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Challenges and Lessons from Development of a Training Program to Inculcate a Culture of Innovation in High Schools

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ABSTRACT

There is an urgent need to create a scalable process for innovation and an atmosphere for scientific enquiry in high schools. The importance of personalized education, social and emotional learnings are becoming a critical requirement in high schools to create a future society that is caring to others and our planet. During the pandemic there was an intense disruption to the learning processes and schools have had to reinvent the education systems to keep students engaged and motivated. Students and teachers have adapted, created, and evolved new ways of learning to build a robust model that is sustainable and withstand any future disruptions. During the pandemic, we have developed a process for inculcating innovative thinking in high schools through a program we call "CV Raman Young Researchers Program (CVR-YRP)". The goal of this initiative was to create a holistic program in high schools designed to help students ideate, plan, and execute innovative projects. These ideas from this innovative project have been submitted for patent protection. The aim of this program was to provide students with exposure to the process of innovation and to create a culture of collaborative teamwork to develop a well-defined project. In this report, we provide an overview of the processes that were developed for training, mentorship framework and implementation of the innovative processes towards idea generation and execution. We have listed the potential challenges in this program, solutions to which were

addressed in the second version, CVR-YPR2. The program has the potential to create a sustainable innovative culture coupled with scientific enquiry in high schools and prepare the students for higher education and bring impactful solutions to address societal needs.

Research and innovation are pillars of the economy. While industries and universities actively contribute to research and innovation, high school education remains traditional and focuses on memory-based learning. Inducting high school students into critical and analytical thinking, systematic investigation process, and safeguarding innovations is critically important for making them ready for successful careers in research and innovation. We have formulated a holistic program called C V Raman Young Research Program (CVR-YRP) to help high school students ideate, plan, and execute innovative projects. We delivered this program in online mode from 2020 to 2021 to students and teachers from two schools located in north and central India. During the program, the students were inducted into literature search and patent filing process. They also learned how to deal with rejection. The students submitted innovative proposals, and a selection committee comprising industry experts and professors evaluated the proposals based on novelty, usability, and scalability. Some of the shortlisted innovations were eventually protected with intellectual property rights. While conducting this program, we encountered administrative, logistic, and emotional challenges. We have formulated a path forward to mitigate these challenges and make learning more productive. We believe that CVR-YRP was successful in inducting high school students into research and innovation.

Keywords: Innovation; Research; Ideation; Execution; Curiosity; Inquisitive

INTRODUCTION

Innovation involves introduction of new ideas, products, services or improvements to existing processes to bring impactful changes in our lives. It involves translating basic research into inventions that have real-world application, thereby enhancing knowledge and improving economies [1]. The curricula in high schools that teach and encourage young students about innovation are highly variable [2]. Skill development is a central component to enable creativity, which can include critical thinking, problem-solving abilities, decision making, teamwork, communication skills, and methods to create social and moral awareness. The focus of learning is shifting away from brick-and-mortar classrooms to open classrooms that involves working on minor or major projects in groups, self-learning supported by digital tools of learning, and on-demand anytime and anywhere education. Today, the culture of learning is interdisciplinary, necessitating team learning in a multidisciplinary environment that promotes the capabilities of integration of knowledge and expertise. These changes require moving away from conventional systems of education and assimilate educational innovations for learning in the new digital age that are resilient, readily adaptable, and scalable. To introduce such changes, traditional courses in schools require major modifications, as the expanse of information and knowledge in each subject is vast. The New Education Policy (NEP 2020) issued by the government of India is built around four pillars: access, equity, quality, and accountability. The

policy is envisaged to develop courses that can address the inter-disciplinary nature of science, thereby encouraging innovation at the school level [3]. Prenger have reviewed literature of programs conducted over a decade for enabling sustainable education [4]. The authors indicate four factors, namely, school organization, innovation, individual participation, and context characteristics, and emphasize transparency and focus for success in these programs [5]. Learning from these processes in the literature, we have developed a process to enable and encourage innovative thinking in high schools. We have curated a program and named it CV Raman Young Researchers Programs (CVR-YRP) after a revered Indian physicist, Dr. C. V. Raman. In this manuscript, we describe the rationale, the methodology, results, and impact of the CVR-YRP program on the innovation culture of two schools in India.

MATERIALS AND METHODS

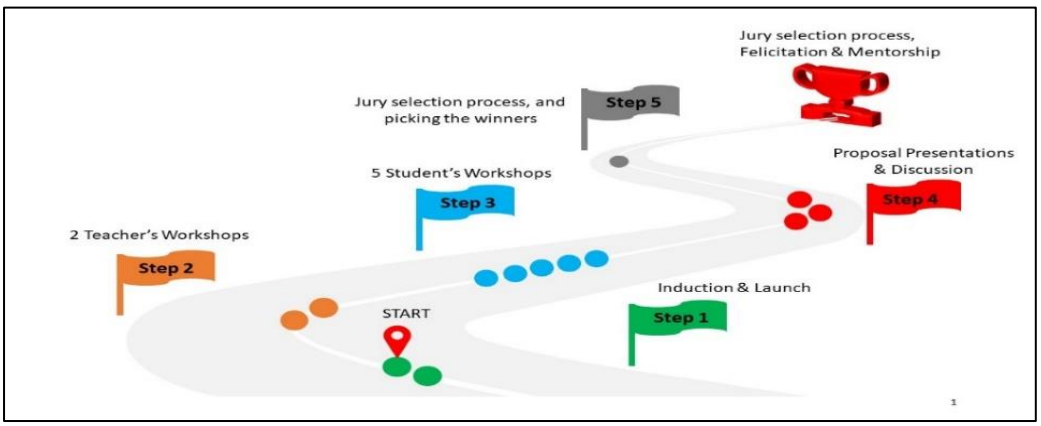
Mission and goal of the CVR-YRP program

The mission of the CVR-YRP program was to enable students and teachers to become change makers beyond the confines of the academic curriculum. The program was aimed for high school students to develop an understanding of innovation through a curated scientific process and create a method of scientific enquiry. The program focused on developing and nurturing skills such as:

1. Asking questions.
2. Learning the process of decision making.
3. Working in a team.
4. Thinking critically.
5. Analyzing and solving problems.
6. Ideating solutions.
7. Writing and communicating through different media.

The goal of this program was to bring excitement and excellence into learning in high schools and provide an exposure to the world of innovation. Through our various initiatives, the program developed a systematic approach to nurture a new generation of innovators who dream big, think deeply, and experiment boldly. The program was designed into several phases, which is illustrated in Figure 1.

Figure 1. Illustration of CVR-YRP program into several phases.



Phase I: Teacher training program

To standardize the process of innovative thinking, a teacher training program was developed. Approximately ten high school teachers, administrators, college students (interns), professors (from college), and mentors (two from high schools and one from a college) participated in this program. The training program was led and conducted by authors who have extensive experience in novel drug development in biotechnology industry (NC) and international grant-funding agency (VS). The tone of the training was conversational; ideas from all the participants were collected, collated, and developed into a course outline (Table 1). Three training lectures were conducted to enable teachers to:

1. Share their experiences in innovation
2. Understand innovation through case studies
3. Learn the processes of innovation and develop an ability to recognize one. These training courses were very useful in obtaining diverse experiences and developing a process to implement an innovative culture among student participants.

Table 1. Teacher training workshops.

Workshop	Pre-read materials	Outcome
Definition of innovation	Innovation [6]	Sharing experiences in innovation
	Innovation and entrepreneurship [7]	
Understanding innovation using case studies	3 examples	Review of literature
Understanding the process of innovation (top-down and bottom up), keen observation skills	Innovation and collaboration [8]	How to identify innovation
Criteria of evaluation of the proposals	Criteria definition	The process of selection of the winners

Phase 2. Student training program

High school students from two schools were included in this training program. Approximately 50 students from each school participated in an online training program of five seminar-cum-workshops. These workshops were conducted by professors and graduate students of the university. The student program consisted of the following steps:

Innovation for delight: Active participation in workshops on creativity, asking questions, and identifying problems. The students were exposed to the process of protection of intellectual property through patent applications. An important workshop was also conducted on the awareness of handling feedback and understanding the process of constant improvement to enable the students to cope with rejection of their proposals. After the workshops, the students were provided an overview and the critical steps in the YRP program Table 2, which included ideation, execution, presentation, and criteria for success. The students formed teams and committed to developing proposals.

Table 2. The student training workshop.

Workshop	Pre-read materials	Outcome
How to think creatively	Examples of creativity and critical thinking	Understand the processes in creativity and critical thinking through teamwork
How to make teams	Highly efficient teams	
How to ask questions	Blog on questions [9]	Activity of asking questions, make informed decisions and understand the processes in solving problems through teamwork.
How to make decisions How to solve problems	Blog on decision making [10]	
How to ideate	Videos of ideation	Understand how to make a proposal.
How to write a proposal	17 sustainability development goals [11]	
Criteria of evaluation of the proposals	Criteria definition	Understand the evaluation processes

Understanding intellectual property and the patent process: "A patent is an exclusive right granted for an invention, which is a product or a process that provides, in general, a new way of doing something, or offers a new technical solution to a problem. To get a patent, technical information about the invention must be disclosed to the public in a patent application". Various aspects of patents, such as the processes involved in applying for a patent, criteria for examination by the patent office, and evaluation of the uniqueness of the application, were discussed. There are two types of patents: utility and design. A utility patent may be granted to anyone who invents or discovers any new and useful process, machine, article of manufacture, or compositions of matters, or any new useful improvement thereof. A design patent provides protection for the ornamental design of something that has a practical utility. In other words, an item that is substantially similar to something that has the protection of a design patent may not be made, copied, used, or imported into the country. There are several ways to patent novel ideas. For example, in the process of developing drugs, novel ideas can be patented through:

1. A product patent
2. Method of use patent
3. A formulation patent
4. A manufacturing process patent.

These aspects of patents were provided to the students and teachers as a preliminary understanding of the patent process. The workshop was conducted by professors and students of the Law School in the university. Table 3 shows various topics involved in the patent awareness training.

Table 3. The patent process.

Workshop	Pre-read materials	Outcome
Patent processes	Billion dollar patent [12]	Understanding the patent process
Patent application of review processes	Patent process for kids [13]	Simplifying the patent processes
Case studies	3 Case studies	Understanding through examples
The practical process	The application, forms	Understanding the detailed processes

Preparing and presenting the proposal: The art of preparing a proposal was presented to the students using the scientific methodology framework and with the help of case studies. A template for the proposal was provided, which included developing a hypothesis, conducting an extensive literature survey, defining the methods, collecting the data, analyzing the data, and then developing the design. The proposal also contains description of the team, the advisors, and people (Table 4).

Table 4. Shows the checklist of activities to make a proposal.

Workshop	Pre-read materials	Outcome
A story	Blog on investor requirements [14]	An understanding of making an impactful presentation.
Team		
Technical expertise		
Regulatory acumen		
Financial acumen		
Efficiency		
Competition		
Risks and mitigation		

Recap of the processes and handling feedback (failure): Figure 1 shows all the steps involved in the process from training, design, proposal, selection, and patenting. Of the 30 proposals submitted (Supplementary data), 3 were selected to be funded and developed to the next phase. A detailed process of evaluation, jury selection, and ensuring fairness is described below. The seven others, which ranked in the top 10, were also given motivational awards. To learn the process of patent application, a specific training program was designed to "accept failures" and learn from them. Table 5 shows the topics that were covered in this module. This part of the process was critical in the CVR-YRP program, as learnings from failures and subsequent persistence are essential components of innovation. Recommended reading materials are listed in the references [15-17].

Table 5. List of trainings from failures.

Workshop	Pre-read materials	Outcome
Keeping the failure in perspective	Good genes gone bad [17]	Provide students with a process to accept failures and prepare them for moving forward.
Receive feedback constructively		
Learn from your support system		
Staying positive		
Acknowledge and list the strengths		
Plan to become better		
View as an opportunity		

Phase 3. Design of the proposal, presentation, criteria for selection, the review process and winners

Following the completion of the training programs for teachers and students, a template for making proposals of innovative projects was provided. The process of innovative proposal was adapted from a study of innovative processes [9,10]. The steps in the proposal included

1. Describing the proposal

2. Explaining the novelty
3. Stating the rationale with the hypothesis
4. Explaining how the work would be implemented
5. Describing how the data would be collected
6. Describe the sustainability of the innovative work
7. Describe the impact the innovation would have in the field.

This proposal template, which was provided to the participants, included the central idea, method of data collection, design of the product or process, analysis of results, interpretation, and impact of the innovation. A slide-deck was requested for submission followed by a presentation to the selection committee.

Criteria for forming the selection committee

The criteria for forming the selection committee included several years of professional experience, expertise in diverse fields of science and humanities, and no conflict of interest. The selection committee was co-chaired by senior authors NC and VS. The committee consisted of the following members: 2 university professors, 2 high school teachers, 2 administrators, and 2 college student-mentors. The proposals were scored based on the following criteria: simplicity, usability, sustainability, clarity, originality, scalability, and practicality. All proposals were ranked based on their scores and overall impression. Relevant justifications were provided for the scoring. The final decision was made in a meeting. The scoring and ranking of the proposals are provided in the (Supplementary data).

RESULTS

Participation in the CVR-YRP program

To initiate the program, we had reached out to 10 schools and described the overview of the CVR-YRP program. Two schools were chosen to initiate the pilot program, based on the enthusiasm of the teachers. The participation in the program was encouraged by the teachers and administrators of respective high schools, but it wasn't made mandatory. One hundred and fifty students (9^{th}-12^{th} grade) from two schools participated in this training program. The sessions were delivered online through Zoom. Active participants were invited and encouraged to participate in an open and engaging discussion. Following the training, the students were given 6 weeks to develop their proposals and submit it for evaluation. In total 30 proposals of innovative projects were received (Supplementary data).

The evaluation process

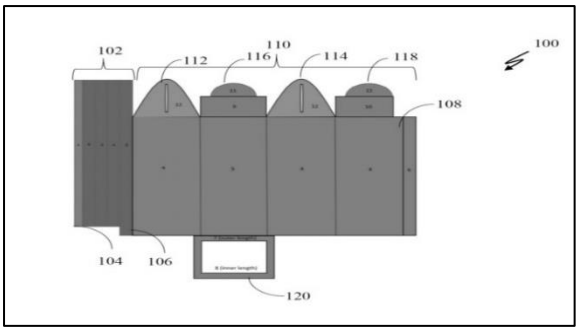
Ten proposals were short-listed for presentation by the teams to a selection committee. The review committee evaluated the proposals based on the criteria defined in methods and selected three winning proposals. The details of the winning proposals are listed below.

Sustainable paper coffee cup: Winner

The project objective was to encourage sustainability among coffee vendors and customers while still allowing them to use a straw. Porcelain/ceramic cups, bamboo/paper/glass/steel straws, and no lid cups are some existing alternatives in the market; however, they have their own drawbacks. The proposed solution uses redesigned cut-outs of paper coffee cups that have inbuilt extra sheet. When the cut-out is assembled, it forms the lid and the straw of the cup. This eliminates the

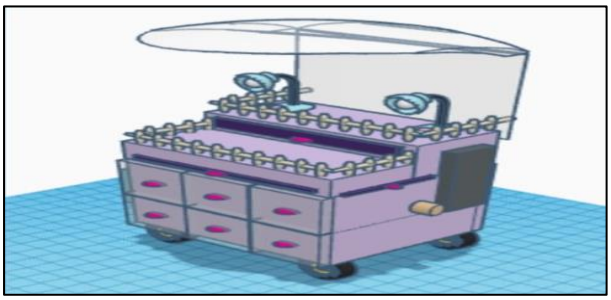
problem of segregating different kinds of materials, as in existing designs, straw, lid, and cup body are made up of different kinds of materials. Eventually, this sleek design reduces plastic waste, prevents over accumulation, and reduces cost. The coffee vendors will only have to bring the compressed cup into shape, fill in coffee, close the lid and serve! The figure of the prototype is shown in Figure 2.

Figure 2. Design showing complete coffee cup.



Street vendors in Indian cities face a lot of problems with their “carts or rehris”. They occupy quite a lot of space on roads and sidewalks, which causes traffic jams, disorganization, and public menace. In this proposal, a solution to this problem is proposed: The Compact Rehri 2.0 (TCR 2.0). Figure 3 shows a three-dimensional diagram of TCR 2.0 made using Auto-CAD. The cart is compact, well organized, and occupies less space. It will be helpful for street vendors to do their business in an organized manner. This cart will be beneficial for all: the hawkers, the people, as well as the government.

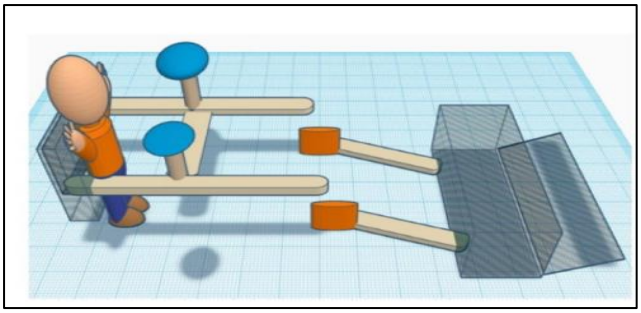
Figure 3. The Compact Rehri 2.0 (TCR 2.0) shows a three-dimensional diagram made using Auto-CAD.



The collect-o-green: Third place

Fallen dry leaves largely contribute to the waste collected from streets. Manually collecting these leaves is time and labour intensive. To mitigate this issue, the team has proposed Collect-o-Green. This is a powerful machine that can suck dry leaves using vacuum. It has a simple but unique design to accompany the user's needs. Collect-o-Green was designed to facilitate the process of dry leaf collection by reducing manpower and time consumption. This heavy-duty machine is readily wearable and fully electric. Being electric, it has no emission, which is good for the environment. The pictures of the physical prototype made are shown in Figure 4.

Figure 4. Electric collect-o-green machine.



Selection committee and review process

The selection committee comprised of five members from diverse backgrounds. The committee included senior professionals from pharmaceutical industry, funding agency, and general management. It also involved university professors and high school teachers. In addition, there were two observers: one from a college and one student intern. Each of the 10 shortlisted proposals were reviewed independently against a standard set of criteria and given a score. In addition to the score, points were given to the written proposal, oral presentation, and ability to answer questions. These winners were announced in an online mega-event. The university has sponsored the progress of these three innovative projects to writing patents and helping with potential funding opportunities.

Limitations and potential sources of biases were evaluated as specific agenda points in the jury review meetings. All the jury members were interviewed to confirm that there was no conflict of interest, neither with the program organizers nor with participants. The committee was constituted based on pre-defined criteria described in the methods section. Based on these observations and procedures, we limited the potential for bias in the overall review and assessment steps of the program.

Communicating the message and words of encouragement for the non-winners

One of the most difficult tasks of the entire process of the program was to motivate the non-winners to continue their efforts to ask questions and create innovative ideas. For this purpose, lecture 5 in the course was designed to understand failures and the process of recovering from them. Lessons learned from a failure teach us about a process when evaluated systematically.

DISCUSSION

We have developed an incentive-based program for innovation from ideation to action at a high school level. The pilot program executed in two high schools in North and Central India provided significant feedback to improve the overall processes and provide a framework to scale it across several other schools. Our initial analysis shows overall positive feedback on the processes; we plan to evaluate the overall impact of the program through systematic analysis of subsequent implementation of this program, over the next year, in multiple school districts.

A culture of innovation requires the involvement of young minds starting from school all the way to different walks of life in the society. The field of entrepreneurship needs a thorough understanding of basic and applied research, funding ecosystem, and internal and external motivating forces (academic, regulatory, economic and cultural). Such an environment is required for problem solving and inducing positive change among innovators. Some examples of these programs used over several decades include innovation competitions, hack-a-thons, and science fairs [4,18].

The CVR-YRP program was conceived to develop a scalable program that could be replicated across many high schools. The program was designed to enhance thinking skills. The basic concepts of the design were to build a standardized training program on innovation for teachers and students at high schools, making it participative, engaging, and sustaining. These training programs are implemented by mentors from pharmaceutical and biotechnology industry, patent professionals, university professors, and university graduate students as interns. Our objective behind organizing this program was to develop a holistic, scalable, and transferable training program that can be implemented in any high school around the world, especially in the regions with limited resources.

Challenges

As in any new program, there were several challenges that could be classified in two categories: operational and logistic.

Operational challenges: There were several operational challenges that were collected from a feedback process conducted after the program. These issues ranged from language barriers, access to physical and digital technologies, communication, peer pressure, to work load. All these were listed to be addressed in the future CVR-YRP programs. Once registered into the program, it was difficult to ensure students had a complete understanding of the various components of the training program. After completion of the training, significant project management efforts were required to keep track of the project progress.

Emotional challenges: One of the most difficult tasks in the program was to counsel the students who did not win awards, justify why their idea was rejected, and motivate them to continue the innovation journey.

Logistic challenges: Since the pilot program was executed during the time of the pandemic (July 2020–July 2021), the entire communication process was through digital technologies of online meetings, WhatsApp groups, and shared drives. The entire program lacked the most important aspect of education: face-to-face human interactions. It remains to be seen if this digital process can be utilized to scale the program in the post-pandemic world.

Overcoming the challenges

A systematic process was developed to collect feedback (through interviews and an exploratory survey), analyze the information, and make a "learning log" to address the challenges in the pilot program. These learnings are being implemented in modifying some aspects of the second phase of the CVR-YRP program. The following specific points were made that will be considered for process improvements that have been implemented in the second year of the program (CVR-YPR2):

1. Teams: Teachers and administrators will enable development of diverse teams of 3–5 students, as team environment and collaboration are critical for the process of innovation.
2. Motivation: Students will be constantly encouraged to participate and actively contribute to their projects by means of advertisement through various communication and social media channels.
3. Recorded Trainings: A recorded version of the training program will be developed and posted on a YouTube channel, so that students can refer to the training throughout the implementation process.
4. Templates: Documentation processes are critical in an innovative process. Templates of documents will be developed to help the teams capture ideas, develop designs, and implement the projects.

Lessons learned

The YRP process was designed and executed over a period of one year. There were many lessons that the team learned on supporting high schools to develop a program on creating an innovation culture in high schools. To understand the impact of the program, a brief exploratory anonymized survey was conducted to evaluate lessons learned by asking questions related to knowledge around the innovative processes before and after the YRP program. We received three major comments for improving the program.

1. In-person training might be more effective than online training.
2. Having local mentors for the students will be helpful.

3. More training should be provided on how to accept failure and continue to be motivated.

To assess the impact of the program, we have summarized the innate innovative aptitude before and learned experience after implementation of the program.

Innovation aptitude before and after the program

1. Before being a part of this program, the process of ideation to us was just thinking of a problem and finding a solution to it. However, as we attended the program, we understood that there is a systematic approach towards developing and presenting the idea to the society.
2. We always thought of taking our best projects beyond competitions, but we did not find any suitable platform. After participating in this program, we realized that patenting was really the best way to shape and secure the ideas for the future.
3. Earlier we thought that conducting a survey is just about questioning people and getting their responses. Through the CVR-YRP program, we learned the purpose of writing questions for a questionnaire and understood how it is helpful in data analysis and has an impact on a project.
4. We believed that such programs should be implemented for students of 6th grade, but we realized that 6th graders are too young to understand the nuances of this training program. For such programs, we can have students from 8th to 12th grade.

Outcome and impact

After completion of the program the student were able to

1. Identify an idea and learn to present it systematically to a knowledgeable audience.
2. Accept the errors and work upon to improve them by embracing a culture of seeking feedback.
3. Demonstrate a capacity to communicate research results clearly, comprehensively, and persuasively.
4. Conduct a substantial research-based analysis and synthesize research findings.
5. Demonstrate capacity to improve their achievement, engagement, and retention.
6. Demonstrate capacity to lead and manage change through collaboration with others.
7. Report research findings in written and verbal forms and present them.

Finally, a major impact of the YRP program was on the positive attitude of the participants as it was conducted during the COVID-19 pandemic.

Accomplishments from the participation in the CVR-YRP program

Of the 40 students who participated in the program, three students applied for patents on their designs, four received inter-school awards on their innovations (in the range of INR 10,000–25,000), and three students got admission to international universities. In this respect, the following three projects won awards in a state competition:

Airosuit: Low-cost wearable safety equipment designed for high-speed motorcycle riders.

GarboBall: A new-age sturdy and long-lasting dustbin that consists of a basketball hoop to make waste disposal fun, an all-natural fragrance enhancer, and an electronic compressor to compress the garbage into sheets utilizing every single milliliter of the bin capacity.

Gutrack: An automated robotic vehicle with a robotic shaft that goes inside the manhole, spins the blade, dilutes the sludge, and extracts it out with a powerful vacuum. The sludge is then stored in a sealed container and then further sent

to factories to be processed to form compost. These accomplishments were tangible results of the CVR-YRP program in high schools.

CONCLUSION

In summary, the abstract highlights the lessons learned from the program, such as the importance of team collaboration, embracing failure, and understanding the patent process. The program resulted in students applying for patents, receiving awards, and gaining admission to international universities. The abstract concludes by summarizing the program's impact, scalability, and potential to transform the innovation culture in high schools. This report lists the steps involved in the CVR-YRP program, including ideation, development, and implementation. We have listed the challenges, analyzed feedback on listed the outcomes of this program. The process we have detailed is scalable and has the potential to transform innovation culture of high school children.

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