Creating a Sustainable, Student-Led Science Research Program

by Sudipti Kumar

This report is based on a series of interviews with Luke De, Upper School science teacher and developer of Nueva's Research Program at The Nueva School, and with Colleen Kirkhart, biology teacher at The Pingry School, in addition to conversations with other teachers who run high school science research programs in both public and independent schools. An extensive literature review and analysis of the current state of K-12 science education was also conducted to provide context and an understanding of the broader landscape.

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Abstract

In most science departments around the country, students are usually learning the application of content in one of two ways. The first is to perform tried and true lab experiments with a predetermined outcome that they "discover", and the second is via school-based partnerships with research universities or local laboratories where students are sent out of the school (or researchers are brought in) to gain a real-world understanding of how the field of science works. This brief discusses a third way of science instruction, offered at both The Nueva School in California and The Pingry School in New Jersey. This third way empowers students to develop their own ground-breaking research ideas and lab experiments within the lab space of the school building itself and under the direction of a teacher with a strong research background. The core components that make this model successful at these schools are discussed in depth in this brief. This third way can be a model for other schools who want greater reach (more students engaged in science), more authentic excitement and engagement in science (a culture of science infused within the walls of their building), and real-world career ready students (students who combine their science skills with project management skills that prepare them for college and beyond).

Spend a few days with science teacher and developer of Nueva's research program Luke De at The Nueva School in California and you will observe high school students conducting science research, the likes of which are comparable to a research program at a top-tier university.

> **"People often think teaching is what happens between the waiter and the customer. What we are actually doing in our science research class is running the kitchen."**
>
> -Luke De, Science Teacher, The Nueva School

You will see a culture and ethos where students "geek out about science", and this excitement and interest permeates the rest of the school. The class you walk into will be one that caters to students who have different interests in the vast world of science research: whether that be performing experiments in a lab, reviewing scientific journal articles, or sharing knowledge on real-world issues affecting their peers and community.

You will leave awed and impressed by students who have complete agency and latitude to lead their class and their peers.

An Overview of Nueva's Research Program

The research program at Nueva is an elective offered to interested students alongside other required course offerings, such as chemistry in 9th grade and biology in 10th grade. The official title of the course is Applied Molecular Biology, and there are three distinct strands that comprise the program and run underneath this umbrella.

The Three Components

Experiment and Research Team/XRT:

How to be a lab researcher-- managing the experiment, caring for the units of study, collecting, tracking and analyzing data. In the scientific community, the work that this group is doing is what is typically called "bench research".

Scientific Literature/Journal Club:

How to read heavily data-driven scientific journals, distill the major points, understand implications, and present findings to a broad audience.

Communications/Project 80:

How to find an issue that is relevant to the larger community, present it in a way that shares knowledge and drives change, and disseminate findings in an easy-to-understand format (e.g. podcasts, video, posters hung up throughout the school).[1]

[1] Project 80 is the term used at Nueva to name this strand, because the goal of the program is to "inform 80% of a target community about the science behind controversial topics, and to to increase the number of people who use scientific data to inform their everyday decisions".

Low Floors (LF), High Ceilings (HC), Wide Walls (WW)

Seymour Papert, a former professor at MIT, popularized the theory that for a technology to be effective in supporting learning, it needs to have low floors (an easy way for a novice to get started) and high ceilings (opportunities to get increasingly sophisticated over time).2 His mentee, Mitchel Resnick, added that it also needs to have wide walls, meaning that there are multiple pathways to get from the floor to the ceiling.[3] Luke's molecular biology class at Nueva epitomizes LF, HC, WW in the science setting. Students can enter in at Level I with little to no background in the work. In some cases, their interest is piqued simply through listening to a presentation by the Journal Club or seeing a podcast by Project 80 (these ideas are discussed later on in this paper). They can then progress to the highest level which allows them to learn and use more complex skills. Additionally, there are multiple pathways - the three distinct strands provide an opportunity for students to engage where their greatest interest lies.

> **"Most high schools provide a narrow range of laboratory activities, engaging students primarily in using tools to make observations and gather data, often in order to verify established scientific knowledge. Students rarely have opportunities to formulate research questions or to build and revise explanatory models."**
>
> -Luke De, Science Teacher, The Nueva School

Levels Within the Three Components

Within each of these strands, students are working at distinct levels, based on their expertise and experience in the class. The three distinct strands in Luke's classes are also meant to interact with one another in a way that creates a functioning and cohesive science research department within the classroom.

	XRT	JOURNAL CLUB	PROJECT 80
Level 3 students, the "leads", are the experts and they oversee the overall group	Level 3	Level 3	Level 3
Level 2 students, the "student techs", take on more responsibility and guide Level 1s	Level 2	Level 2	Level 2
Level 1 students, the newest and have the least responsibilities, serve as "student assistants"	Level 1	Level 1	Level 1

The Case for a Third Way

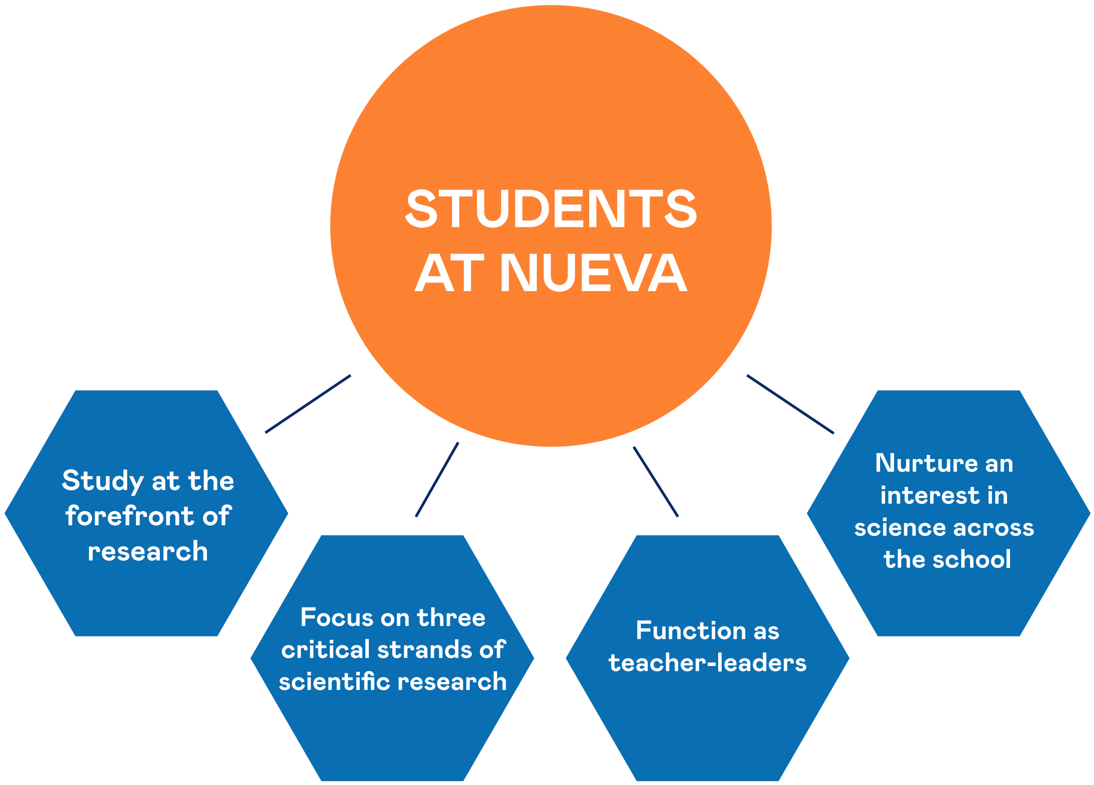
Laboratory investigations have existed in science classrooms since the mid 1800's. However, even today researchers and educators disagree on the role they should play to be effective.

The National Research Council's 2006 report investigating high school science labs noted that student laboratory experiences should reflect the actual work of scientists, which includes learning through reading, formulating questions, designing and carrying out investigations, creating and revising explanatory models, and presenting their ideas for others to discuss or evaluate. However, they also found that this thorough process rarely happens.[5]

> **"We [studied] the results of caffeine exposure on TG-12 worms. Caffeine is the most widely used psychoactive drug and forms a mild dependency in individuals who overuse the drug for an extended period. Other drugs, including methamphetamines, have been shown to induce apoptosis (the death of cells) in the brain's reward pathways, suggesting stimulants [such as caffeine] may lead to apoptosis to lasting neuronal damage."**
>
> -Ethan, Level I Student, XRT (taken from journal abstract written by XRT team, published in the FASEB journal)

Recent solutions include schools sending students to nearby laboratories or research universities. This provides students with an opportunity to experience what their school might lack because they can work alongside real researchers, see and use professional high-grade lab equipment, and explore real applications of their textbook learning. However, it does mean that the research arm of the student experience lives outside the school building within another entity or organization. Nueva's science research class differs from these types of partnerships in four distinct ways representing a potential third path forward for schools to employ and offering the opportunity for schools to build the science research function in-house.

[4] National Research Council. 2006. America's Lab Report: Investigations in High School Science. Washington, DC: The National Academies Press. https://doi.org/10.17226/11311.
[5] ibid.



Nueva in-house science research function:

1. Students are at the forefront of research and are not working towards a predetermined outcome.

Students are the real researchers, either developing their own projects and topics of study based on interest and trends in the field or studying the unknown with guidance from their teacher.

2. Students are focused on three critical strands of science research while learning how to effectively project manage.

In addition to learning how to be bench researchers, the program also places equal importance on two other critical components of science: understanding and writing about scientific literature as well as effectively understanding and communicating findings about real-world issues. Embedded across all three strands are core project management skills that will prepare them for a career in science or other fields.

3. Students are the teachers, with real empowerment and autonomy to lead.

Classes mimic how a science research program works at the graduate level, where students are leading and training each other and the teacher serves as a principal investigator. In his role, the teacher is able to step back and monitor the entire system.

4. Students are nurturing an interest in science across the school.

Even students who are not in the class formally are an integral part of the overall model. Thus, the science program is reaching far more students than those enrolled in the course.

In the next few sections, we will take an in-depth look at each of these four elements.

1. Students are at the forefront of the research and are not working towards a predetermined outcome

In many traditional science classrooms, the majority of the curriculum is centered around students conducting lab experiments where the results are already known. These labs are tried and true, and fairly low effort for teachers to replicate annually with a new set of students. While students are making "discoveries" based on their experiments, it is generally a structured discovery process with the teacher expecting the outcomes for all students, and experiments are the same or fairly close to one another.[6] There is much to learn in a traditional science classroom, including how to develop a hypothesis, work on a team, conduct an experiment, and analyze the results. This methodical approach allows students to gain an appreciation for and understanding of the scientific method.

In the majority of these cases, however, students are not the ones developing the research idea or laying out how to conduct the experiment. This distinction is important. Studies have shown that in environments where students can develop their own research ideas and experiments, their understanding of the content is far greater.[7] They also may be more apt to pursue a career in science given the role they had at the forefront of science exploration rather than as a bystander.[8]

Even in many inquiry-based classrooms, where students are encouraged to ask questions and explore the course material rather than the teacher telling them what they need to know, the actual learning could still be "contained" for students based on the teacher's lesson plan for the day and the specific learning they desire to impart on the student. In that sense, it may be inquiry, but not discovery.

Recent studies discuss the importance of improvisational science discourse, a step beyond an inquiry model.

Recent studies discuss the importance of improvisational science discourse, a step beyond an inquiry model, where the teacher's future exploration and next steps are informed by students' interests and ideas.[9] This shift on the part of the science teacher from knowledge keeper to knowledgeable peer can be vitally important for the students' growth, learning, and long-term interest in the field of science.

Teacher as Knowledge Keeper + Transmission of Facts, "Tried and True Labs", Contained Inquiry = Low Student Engagment/Lack of Conceptual Understanding

Teacher as knowledgeable peer + *Learning alongside the student through experiments without guardrails and open inquiry* = *Highly engaged students/ Students with high conceptual understanding*

Luke notes that he and the students in his class "are not just interested in taking something that somebody else made and putting it out in front of somebody". One of the most recent projects for the XRT strand is based on a student-led decision to study caffeine's impact on worms. It was borne completely out of student interest on how drug addiction impacts brain cells.

There is no playbook for Luke on how the experiment will go and what students will discover. Similarly, students in the Journal Club and in Project 80 are choosing the topics that are of the greatest interest to them and their peers. There is no year-long scope and sequence of articles that students have to cover or communications topics that are important to discuss. Because it is based on interest, students develop a deep understanding in the topic of their choice which far surpasses a peripheral or surface grasp of basic knowledge.

Current Best Practice: Scientific inquiry

Next Best Practice: Improvisational science discourse
In many science classrooms today, students are learning through an inquiry-based model where they are invited to investigate a problem, construct knowledge and make meaning, and discuss their findings with their peers. However, oftentimes, scientific inquiry can still present a barrier for the student and teacher between the known and the unknown. Students are often conducting "contained inquiry", because the answers they are reaching through discussion are already known to the teacher. Improvisational science discourse allows for teachers to build on students' thinking and use that as the impetus for exploration. It pushes the limits of inquiry into the realm of the unknown both for the teacher and the student.

[6] Pike, A.G., Dunne, M. Student reflections on choosing to study science post-16. Cult Stud of Sci Educ 6, 48a5–500 (2011). https://doi.org/10.1007/s11422-010-9273-7; Jenkins, L.L. Using citizen science beyond teaching science content: a strategy for making science relevant to students' lives. Cult Stud of Sci Educ 6, 501–508 (2011). https://doi.org/10.1007/s11422-010-9304-4; Enright K.A., Strohl C.A. (2017) When Procedure Limits Practice: Lab Versus Lecture in High School Science Classrooms. In: Langman J., Hansen-Thomas H. (eds) Discourse Analytic Perspectives on STEM Education. Educational Linguistics, vol 32. Springer, Cham
[7] Hatch, Joshua. (2018). Better teachers are needed to improve science education. Nature. 562. S2-S4. 10.1038/d41586-018-06830-2.
[8] Pike, A.G., Dunne, M. Student reflections on choosing to study science post-16. Cult Stud of Sci Educ 6, 485–500 (2011). https://doi.org/10.1007/s11422-010-9273-7.
[9] Jurow, A. & Creighton, Laura. (2005). Improvisational science discourse: Teaching science in two K-1 classrooms. Linguistics and Education. 16. 275-297. 10.1016/j.linged.2006.02.002.

2. Students are focusing on three critical strands of science research

In Luke's class at Nueva, students are self-selecting into an area of science that is of interest to them. In fact, he has "modularized" the approach to science to appeal to an incredibly broad swath of students. A student who may not be interested in lab or traditional research but still cares about science has other opportunities in his classroom to learn and engage.

The holistic nature of the program and the fact that all three strands are treated equally means that students who are interested in scientific writing or citizen science still have the opportunity to do deep work that is critical in the world of science research. The importance of a strong understanding of scientific literature and an ability to communicate about it are skills that should not be under-emphasized. A study in 2009 estimated that scientists spend 23% of their time reading scientific journals.10 Given the density of the material, heavy focus on quantitative data, and type of vocabulary used, these materials can carry quite a heavy cognitive load and require a clear skill-set in understanding and breaking down the concepts.[11]

In addition, incorporating a literacy focus in science through a Journal Club is a vital strategy for students to see that science is not just about numbers and facts. The innately personal angle of scientific issues such as climate change, food industrialization, and the mental health crisis can be brought to the fore through analyzing and reviewing the literature in a way that traditional labs that focus only on data collection and review may not allow for.

What's in store for the program?

A remaining challenge for Luke is around building a cohesive science research department where the students work across teams fluidly and with clarity on their individual and collective roles. He explains that they are not "there yet", but this is a goal for the future. To date, Luke has focused on building out each individual strand and getting them to a place where they can run on their own. Now that this foundational work has been completed, he can turn his attention to the interdependencies within the three strands so that they collaborate together rather than in silos.

[10] Phillips, L.M., Norris, S.P. Bridging the Gap Between the Language of Science and the Language of School Science Through the Use of Adapted Primary Literature. Res Sci Educ 39, 313–319 (2009). https://doi. org/10.1007/s11165-008-9111-z.
[11] Round JE, Campbell AM. Figure facts: encouraging undergraduates to take a data-centered approach to reading primary literature. CBE Life Sci Educ. 2013;12(1):39–46. doi:10.1187/cbe.11-07-0057.

“The Journal Club is very unique in that we give people a venue to talk about whatever they want to discuss because it’s so data-driven. We were talking about data as it is related to abortion and racism. These are topics you can’t talk about in other places because they are really controversial but if you are just focused on the data, the objective truth on an issue, people care to discuss it and it can be a really productive conversation.”

-Morgan, Level III Student, Journal Club

3. Students are the teachers with real empowerment and autonomy to lead

Luke's ultimate goal when he started this program at Nueva was for it to become "self-propagating".

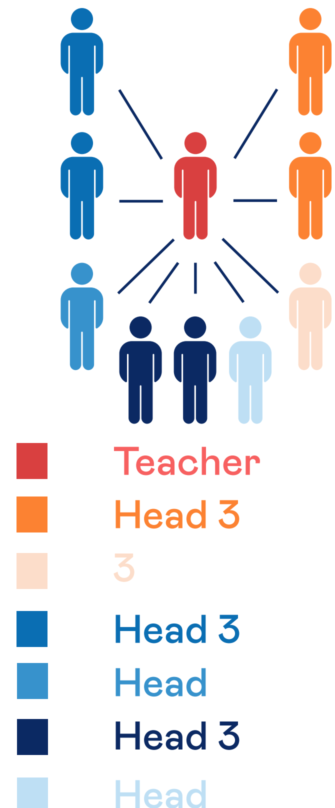
Luke has carved out his role as a facilitator managing and supporting the Level III students. Each of the three strands have two Level III "heads" - the day to day operations head (the "stable") and the outward facing head who interfaces with administration ("the post"). Luke meets with each strand regularly and engages them in answering the following three questions:

1. What have you done?
2. What do you want to do?
3. What are you having trouble with?

The Level I students are answering question 1 in the list above. They are able to articulate the steps taken to date by the group. The Level II students answer question 2. They are able to articulate where they want to go next and what it will take. The most difficult job is reserved for the Level III students. They discuss the challenges the group is facing and determine what support is needed. Luke then spends the bulk of his time with the Level III students, helping them to navigate these challenges. In order for students to move from one level to the next, they have to master the skills at their current level.

This student-as-leader model has many benefits, a significant one being that more students are being served on any given day than if Luke were a single teacher trying to reach all of them on his own.

Luke's entire grading process focuses on the broader skills students are learning that go beyond just science content. This includes project management, a critical gap that he himself said he was missing when he got his first job as a bench researcher after graduate school. Only at that time did he realize how unprepared he really was: "I was spending a lot of time on the job doing basic things that I should have already known how to do."
Luke said it took him six months to build up his project management skills when it should have been an area of expertise that he came to the lab already having. At Nueva, Luke has embedded project management skills as something each student, whether they are a Level I II, or III, should be well-versed in (as shown in the visual below, which is a snapshot of a portion of Luke's grading tool). As a class, they use Asana, a project management software tool. Luke says that training students on how to project manage is a big part of his job, and project management is a big part of the work students have to master as they move from level to level.

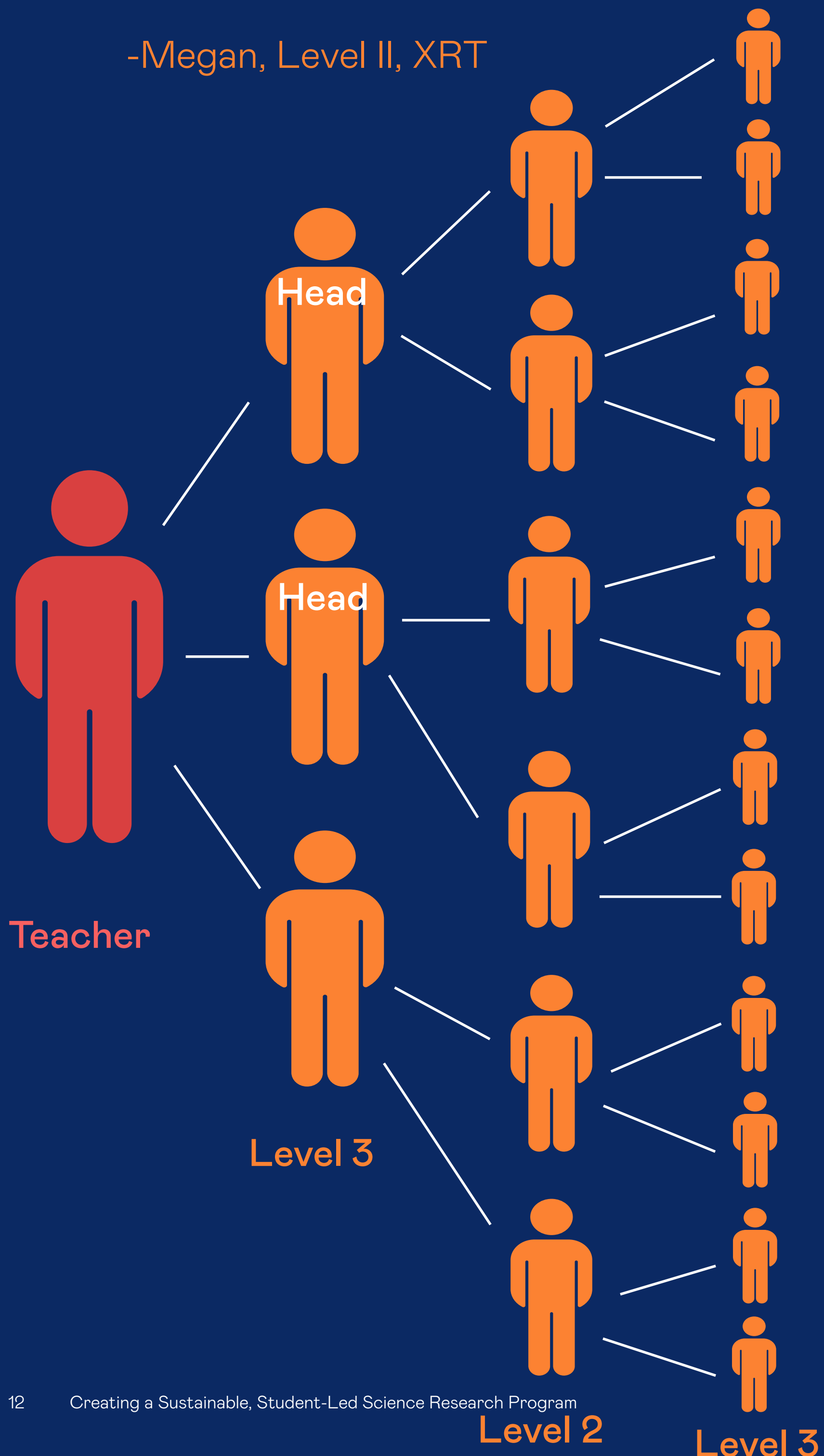


What does self-propagating mean?

In Luke's class, the projects are entirely student-designed and student-led. Because the students are the teachers, they are the ones who are training students
to get to the next level. Interested students learn about his class through Project 80 or sitting in on a presentation by the Journal Club.

In this way, the system is able to run and grow on its own.

> **“As a Level 1, I really appreciated what the other levels did for us. I wanted to reciprocate [when I became a Level 2], to be a leader in that sense.”**
>
> -Megan, Level II, XRT



Not just project management

In Luke’s class, students are learning how to project manage but they are also developing clear leadership and management skills. Students at the higher levels have to ensure that deadlines are being met, feedback is being shared with the other students, and that appropriate training is being provided on relevant responsibilities. In fact, one of the ways that students graduate from one level to the next is by being able to put together a high-quality training packet that is filled with anecdotes from the student’s own personal experiences.

4. Students are supporting an interest in science across the school and community

One of the most compelling aspects of the science research program is how the culture of science has transcended Luke's class and is in the air at Nueva.

One specific way this has happened is through the Journal Club. Every week, students from this strand work with a student at Nueva who is not in Luke's class but is interested in the content more generally. This group trains the student to read a highly quantitative and data-rich article , understand the article, distill the major points, and present it at a weekly lunch to any interested students and faculty who want to attend. These popular Thursday lunches are held at a crossroads area of the school which is highly public for anyone who is passing through to get drawn in.

> We put on the anxiety podcast because we all realized that anxiety is a huge issue a lot of people are dealing with. It is important that we get our information straight".
> Avi, Level II Student, Project 80

In an exciting turn, the Journal Club at Nueva has been so successful that a group of students have chosen to replicate these weekly lunches but in the social sciences. They are reading their own literature, which is more qualitative in nature, and presenting it on Wednesdays instead of Thursdays. This spin-off is completely student led and not driven by any teacher.

How does Journal Club work?

Any student at Nueva who wants to present on a topic can come to the Journal Club with his or her idea. The students in Luke's class will work with that student for seven weeks to develop their content and presentation.

What is the reach?

The reach of the Journal Club alone, at a minimum, is about 90-100 students per week. That is 25% of the entire student body at Nueva.

20
Students in Luke's class on the "executive team" train other students

30
Students (not in Luke's class) present each year

40-70
Students (minimum) attend Thursday lunches

Students listening to a journal club presentation. These presentations are held on Thursdays during lunch and are an opportunity for any interested student to learn about a critical topic that a presenter has spent 7 weeks preparing for.

> **"We have successfully put on a presentation every Thursday the entire year. There was not one Thursday we missed a presentation. We figured out ways that everyone can be contributing to the Journal Club equally and valuably so that we can put on a high-quality product every week".**
>
> -Morgan, Level III Student, Journal Club

What's in store?

In the future, Luke wants his students to work with other schools in the community to build reach and engagement in science beyond the walls of Nueva. While he has tried to build partnerships with nearby schools in the past, he notes that this has not been as successful as he would have hoped. Timing was partly the challenge: he tried to build these partnerships at the beginning of the school year and it was difficult to gain traction with other schools during such a hectic time. In addition, finding like-minded administrators who are willing to initiate real changes to how science is done at their schools is not always easy. Now that the program is up and running fully at Nueva, he can put his attention back to building these types of partnerships.

How can schools replicate this third way at their school?

While it may feel daunting for a school to consider starting a similar science research program, there are lessons to be learned from Nueva's experience.

1- Make the case

There are three points that can help make the case for developing such a program:

· Opportunity for greater reach: Luke's science research class is hitting at least 25% of the student population at Nueva, and that is a conservative estimate. One teacher who is reaching more than 100 students through journal club alone is an important reason to implement a similar model at other schools.

· Opportunity for greater engagement: If your school wants to create a culture of science, then having a program with a variety of ways to participate, whether that be joining the class in one of the three strands or training to be a speaker for a Thursday lunch, provides a real chance for the halls to be figuratively and literally alive with science.

· Creating career-ready students: Classes that move beyond the traditional school concepts to real-world training such as project management, leadership, and management are preparing students for college and their careers in a way that can only benefit them when applying for that crucial first job in a few years.

2- Hire the right person

The "who" behind this program is a critical piece to this puzzle for schools who may be looking to change their approach to science instruction. Luke notes that his background as a PhD level researcher allows him to dive deep on content in a way that would be extremely difficult if he did not have that experience.

He and other researchers who serve as teachers at schools such as Pingry and Garden City High School in Long Island also named that teaching can be a dream job for researchers. There is job stability and no publishing pressures as compared to academia. Part of the value proposition is that teachers can spend their days with students rather than in a lab and they can still be doing novel research that contributes to the field.

As a first step, schools should:

1. Find the researchers who have the desire to be immersed in their subject

2. Look for researchers who have teaching experience under their belts: a teaching assistant role or tutor

3. Invest time and develop a strategy to train the researcher with teaching skills

3- Determine physical space

While the school does not need to create a new physical space, it is important that they dedicate space for this work within the school building. To replicate what Nueva and Pingry have in place, the process could be quite expensive. For example, Pingry has a biology laboratory that, in Colleen's words, "is more like a university lab than a high school lab." They have a variety of high-tech equipment including a dissection microscope, a deep freezer, and equipment for running DNA and protein gels. Every week the school is ordering more of what they need. Luke De also noted that ordering the supplies and materials students need is a significant part of his day to day job.

On the other hand, the Journal Club and Project 80 have a low cost of entry in terms of supply needs. It is possible to start a strong Applied Molecular Biology program without the fancy equipment, but it will require the person running it to think about what is necessary to start off within the limited budget.

4- Start the program in pieces

Luke recommends that schools start with training up their Level III's and by choosing one component of the program to begin with. In his case, he chose Project 80 and built that first. As his first step, he recruited a group of students at the school who were interested in controversial topics and who he knew could get other students interested as well. These students shared their messages and findings throughout the school via posters and other media. This got the buzz going not just with students but also with the larger school community, as well as parents.

He then plucked interested students for his XRT track from his Biology I class and the Journal Club from his neuroscience class. Over time, these students got the training from Luke to grow into Level III's.
Luke notes that starting with Project 80 gave him credibility, not only with students but also parents. They already knew he was a teacher doing interesting and edgy work that students were bought into and excited about. This allowed him the leeway to expand beyond the traditional biology courses into a more holistic research program.

Training students to move from one level to the next has taken up much of Luke's time as he has gotten the program up and running. With his first set of Level I's, Luke had them track and monitor all the ways in which he was training them. The skills he gave them as they moved from Level I to Level II to Level III were then institutionalized and could be used as they started training the next round of students.

It has taken Luke three years to get this program to the point where it is now. He notes that patience is key for schools and over time, the system will work in a sustainable way that the build will be worth it.

5- Attract colleagues & other faculty

In order for the program to sustain and be truly successful, it cannot be, according to Luke, "a one person empire". This is true both in perception and in practice. To ensure that this isn't the case, Luke and his students have asked teachers from different disciplines to present at Journal Club as well. Some of these presentations included understanding the data on dictatorial overthrow as an ineffective means of destabilizing countries and gender bias in the field of science. Luke is also working hard to get new ideas into the day to day administration of the research program overall. Another faculty member, Dr. Paul Hauser, is making key decisions on the program and the goal is for him to officially join alongside Luke in 2021.

What comes first: A researcher or teacher?

When the Pingry School hired researcher Colleen Kirkhart, they were explicit in naming that they could train her to be a teacher but it was far harder to train a teacher to be a researcher. They made sure she did a demo lesson during the interview so they understood her base-level teaching skills and invested in making sure she had a mentor on-staff that she could work closely with. According to Colleen, her background as a researcher has been critical in her ability to design courses that are authentic in the student's discovery of scientific content.

Lessons Learned

One of the main challenges Luke has experienced is the resistance to change, even when people agree that they actually do want the change he is bringing. He also notes that his students' in-depth focus on a particular research topic can rub some parents the wrong way, if it feels like it is at the expense of content.
To combat this, in the first year he started by sending out newsletters to parents where he could control the messaging and narrative by explaining the type of work students were doing, the level of rigor, and the skills they were learning. Luke also created a sample resume of what their children will be able to say when they have completed the program and it is time to apply to college.

Another Interesting School Model: The Pingry School

On the other side of the country, at the Pingry School in New Jersey, you will observe a different school and approach but the science culture that is infused inside Nueva's walls is omni-present here too.

Take Biology teacher Colleen Kirkhart's Honors Biology of Cancer course or the science research course taught by Morgan D'Ausilio on protein biochemistry, or their Independent Research Team (IRT) that runs as an extracurricular and is akin to Luke's overall science research model at Nueva. The similarities across all of these science classes at Pingry is the pointed focus on primary literature and original problem solving, as well as the opportunity for students to get knee-deep in experimental design.

Colleen, the Biology teacher at Pingry, spoke about how her own experience in high school biology was simply an exercise in memorizing facts and it felt very "dead". It wasn't until she got to college that she realized what science could be - that there was real logic behind the experimental design process and that there was true discovery of new ideas through the research.

Colleen's Biology of Cancer Course, a course for 9th or 10th graders, gives students the chance to be the researchers themselves. Students in her class are studying mutations of the BRCA-2 gene. This project was borne out of work students in IRT were doing in partnership with a professor from Yale who is studying the gene. This is just one example of how the IRT, which is an extracurricular, provides an avenue for new and rich ideas to transfer over into the daily class schedule at Pingry.

The students' research in the Biology of Cancer class is in uncharted territory; if they induce mutations to create a particular sequence in the DNA (and then analyze to see if they succeeded), that DNA will then be used for further experiments in the IRT program or sent to Yale.

Pingry's science research course, taught by Morgan D'Ausilio, is designed around students looking at enzymes that have been structurally solved but their function is still unknown. The students are learning standard molecular biology techniques to unpack the mystery enzyme and understand its function. While Colleen notes that this research may not always be publishable, it is at its very core providing students with an opportunity to learn and hone skills to discover something that is unknown.

> At Pingry, students spend time as bench researchers looking at the mutation of the gene, but they also spend significant time reading about failed and successful experiments in cancer research and sharing their learnings in presentations with the class.

In Colleen's class, students are also focused on learning the three components of science research: bench research, understanding scientific literature, and communications. However, the structure looks somewhat different than at Nueva. At Pingry, students spend time as bench researchers looking at the mutation of the gene, but they also spend significant time reading about failed and successful experiments in cancer research and sharing their learnings in presentations with the class.

In particular, Colleen's focus is on presenting an analysis of the data to see how this changed humanity's knowledge of cancer. She wants them to see how knowledge is formed and how it changes the trajectory of science and medicine. Communication is also a critical part of the course: the students' final project is to better understand the mechanism of action of a new drug on the market (either approved or about to be approved by the FDA) and be able to explain how it works to their peers in layman's terms.

Pingry's IRT program mimics a similar model of the overarching science research program at Nueva for interested students in the after-school setting. Here, students are conducting novel research in partnership with a faculty advisor who acts as their principal investigator and who has experience in that specific genre of science. While the students may not be placed in distinct levels as at Nueva, they are supporting and training one another as new students enter the group.

Colleen notes that depth versus breadth is key to the design of her course: "For my Biology of Cancer class, we are sacrificing some breadth for depth. I want them to go super in-depth in one topic so they see the nitty gritty of how it is done. I focus on that over breadth or memorization. If I am teaching the students how to find information, think critically about that information, then they can teach themselves how to use these same skills in another setting."

> "It wasn't until I got to college that I realized that a scientist was a real job. I had this image of the crazy man in the castle."
>
> -Colleen Kirkhart, Biology Teacher, Pingry

Colleen recommends that if a teacher wants to start courses like Biology of Cancer they should consider the following principles:

1. Focus on the skills you want the students to attain and use these consistently as your guideposts

2. Don't be afraid of depth - while it may be difficult

3. Not to cover every component of the science textbook, the depth will allow students to flex their meta-cognitive muscles in a way that breadth doesn't always allow for

4. Look at a lot of unsuccessful and failed science: there are major lessons to be learned for students here and science classes often overlook these stories

5. Squeeze in as an overarching viewpoint: the philosophy of science and the why behind the work

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Summary

The science research program at Nueva and the holistic approach to science instruction at Pingry provide compelling examples of what strong science research programs in high school settings can look like. In both cases, there is a significant motivation on the part of the teacher to have students explore the unknown, and there is an opportunity for students to focus on the strand of science research that is of greatest interest to them, whether that be bench research, communications, or understanding and translating scientific journals.

Transferring the leadership of the course to students, as Luke's program does at Nueva, provides an opportunity to expand the scope and scale as well as give students with key skills that transcend science concepts and also focus on leadership, project management, and collaboration.

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