Introducing University Laboratory Tools Into K-12 Classrooms: Benefits and Challenges

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***Abstract*— High-level university technology can enhance student learning with hands-on experience, but the complexity of these tools can also create challenges for users. This study investigates the benefits and challenges of laboratory tools in high school settings through the lens of a project-based learning model. Participants in the investigation are stakeholders in a university outreach program known as AQ-IQ, which is built around teaching rural high school students how to use low-cost air quality monitors. In the fourth year of the AQ-IQ program, two of the major goals were to improve the reliability of the monitor data collection and to make the data analysis more accessible for K-12 students and teachers. This study found that benefits of high school students using university technology included increased excitement and student engagement due to the hands-on and real-world nature of the technology. Two of the challenges in using the technology included power supply issues and users not following operation instructions regarding how to warm up the monitors at the beginning of their experiments. Recent improvements to the monitor and data analysis tools succeeded in reducing data losses and making it easier for students and teachers to view and interpret their results. We have found that making continual efforts to improve technology based on user feedback and ensuring that resources are adequate to address user challenges increases the success of integration of university tools into high school classrooms.**

Keywords—K-12 outreach; project-based learning; laboratory technology

I. INTRODUCTION

The high school outreach program investigated in this paper is built around a low-cost air quality measurement tool that was developed by the Hannigan research group at the University of Colorado in Boulder (CU). The air quality monitor, also known as the "Pod", houses commercially available low-cost sensors and can record data for multiple air pollutants including carbon dioxide, ozone, volatile organic compounds (both light and heavy) in addition to measuring temperature and humidity. The Pod, shown in Fig. 1, is an open-source design and costs approximately $1000 to assemble per monitor [1]. The Pods have a wide variety of applications including university research, citizen science, and high school outreach.

The Hannigan lab originally developed the first generation of the Pod, the MPod, when a fellow researcher offered to co-write a proposal for a National Science Foundation (NSF) funded project. The application of the Pod as a citizen science tool was motivated by the broader impacts requirement of the grant. The lab got involved in a citizen science project in Delta County that eventually connected them to high school outreach opportunities in Delta County high schools. The community in Delta wanted baseline air quality monitoring data. When the lab set up the monitors at a local high school they connected with a teacher who wanted to bring the Pods into the classroom. A graduate student in the Hannigan group worked with the teacher to develop curriculum to incorporate the pods into high school classrooms [2].

This paper demonstrates how citizen science tools can be used as a bridge to engaging with high school classrooms. The development of low-cost air quality monitors has involved the public in the air pollution measurement process and created more dialogue in communities regarding their air quality [3,4]. Air quality measurement tools that are more affordable and usable for citizen scientists also have applications in the high school setting for student projects. Researchers that are developing low-cost tools should consider involving high school groups in addition to citizen scientists. This could broaden their impact, help recruit more students to science and engineering, and inspire the next generation of researchers and citizen scientists. Additionally, Air quality sensors can be implemented in interdisciplinary subject matter [5] and engaging K-12 students in projects using authentic research tools is proven to increase interest and motivation to learn [5,6,7,8].

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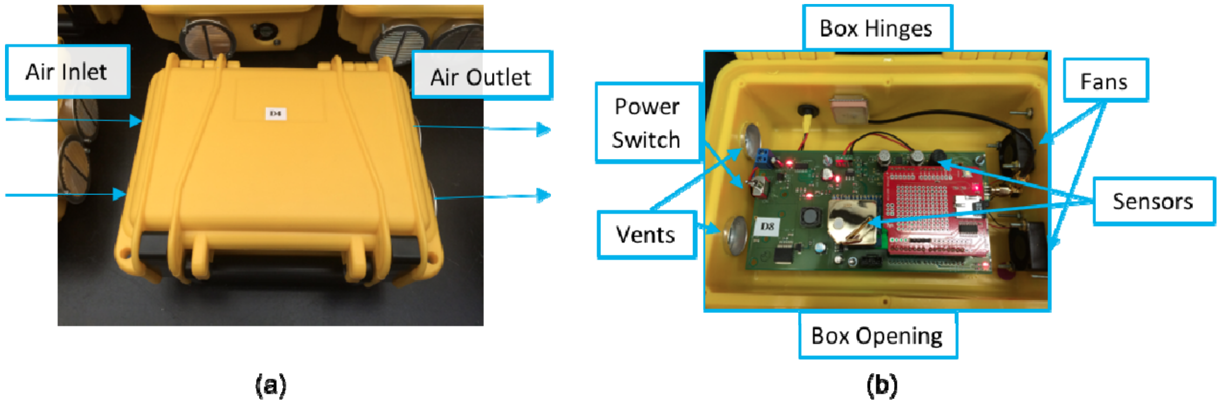

Figure 1. Images of the Pod air quality monitor showing exterior (a) and interior (b).

Some K-12 programs have evolved using more commercialized air quality monitoring tools. Kids Making Sense is a program developed by Sonoma Technology Inc. and HabitatMap that uses commercial Airbeam sensors to empower youth in grades 6-12 to collect their own air quality data and participate in hands-on science tasks. The program includes curriculum developed by scientists in addition to the sensors that are available to purchase in packages, typically with support from an organization with grant money [9]. Conversely, the Hannigan group Pods have not been commercialized and students who are using them can look inside and see all the various components and how they're connected. The Pods are unique in that they are not a black box technology and students may benefit from getting to see the inner workings of the device [2,1]. The purpose of the pods is to empower students and citizens to conduct their own air quality research and providing them for rent at minimal costs lowers barriers for under-resourced school districts and non-profits. The Pods are available to be checked out through the University of Colorado Boulder Museum of Natural History [10] and the curriculum is accessible for free via TeachEngineering [11].

A. AQ-IQ

The Air Quality InQuiry (AQ-IQ) Program uses project-based learning curriculum in conjunction with low-cost air quality monitoring sensors to promote science, technology, engineering, and mathematics (STEM) education in high school settings. The program was started in 2013 by the Hannigan Air Quality Research Lab in the CU Department of Mechanical Engineering [12]. It began as a citizen science project called the North Fork Valley Air Monitoring Project but evolved to include rural high school students from an additional county who were interested in investigating their own research questions [2].

The program evolved in part due to funding by the NSF AirWaterGas Sustainability Research Network, an interdisciplinary research project involving teams that have focused on understanding the benefits, risks, and challenges associated with unconventional oil and gas development (i.e., hydraulic fracturing). AQ-IQ is a part of the AirWaterGas education and outreach team that is focused on broader impacts of the NSF award and building relationships with communities who are potentially impacted by oil and gas. One goal of the research network is to initiate conversations with citizens and help provide a communication and dissemination channel for relevant research to those communities [2].

B. Research Question

The research question for this study is as follows: *What are the benefits and challenges of integrating university laboratory technology into high school classrooms?* Based on this question, expected benefits include increased excitement for students and enhanced learning through project-based curriculum [12]. This investigation will be viewed through the lens of a theoretical framework of project-based learning (PBL)[16,17]. PBL is student-centered instruction where students can investigate their own real-world research questions using hands-on resources [13]. The benefits of PBL include improved problem solving, critical thinking, and increased engagement of students in their learning [14,15]. PBL was used as a framework in this study as all student work with the Pods is focused on the K-12 student projects. We expected increased engagement from using the Pods, but based on findings in Knight et al. we found that high school student interest actually decreased slightly over the course of the AQ-IQ program [12]. We wondered if that decrease was due in part to the issues with usability of the Pods or the lengthy time period of the project; both of these issues were addressed in improvements made from 2015-2016 to 2016-2017 to the technology as well as the program.

Some of the potential challenges of integrating university research tools into classrooms stem from the complexity of the technology; university lab instrument technology is always in development. These challenges were supported by the findings of Knight et al. who concluded that mentors, teachers, and students all experienced issues with using the Pods including lost data and difficulties interpreting data [12]. In addition to exploring the benefits and challenges associated with the Pods, this paper aims to look in depth into efforts that have been made to address some of the challenges of using the Pods and assess how effective those changes have been. Both the Pods' hardware and the data analysis tools have evolved from 2015-

16 to 2016-17, and evaluating how the high school students and teachers have benefitted from those improvements will help guide future improvements as well as advise other programs on best practices. In particular, this paper will investigate the hardware upgrade from the "UPod" model to the "YPod" and the creation of a new data visualization website to help improve data processing for students. Expected benefits of these improvements are improved usability, reliability, and ease of processing data.

II. Methods

A. Participants

Participants from the AQ-IQ program that contributed to this paper include the high school students and teachers, CU student mentors, and the Hannigan lab group. High school student participants were from rural schools in Colorado and attended three schools from Weld County (Highland High School, Union Colony Preparatory School, and Greeley Central High School) and four schools from Delta County (Delta High School, Paonia High School, Hotchkiss High School, and Cedaredge High School) and were primarily freshmen (60%), the first generation in their immediate family who would attend college (45%), and Caucasian (59%) with a significant Hispanic minority (28%). The teachers that were interviewed were from Union Colony Preparatory School, Paonia High School, and Hotchkiss High School and had all participated in the program for at least two years. All but one was teaching AP Environmental Science classes and the remaining teacher was the librarian who was leading a special topics course. Two of the interviewed teachers were women and the third was a man.

There were eight CU student mentors surveyed for the paper, 5 women and 3 men. Six of the mentors were seniors in mechanical engineering and the remaining two were graduate students, one in mechanical engineering and one in chemistry. Two Hannigan lab group members were interviewed to obtain more details on the AQ-IQ program and the Pods: the lab's Professional Research Assistant who supports Pod development, and the head of the research group who is also a professor in mechanical engineering.

B. Assessments and Procedures

Pre and post-program surveys were distributed to the high school students to gain information about their demographics and also to track their interest and learning throughout the program. Pre-program surveys were given during the CU mentors' first classroom visit in January 2017 and post-program surveys were collected in April and May 2017 via online assessments that were emailed to student participants. In addition to the surveys, high school students were interviewed by judges at the final AQ-IQ science symposiums in Greeley and in Delta in order to gain insight into some of the benefits and challenges they experienced using the Pods.

Three phone interviews were conducted with high school teachers in March and April 2017 to obtain specific details about their experiences using the Pods and how they thought the air quality monitors impacted student learning. They were also asked to compare their experiences to the previous year to evaluate the effectiveness of the Pod technology improvements.

CU student mentors completed pre-program surveys in September 2016 and post-program surveys were completed in May 2017 to determine learning gains and mentors' experiences in the program. A focus group with the mentors was led on April 12 to obtain feedback on their experience in AQ-IQ and also to compile suggestions for how to improve the program next year.

Interviews with the Hannigan lap group members were conducted in person in early March, 2017. The lab's Professional Research Assistant was interviewed about the history of the Pod and some of the improvements from the UPod to the YPod. Additionally, an interview was conducted with the head of the research group to understand how the high school outreach program developed.

III. Results and discussion

The surveys and interviews were conducted with the goal of answering the research question: *What are the benefits and challenges of integrating university laboratory technology into high school classrooms?* Some of the benefits we expected were enhanced learning and increased excitement for students due to the PBL curriculum and use of the Pods. Student interest was rated on a scale of 1-5 with 5 being the highest level of interest. Last year (2015-16), the student interest in learning about air quality decreased from the pre to post-survey from 3.54 to 3.16, an 11% drop [12]. We think this decline in interest could have been due in part to frustrations with the UPods; many students failed to collect data or had difficulties interpreting their data. During the 2016-17 year, student interest in learning about air quality on the pre-survey averaged 3.19. In comparison, post-survey interest averaged 3.05, a 4% drop in interest, which was not statistically significant. In fact, there was no significant change in interest in any interest category from 2016-17 pre-survey to post-survey.

2016-2017 Survey Questions	**Student Interest**		
	Pre-Mean	***Post-Mean***	***Two Tailed T-Test***
I want to know more about college majors in science and engineering	3.26	3.24	**Not significant**
I am interested in learning more about air quality	3.19	3.05	**Not significant**
I want to know more about what an engineer does	3.41	3.24	**Not significant**
I want to learn more about how engineering and science can improve the local community	3.45	3.24	**Not significant**

Students' ratings of their knowledge about how to use the Pod to measure air quality increased in both of the past two years. Results from 2015-2016 rated from 1 to 5 with 5 being the highest indicated a 3.79 on the pre-assessment and a 4.31

on the post-survey, a 12% gain. Results from 2016-2017, indicated a lower starting point this year with a 2.46 on the pre-assessment, likely from the inclusion of an additional rural underserved school in Weld County. Post-survey results revealed an average of 3.98, a 51% gain.

Qualitatively, both student and teacher interviews described the benefit of being able to use the Pods to conduct projects they couldn't otherwise complete. The students appreciated the chance to work with "cool" high-tech equipment and liked the freedom of choosing their own research questions to guide their experiments. Being able to use the Pods to measure real gases in the atmosphere made learning atmospheric science much more real for the students and gave them a more hands-on, real-word education. One high school teacher commented, "The Pods have been great this year, easy to use. The website worked much better than the Matlab program last year, (students) could open things and get to them." CU mentors also echoed those benefits of using the pods with high school students; they expressed how helpful it was to physically show the students the gaseous species they were teaching them about. These benefits were similar to previous results from projects that utilized PBL with K-12 students. It is commonly found that using PBL and providing students the chance to investigate their own real-world research questions can have a positive impact on student attitudes and learning [13,14,15]. One teacher echoed this with a comment (referring to her students' interest in measuring air fresheners from their own vehicles), "Particular students pay more attention to things in front of them than things they are reading; in this sense, the Pods are really engaging, got the students motivated to get things out of their trucks and measure them."

The second aspect of the research question was identifying the challenges of using the Pods in high school settings. Expected challenges were related to the complexity of the technology and its continuous need for improvements. We expected fewer issues this year with students failing to collect data due to either user error or Pod malfunction and also less issues with interpreting their data and analyzing their results. We also expected fewer issues with Pod malfunction this year due to the new Pod design. The two main challenges we found from student and teacher interviews were loss of power supply to the Pods and issues with allowing the proper amount of time for the sensors to warm up. Regarding power supplies, there were some instances of the Pods being unplugged by other school personnel during experiments, car batteries used to power the Pods not working properly, and power cords breaking down. This did impact some of the data collection but would be relatively easy to improve for next year by making the power cords more robust and adding more signage to the Pods to discourage experiment disruptions. The warm up time issue was related to the low-cost sensors: in order to function properly they need to run for 30 minutes prior to conducting any experiments. As one student group reported, "We had to repeat our experiment because the first time we did it we didn't let it run long enough so our data wasn't good." Some students didn't understand the warm up process or didn't leave the Pods running long enough; a future improvement to address this challenge could be to add more detailed instructions inside of the Pods to specify how much time to allocate for the warm up process.

One noted difference from last year was that no sensors failed and had to be replaced. The teachers did not experience many hardware or usability challenges, instead many of their concerns were time related either due to fitting AQ-IQ in the curriculum with their other material or not having enough Pods for students to use, especially when the students have a tendency to procrastinate. Providing more Pods to schools could help resolve this challenge and having the students schedule out their time to use the Pods at the beginning of the project might help minimize procrastination. Based on the results from the previous year [12] we expected to encounter more challenges with Pod malfunctions and data collection issues than we found in our student and teacher interviews (i.e. results were better than expected.) Mentors in the focus group also reported that the Pods were "simple and straightforward to use for data collection" which was different from the previous year when mentors said they needed more training on how to use the Pods [12]. This shows that overall the functionality and usability of the Pods likely did improve from the previous year.

The third topic we investigated was whether the efforts that were made to address some of those challenges from the 2015-16 year to the 2016-17 year were successful. The main goals with the changes from the UPod to the YPod model were to improve data quality and get more consistent data. Through interviews with students and teachers we tried to understand if the implemented improvements achieved those goals. From our interview with the Hannigan group Professional Research Assistant we found out that some of the notable hardware changes from the UPod to the YPod were: simplifying the board and streamlining construction, replacing the timekeeper with a slightly more expensive model, and replacing some resistors to improve power management. Another upgrade that made the YPod more user friendly than the UPod was the addition of light indicators to make it clear when the YPod was not operating correctly. The head of the Hannigan group stressed that improvements were implemented with all users in mind; researchers, citizen scientists, and high school users alike benefit from more consistent and accurate data. Teachers who participated in the program for two years unanimously reported fewer data losses and hardware issues when using the YPod versus the UPod. Students and mentors who used the YPod model identified the monitor as being easy to use to collect data, which was a contrast to the feedback we received the previous year regarding the UPod [12].

Another important addition from the 2015-16 year to the 2016-17 year in the AQ-IQ program was the creation of a data visualization website. The Hannigan group recognized that processing and displaying data was a weakness with the UPod system; the data files were difficult for high school students to understand and using Excel can be challenging for users who are unfamiliar with the software. The group hired a computer science graduate student, external to the lab, to design a website where Pod users can upload their data, plot results in different formats, and access data collected by other Pod users. The hope was that the website would make it easier for students to display and interpret their data. Qualitative feedback indicated that this proved to be very successful and popular with the teachers because it allowed them to focus more on learning air quality and not spend all their time teaching Excel. One teacher mentioned the challenge of using Excel with the students, "As a teacher, using Excel and manipulating large datasets in excel is probably a skill I need to work on with kids earlier in the year so we can keep building on those skills." While the students and teachers both appreciated the ease of the using the website, the head of the Hannigan group did voice some concerns about not teaching as many Excel skills as in previous years due to the availability of the website; Excel is an important engineering tool and there are benefits to exposing high school students to it early on. However, having the website is helpful in that it allows students to interpret the large amounts of data they collect using the Pods in an efficient fashion and engage more with the air quality education portion of the AQ-IQ program. We expected to see some improvements from our upgrade from UPod to YPod model and the creation of the data visualization website, but the interest results from our surveys that have been gathered so far have surpassed our expectations of improvements. Improving the usability of the Pods proved to be successful and helped make the program experience more positive for high school students and teachers alike.

The findings from this study show that PBL is useful for enhancing high school student learning and interest, and giving them the independence to create their own projects does produce benefits. In order for PBL programs to be successful, it is important for resources to be adequate to support the projects. When the UPods were utilized for student projects in 2015-16, there was actually an 11% decrease in student interest towards learning about air quality. When the technology was improved with the more robust YPod and data visualization website, student interest saw no significant change and there were fewer frustrations with data collection and analysis. Our results show that successful implementation of university technology into high school classrooms requires constant efforts to improve resources and make the tools user-friendly.

IV. Implications

One of the important takeaways from this study is that it can be possible to improve your research technology through assessment and make it usable in high school settings. The key for university researchers is to continually collaborate with all stakeholders and incorporate their suggestions into technology improvements. We demonstrated that frustrations associated with transferring tools from the laboratory to the classroom, an issue for many K-12 outreach programs, can be improved.

An additional implication of this research is that using laboratory tools has the ability to make learning more real-world for students. We saw increased engagement and excitement with students that they attributed to the opportunity to use high tech tools. Teachers and students both described how getting to actually measure invisible gases made their air quality education seem more real and exciting compared to traditional classroom learning methods.

V. Limitations and Future Research

. It is important to note that this program takes place in a rural setting where students have had limited exposure to Excel and other educational tools. Some of the challenges we observed may not be present in other, less underserved settings.

Although no new versions of the Pod are currently being planned, future research and usage of Pods in high schools will work to improve the current model regarding some of the power issues and providing more detailed instructions regarding the sensor warm up time. Additionally, we plan on making continuing improvements to the data visualization website to improve the user experience and provide more options for data analysis.

VI. Summary

This paper investigates a K-12 outreach program that is centered around a low-cost air quality measurement tool that was developed by the Hannigan research group at the University of Colorado in Boulder. The AQ-IQ Program promotes STEM education in high school settings by incorporating low-cost air quality monitoring sensors into project-based learning curriculum. The purpose of this study was to investigate the following research question: *What are the benefits and challenges of integrating university laboratory technology into high school classrooms?* The investigation was viewed through the lens of a PBL theoretical framework.

Benefits of using the laboratory technology included providing an opportunity to conduct unique research experiments, freedom for students to choose their own research questions, and making learning more hands-on, real-world and interesting for students. The two main challenges presented in the results were issues with power supply to the monitors and not providing ample warm up time for the air pollution sensors. The final topic investigated was an analysis of the effectiveness of improvements that were made to the monitor technology from 2015-16 to 2016-17. Improvements to the hardware and software proved to be successful in making the technology more usable for high school students and teachers. A key implication of this study is that university laboratory technology can be successfully integrated into high school outreach programs as long as continual improvements are made based on input from all key stakeholders.

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References

[1] Mobile Sensing Technology. [Online]. Available: www.mobilesensingtechnology.com [Accessed 1 February 2017].

[2] A. Collier, D. Knight, K. Hafich, M. Hannigan, M. Polmear, and B. Graves, “On the Development and Implementation of a Project-Based Learning Curriculum for Air Quality in K-12 Schools,” *in Frontiers in Education Conference (FIE)*, El Paso, 2015.

[3] P. Kumar, L, Morawska, C, Martani, G, Biskos, M, Neophytou, S. Di Sabatino, M. Bell, L. Norford, and R. Britter, “The Rise of Low-Cost Sensing for Managing Air Pollution in Cities,” *Environment International*, vol. 75, pp. 199–205, 2015.

[4] E. G. Snyder, T. H. Watkins, P. A. Solomon, E. D. Thoma, R. W. Williams, G. S. W. Hagler, D. Shelow, D. A. Hindin, V. J. Kilaru, and P. W. Preuss, “The Changing Paradigm of Air Pollution Monitoring,” *Environmental Science & Technology*, vol. 47, no. 20, pp. 11369–11377, 2013.

[5] L. Hotaling, S. Lowes, R. Stolkin, P. Lin, J. Bonner, W. Kirkey, and T. Ojo, “Sense IT: Teaching STEM principles to middle and high school students through the design, construction and deployment of water quality sensors,” *Advances in Engineering Education*, vol. 3, no. 2, pp. 1–34, 2012.

[6] S. Laursen, C. Liston, H. Thiry, and J. Graf, “What Good Is a Scientist in the Classroom? Participant Outcomes and Program Design Features for a Short- Duration Science Outreach Intervention in K–12 Classrooms,” *CBE Life Sciences Education*, vol. 6, no. 1, pp. 49-64, 2007.

[7] K. F. Hew and T. Brush, “Integrating technology into K-12 teaching and learning: current knowledge gaps and recommendations for future research,” *Education Technology Research and Development*, vol. 55, no. 3, pp. 223-252, 2007.

[8] D. M. Gilbuena, F. A. Kirsch, and M. D. Koretsky, “Use of an authentic, industrially situated virtual laboratory project to address engineering design and scientific inquiry in high schools,” *Advances in Engineering Education*, vol. 3, no. 2, pp. 1-32, 2012.

[9] Kids Making Sense. [Online]. Available: www.kidsmakingsense.org [Accessed 15 February 2017].

[10] Air Quality InQuiry (AQ-IQ) Kits. [Online]. Available: http://www.colorado.edu/cumuseum/air-quality-inquiry-aq-iq-kits [Accessed 20 February 2017].

[11] A. Collier, K. Hafich, D. Knight, M. Hannigan, J. Gordon-Casey, B. Graves, E. Ambos, O. Cecil V. Danner, E. Hotaling, E. Lee, D. Meyers, H. A. Salamah, N. VanderKolk, and E. Coffey. “AQ-IQ (Air Quality InQuiry), Unit.” *Teach Engineering Digital Library*, 2016. Available: http://teachengineering.org/curricularunits/view/cub_airquality_unit.

[12] D. Knight, A. Collier, M. Hannigan, and K. Hafich, “Broadening and Sustaining an Air Quality K-12 Curriculum through a Digital Library and Undergraduate Service Learning Course,”, *in Frontiers in Education Conference (FIE)*, Erie, 2016.

[13] M. Holm, “Project-based instruction: A review of the literature on effectiveness in prekindergarten through 12th grade classrooms,” *Rivier Academic Journal*, vol. 7, no. 2, 2011.

[14] H. Berends, K. Boersma, and M. Weggeman, “The structuration of organizational learning,” *Human Relations*, vol. 56, no. 9, pp. 1035-1056, 2003.

[15] H. Scarbrough, M. Bresnen, L. Edelman, S. Laurent, S. Newell, and J. A. Swan, “The Processes of Project-based Learning: An Exploratory Study,” *Management Learning*, vol. 35, no. 4, pp. 491-506, 2004.

[16] Luxhol, J.T., and Hansen, P.H.K., “Engineering Curriculum Reform at Aalborg,” Journal of Engineering Education, Vol. 85, No. 3, 1996, pp. 83–84.

[17] Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. Journal of EngineeringEducation, 94(1),103-120 .