentives of students' participation in LIEP and reasons behind choosing engineering as academic majors?

RQ3 has an exploratory nature, while RQ1 and RQ2 can be formulated in terms of Null Hypotheses as follows:

Hypothesis 1 (RQ1): LIEP does NOT have significant impact on development of 21st Century engineering skills as compared with pre-participation and non-participating groups.

Hypothesis 2 (RQ2): LIEP does NOT have significant impact on students' attitude towards engineering as compared with pre-participation and non-participating groups.

## Methodology

Quantitative survey approach was utilized for measuring the impact of LIEP on students. Descriptive and inferential statistical methods are utilized to analyze the data and report on the findings. Quantitative data analysis was conducted using SPSS (Software Package for Social Sciences).

This study make use of a variety of statistical tools in order to reach its conclusion; about 95% confidence intervals were produced using both Wilcoxon signed rank test and Mann Whitney U test for non-parametric data to determine skills satisfaction gaps between participating and non-participating students and also between pre and post participation, skills and knowledge satisfaction and students motivations towards engineering as academic major.

Reliability was demonstrated using Cronbach`s alpha in order to determine the internal consistencies of the used satisfaction scales, Cronbach alpha values above 0.9 indicate excellent reliability [14] and in this study it was found to be 0.958 for control group and 0.968 for experimental one indicating excellent scales showing high internal consistency.

Validity was also demonstrated through conclusion validity which is described as appropriateness of the conclusions reported based on statistical relationships [15], thus within this analysis conclusion validity was reported through the use of inferential statistics relying on statistical significance results at the 5% threshold.

**Survey Design**

The survey was composed of 16 questions with Four main sections in which:

***Section.1*** is dealing with participants demographics included for instance questions about gender, level of study, nationality, school of study, GPA, parents profession, and some other relevant questions as Future plans, college preference and university preference.

***Section.2*** "Engineering design/soft skills", deals with skills acquired during LIEP participation aimed to measure the students' comparative perceptual evaluation of the contribution of schools and the experience of LIEP in developing 21$^{st}$ century skills.

***Section.3*** "STEM knowledge" aimed to measure the student's perceptions towards STEM disciplines after LIEP participation and finally *Sec.4* exploring reasons behind choosing Engineering as an academic major and the most significant incentives behind taking part in such experience. both of Sec 2. & Sec3, students have to rate their perception on a likert scale of 5 whereby: 1= "Strongly Disagree", 2= "Disagree", 3= "Neutral", 4= "Agree", and 5= "Strongly Agree".

**Survey Administration and Sample Number**

Two surveys were administered to 14 high schools in Qatar; Part of these were with participating students "Experimental group" and the rest were with non-participating students "Control Group". Hard copies of the surveys were delivered to both participating students and non-participating ones in which the main difference between both surveys is that experimental group samples were asked to compare between their attitudes towards engineering profession before and after participation, a brief explanation of the survey was provided. Students were asked to fill the survey on their pace. After filtering, a total of 108 valid responses were included for data processing and analysis. Survey delivery was random; the surveys was conducted in Arabic language to avoid adding noise to the collected data due to language misunderstanding.

**Data Analysis**

**A. Demographics**

The participants were students from 14 different schools N= 108, both the entire control group (sample no. N=51) and Experimental group participants (sample no. N=57) are males (100%); from the 2$^{nd}$ secondary grade (sample no. N=23 (45.1%) of the control group) and (sample no. N=35 (63.8%) from the experimental group). The majority of participants pointed their preference to join the university after graduation (sample no. N=33 (65%) of the control group and N=40 (72.7%) of the experimental group) in which some of them showed their preference in majoring in Engineering as an academic major ( (N=19(37.3%)) of the control group, and N=24(43.6%) of the experimental group).

**B. LIEP impact on developing 21st century skills**

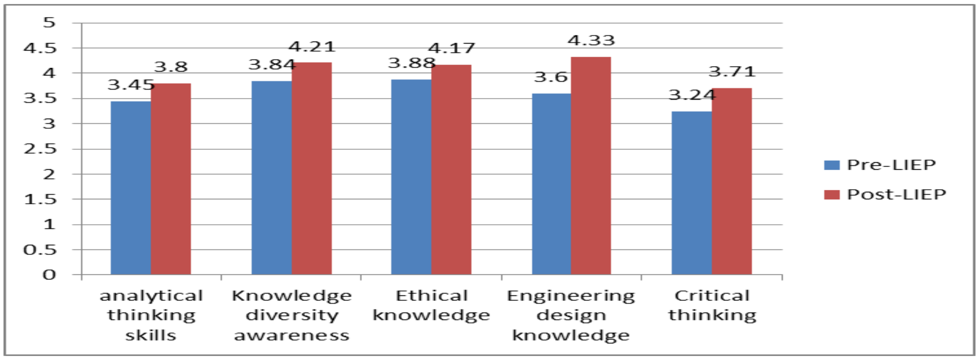
Students opinions towards 18 listed 21$^{st}$ century skills were analyzed comparing both the experimental group participants pre and post opinions and also comparing experimental students post opinion with those who haven`t joined the event "Control Group".

Descriptive statistics showed that LIEP have better equipped students with all of the 18 listed skills. Results have shown that students have had a higher self-report with higher means close to 5 "Strongly Agree" of all of the18 skills after evaluating the Post-LIEP status compared with that of the Pre-one whose means where close to 3 "Neutral". Hypothesis testing using Wilcoxon non-parametric signed rank Test showed positive ranks for 17 skills , However only 5 skills revealed statistically significant difference (p-value $\leq$0.05) (Analytical thinking, engineering design knowledge, critical thinking, Knowledge diversity awareness and ethical knowledge) with Z-value below ±1.96 Rejecting the null hypothesis of no difference in students skills enhancement before and after LIEP participation and accepting the alternative hypothesis of presence of such improvements proving.

Hence, "*LIEP does has a positive impact "as self-reported by students" towards development of 21$^{st}$ skills and competencies*"; see Table 1 and Figure 3.

**Table 1: Details of means, Sample number and P-value of Wilcoxon signed rank test for Experimental student's skills development comparing LIEP post-participation with pre-LIEP one.**

| **Variable** | **Mean** | | **Sample Number (N)** | **P-value (Wilcoxon signed rank )** | **Statistical significance** |
|---|---|---|---|---|---|
| Analytical thinking skills | Pre-LIEP | 3.45 | 49 | 0.042 | Yes |
| | Post-LIEP | 3.80 | 45 | | |
| Knowledge diversity awareness | Pre-LIEP | 3.84 | 49 | 0.033 | Yes |
| | Post-LIEP | 4.21 | 44 | | |
| Ethical knowledge | Pre-LIEP | 3.88 | 48 | 0.047 | Yes |
| | Post-LIEP | 4.17 | 43 | | |
| Engineering design knowledge | Pre-LIEP | 3.60 | 49 | 0.014 | Yes |
| | Post-LIEP | 4.33 | 42 | | |
| Critical thinking | Pre-LIEP | 3.24 | 48 | 0.015 | Yes |
| | Post-LIEP | 3.71 | 42 | | |



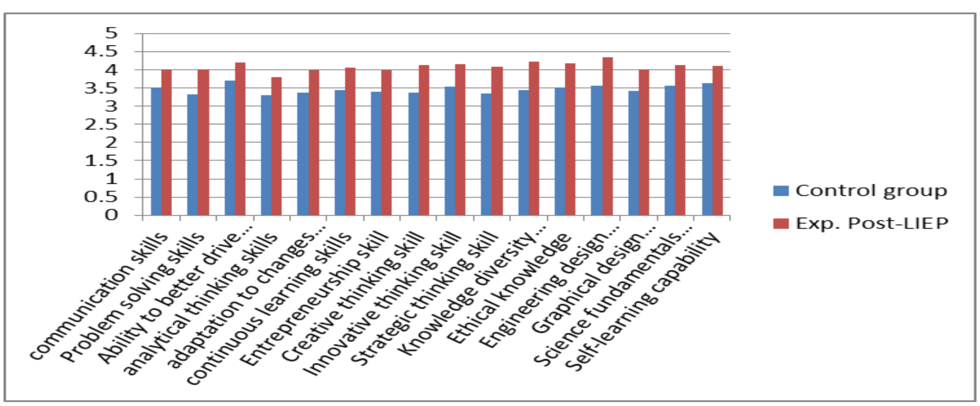

**Figure(3): LIEP 21st century statistically significant skills engineering skills comparing pre and post participation**

Comparing post-LIEP Experimental student's opinion against control group students using Hypothesis testing; **Mann Whitney U Test,** revealed a statistically significant difference between the two groups in 15 skills (p-value ≤0.05) and although only 3 skills (leadership skills, critical thinking, scientific research significance) showed no statistical significance between both groups but LIEP participating students showed higher agreement level with means close to 4 "Agree" as revealed by descriptive statistics; See Table 2 and Figure 4.

**Table 2: Details of means, Sample number and P-value of Mann Whitney U Test for Experimental student's skills development post-participation with Control group ones.**

| **Variable** | **Mean** | | **Sample Number (N)** | **P-value (Mann Whitney U Test )** | **Statistical significance** |
|---|---|---|---|---|---|
| communication skills | Control group | 3.51 | 49 | 0.045 | Yes |
| | Exp. Post-LIEP | 4.02 | 44 | | |
| Problem solving skills | Control group | 3.31 | 48 | 0.005 | Yes |
| | Exp. Post-LIEP | 4.02 | 45 | | |
| Ability to better drive change skill | Control group | 3.69 | 49 | 0.016 | Yes |
| | Exp. Post-LIEP | 4.20 | 44 | | |
| analytical thinking skills | Control group | 3.29 | 49 | 0.013 | Yes |
| | Exp. Post-LIEP | 3.80 | 44 | | |
| adaptation to changes skills | Control group | 3.38 | 48 | 0.010 | Yes |
| | Exp. Post-LIEP | 3.98 | 44 | | |
| continuous learning skills | Control group | 3.43 | 49 | 0.009 | Yes |
| | Exp. Post-LIEP | 4.05 | 42 | | |

| | | | | | |
|---|---|---|---|---|---|
| Entrepreneurship skill | Control group | 3.40 | 48 | 0.009 | Yes |
| | Exp. Post-LIEP | 3.98 | 45 | | |
| Creative thinking skill | Control group | 3.37 | 49 | 0.004 | Yes |
| | Exp. Post-LIEP | 4.13 | 45 | | |
| Innovative thinking skill | Control group | 3.53 | 49 | 0.012 | Yes |
| | Exp. Post-LIEP | 4.16 | 44 | | |
| Strategic thinking skill | Control group | 3.35 | 49 | 0.002 | Yes |
| | Exp. Post-LIEP | 4.09 | 44 | | |
| Knowledge diversity awareness | Control group | 3.43 | 49 | 0.001 | Yes |
| | Exp. Post-LIEP | 4.23 | 44 | | |
| Ethical knowledge | Control group | 3.50 | 48 | 0.010 | Yes |
| | Exp. Post-LIEP | 4.17 | 42 | | |
| Engineering design knowledge | Control group | 3.57 | 49 | 0.001 | Yes |
| | Exp. Post-LIEP | 4.34 | 41 | | |
| Graphical design knowledge | Control group | 3.41 | 49 | 0.009 | Yes |
| | Exp. Post-LIEP | 4.02 | 41 | | |
| Science fundamentals knowledge | Control group | 3.57 | 49 | 0.013 | Yes |
| | Exp. Post-LIEP | 4.12 | 42 | | |
| Self-learning capability | Control group | 3.63 | 49 | 0.024 | Yes |
| | Exp. Post-LIEP | 4.11 | 44 | | |




**Figure(4): LIEP 21st century engineering skills comparing post participating students and non-participating ones**

## C. LIEP impact on STEM knowledge/Attitudes

One of the main reasons behind of deploying the LIEP project is to impact student`s understanding or attitudes of STEM disciplines and encourage them to join such fields.

Descriptive analysis for students perception towards math as a subject (its importance and impact in their employability), showed that they have positive attitude with means close to 5 “Strongly Agree” showing their professionalism at math and means close to 4 “Agree” for their attitudes towards science as a subject.

And when they were asked about their perception towards engineering fundamentals, related jobs, the importance of engineering for the society and their desire to become engineers they showed highly positive attitude with means close to 5 “Strongly Agree”.

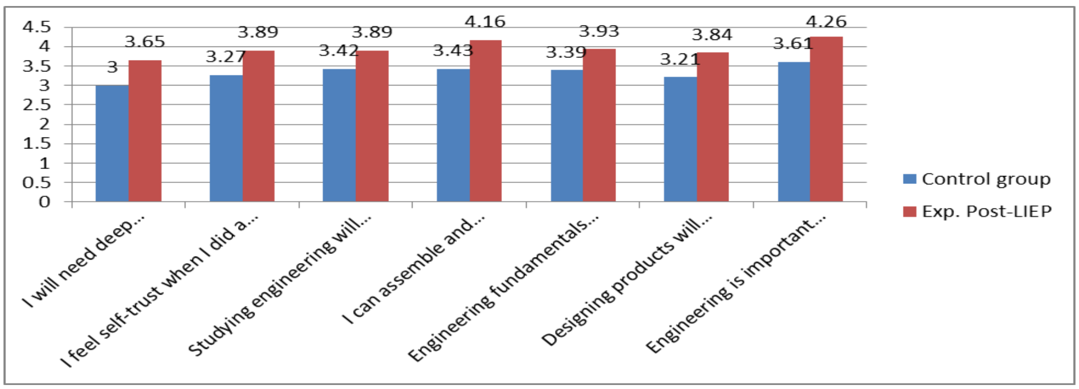
Hypothetical analysis was carried out using **Mann Whitney U Test** in which mean ranks were calculated for both the experimental group students (Post-LIEP participation) and the control group students. Results have shown that experimental students have had a higher self-report of all STEM disciplines variables (mathematics, Science and Engineering), However only 7 variables were statistically significant with a P-Value $\leq 0.05$ evidencing the higher perceptions of Post-LIEP students; See Table 3 and Figure 5. Hence the following conclusion was revealed:

“*LIEP Does have positive impact on students' attitudes towards STEM fields and disciplines enhancing students' knowledge, competencies and skills as well as changing their negative perception about these fundamentals*”.

**Table 3: Details of means, Sample number and P-value of Mann Whitney U test for Experimental student's perception Post-LIEP participation against control group students.**

| **Variable** | **Mean** | | **Sample Number (N)** | **P-value (Mann Whitney U Test)** | **Statistical significance** |
|---|---|---|---|---|---|
| I will need deep acknowledgment in math in my career path | Control group | 3.00 | 49 | 0.034 | Yes |
| | Exp. Post-LIEP | 3.65 | 46 | | |
| I feel self-trust when I did a science related work | Control group | 3.27 | 48 | 0.014 | Yes |
| | Exp. Post-LIEP | 3.89 | 44 | | |
| Studying engineering will help me improve people daily needs | Control group | 3.42 | 48 | 0.050 | Yes |
| | Exp. Post-LIEP | 3.89 | 44 | | |
| I can assemble and dissemble parts efficiently | Control group | 3.43 | 49 | 0.004 | Yes |
| | Exp. Post-LIEP | 4.16 | 44 | | |
| Engineering fundamentals | Control group | 3.39 | 49 | 0.045 | Yes |

| | | | | | |
|---|---|---|---|---|---|
| knowledge will help me finding job | Exp. Post-LIEP | 3.93 | 44 | | |
| Designing products will have great impact in my future job | Control group | 3.21 | 48 | 0.014 | Yes |
| | Exp. Post-LIEP | 3.84 | 43 | | |
| Engineering is important for the society | Control group | 3.61 | 49 | 0.017 | Yes |
| | Exp. Post-LIEP | 4.26 | 43 | | |




**Figure(5): statistically significant STEM fundamental variables comparing post participating students and non-participating ones**

## D. Incentives Behind choosing Engineering as an academic major

A number of potential incentives for choosing Engineering as an academic major were hypothesized based on internal discussion among the research team such as “Like discovering vague things”, Engineering salaries are high”, “will help me to be effective contributor in the world future”, “will guarantee job after graduation” etc.

Students were asked to select which incentive(s) will push them to choose engineering as a major and to indicate top 3 ranked incentives, out of the 6 given ones.

The highest incentive among LIEP participating students was “will help me to be an effective contributor in the future” (N=10, 45.5%), while the least reported incentive was “Engineering salaries are high” (N=0, 0%). However control group opinion was significantly different as the incentive “will guarantee job after graduation” was reported as the highest (N=9, 30%) and “I will contribute in world development” as the lowest among them (N=2, 6.7%).

“The mode of each of these ranks was determined for LIEP participating students, and this has shown that the incentive of “will be an effective contributor in building the future” have had rank of (1) and “Engineering will guarantee job after graduation” as rank of (2) and “I like discovering vague things” as rank of (3). This would lead to quantitatively conclude that the most important incentives for choosing engineering after experience of an activity like LIEP were:

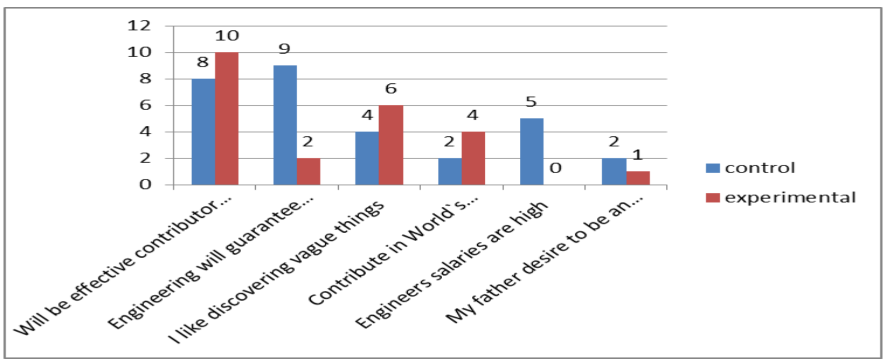
1- Students aim to be effective contributor in building future showing LIEP impacting their awareness to the engineering and other STEM field important roles.

2- Such competitions give experience for students helping them to build their self-confidence of finding job after graduation

3- Students were interested in such experiences believing on their capabilities to discover vague things

**Table 4: shows a summary of incentives frequencies reported for each of Rank 1, 2, or 3**

| **Incentive** | **Will be effective contributor in building the future in** | **Engineering will guarantee work after graduation** | **I like discovering vague things** | **Contribute in World`s development** | **Engineers salaries are high** | **My father desire to be an engineer** |
|---|---|---|---|---|---|---|
| control | 8 | 9 | 4 | 2 | 5 | 2 |
| experimental | 10 | 2 | 6 | 4 | 0 | 1 |




**Figure(6): major incentives behind joining engineering as an academic major**

In analyzing the items in Table 4, it could be indicated that the experimental group have more emotional/affective connection/perception towards engineering (e.g. high frequencies in the items: “will be effective contributor in building the future”, or “Contribute in world’s development”) than those in the control group. Those in the control group have more materialistic or security connections/attitudes towards choosing engineering (e.g. high frequencies in the items: “Engineering will guarantee work after graduation”, or “Engineering salaries are high”).

## Discussion, recommendations, and conclusions

This study aimed to explore the impact of engineering design on enhancing K-12 students skills, and students self-satisfaction and attitudes towards STEM fundamentals and disciplines.

As the main driver to utilize engineering design models in K-12 engineering education was to equip students with hands-on and design skills, the findings reported from this study showed significant contributions of LIEP on enhancing students skills and competencies as well as enhancing students awareness towards STEM disciplines and professions contribution in building their country future.

Students have significant positive perception proved by descriptive means and hypothesis testing confidence intervals that such experiences contributes effectively to a wide range of technical competencies and soft skills enhancing their comprehension towards STEM disciplines importance on their future careers. The main value students have seen in such experiences was the reinforcement of engineering concepts as well as exploration of mathematics and sciences in more personalized context as well as the development of their soft skills. Such intervention impacted students self-confidence and preparedness to work pushing them forward to act as effective contributors in building Qatar future and achieving Qatar`s national vision of 2030.

Quantitative research conducted with focus on Qatari students particularly males have shown significant positive impact of LIEP on student’s perceptions, confidence, and attitudes towards STEM disciplines, engineering profession, engineering nature, and personal skills with significant gaps revealed in all of the skills explored between pre, post and non-participating students.

Feasibility of increasing engineering outreach activities and scale among K-12 schools is being studied and the college in Qatar university is currently checking options of developing an elective engineering course that is suitable for K-12 level to widen benefits of embedding engineering based activities in high schools. This study needs an further comparison of engineering 21st skills and competencies development for K-12 Qatari students with those of K-12 students in regional or international countries.

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