

What has Persisted and What has Not: A Longitudinal Study of Changes in Teachers' Experiences of Project-Based Teaching and Learning Through the COVID-19 Pandemic*

AVNEET HIRA

245 Beacon St, Chestnut Hill, MA, USA, Boston College. E-mail: avneet.hira@bc.edu

EMMA ANDERSON

600 Technology Square, Cambridge, MA, USA, Massachusetts Institute of Technology, USA. E-mail: eanderso@education.mit.edu

PETER J. WOODS

Dearing Building, Jubilee Campus, Nottingham, UK, University of Nottingham, UK. E-mail: peter.woods@nottingham.ac.uk

In this qualitative longitudinal study, we follow and share experiences of teachers from four different high schools in the United States that represent different institutional contexts (Urban, Suburban, Rural, Public and Charter) around how the COVID-19 pandemic impacted their teaching of hands-on Project-Based Learning (PBL) courses. The data is part of a larger study that is aimed at supporting schools transition from traditional to PBL teaching that allowed us to have multiple touch points for this longitudinal study in May 2020, May–June 2021, and December 2021–January 2022. Following a qualitative inductive and then deductive analysis approach, we ask three research questions: RQ1: What changes to teaching made in response to the pandemic in PBL high schools have persisted? RQ2: What aspects of teaching from before the pandemic have returned in PBL high schools? RQ3: What role has technology played in changes to teaching and learning over the course of the pandemic in PBL high schools? We learn how teachers' responses to the pandemic afforded them an ability to use technologies as tools in support of teaching and learning, and finding ways to prioritize what is truly meaningful for their students. We also learned that teachers and students missed in person connection with each other and with the communities their projects were situated in, and also realized the limitations of working on screens. We also share our findings around how learning management and specific task-oriented technologies have persisted in use beyond the pandemic. We conclude the paper with a discussion on the dichotomy of the promise of PBL for pandemic-time and post-pandemic education, and how teachers, the hidden work they do every day, and the ethic of care they bring to their practices is by no means replicable by technology.

Keywords: project-based learning; educational technologies; hands-on learning; teachers

1. Introduction

The COVID-19 pandemic brought forth unprecedented challenges for everyone, and one of the professions most in the public eye to monitor responses to the pandemic were teachers [1]. We, the authors, were fortunate to be working on a project with teachers from across the United States at the time of the pandemic to support high schools transitioning from traditional high schools to schools that embraced Project Based Learning (PBL) across their curriculum. Until February 2020, we were meeting with teachers and school administrators in-person at their schools and at summer workshops at our then home institution to develop a community of practice around PBL at the high school level. The declaration of the pandemic and its impacts on health and life in March 2020 altered the initially set path for our research study significantly. We pivoted from trying to understand teachers' experiences with PBL adoption to their experiences responding to the pandemic. PBL inherently lends itself to hands-on

learning and the use of technology, the pandemic further necessitated the use of technology. We were able to speak with the teachers we worked with at three different instances spread across the pandemic: May 2020, May–June 2021, and December 2021–January 2022. We started our interviews with eleven teachers, a majority of whom taught STEM courses at four different schools in different institutional contexts (Urban, Suburban and Rural Public and Charter schools). For our third wave of interviews, we were still able to connect with eight of the original eleven teachers. It is interesting to note that at least two of the teachers we originally started with left the teaching profession to pursue different work. Since ideal PBL teaching is always interdisciplinary and our team came from a large engineering university in the Northeast of the United States all teachers were involving students in some STEM learning irrespective of the original area of teaching. With this work, we hope to capture less of the pivot that the teachers made in response to the pandemic but more how the pandemic changed teaching, which changes were

promptly reverted to the “before” times, and what role technology played in the changes that persisted.

2. Background

2.1 Hands-on Learning and the COVID-19 Pandemic

During the COVID-19 pandemic, programs offering hands-on STEM education at the school or K-12 levels responded in several creative ways. For example Tuan et al. [2] report how they provided hands-on playful learning activities for female identifying students between the ages of 11 and 17 by developing kits that were delivered to the students' homes and developing and sharing videos with students and teachers that depicted the participation of girls in science. Ufnar et al. [3] surveyed 115 outreach programs in the United States to understand how the pandemic had impacted the programs and how they were adapting to it. At the time of the survey, 80% of the respondents had moved their programs to online. Das [4] describes how they developed a STEAM curriculum for students aged 6–13 using a makerspace environment adapted for students of this age including their curriculum and case studies of student experiences. Morgan et al. [5], adapted a previously in person five-week program on molecular biology research for low-income high school youth of color. They found that that virtual program was successful on several fronts including relationships between participants and staff, students learning life skills in the workshop, and the implementing of hands-on activities. Internet capacity and “zoom fatigue” were assessed as detriments to the experience. Tsakeni [6] developed best practices for STEM practical work in remote classrooms using a systematic review including “(i) STEM practical work in VR environments, (ii) STEM practical work in remote laboratories, (iii) STEM practical work in AR environments, (iv) use of take-home DIY STEM practical work kits, and (v) use of educational robotics to teach STEM practical work” (p. 157). Perhaps most closely related to our work, Makamure & Tsakeni [7] interviewed two mathematics and three science teachers to understand their transition from in person to online teaching and one of their primary findings was teachers were using Web 2.0 tools like instant messaging to connect with their students and facing struggles with adapting hands-on curriculum to an online modality.

2.2 Project-Based Learning During the Pandemic

During the pandemic, several researchers examined the impact of the pandemic on PBL and how PBL

may be a suitable pedagogy to practice during the pandemic. Zahir & Maheshwari-Kanoria [8] studied a proof-of-concept PBL intervention during the pandemic to understand impacts of the approach on digitally marginalized populations and observed a 28% increase in the participants' academic and non-academic skills and 98% were satisfied with their PBL experiences. Yuliansyah & Ayu [9] purport that teaching PBL online has helped support teachers' and students' ability to use technology and online learning PBL still allows students to develop and plan their projects and produce externally facing project deliverables and solutions. Further examining the appropriateness of PBL for online distance education, Ardhyantama et al. [10] conducted a qualitative analysis to develop a framework of considerations for using PBL during the pandemic. The considerations include “(1) readiness, (2) safety, (3) monitoring, (4) thematic, (5) project learning principles and (6) learning stages” (p. 141). We the authors [11] created a conceptual framework rooted in motivational theories to understand teachers' experiences of enacting PBL during the pandemic and learned that while several motivational factors still support the learning, the lack on human connection significantly impacts even PBL education in school settings. Relatedly, Miller et al. [12] conducted a comparative case study between two elementary science teachers teaching using PBL during the pandemic and found that while teachers maintained fundamental aspects of PBL across the two cases, they prioritized certain features based on their own conceptions of equitable learning.

2.3 The Role of Technology During Pandemic Education

Much like all fields and the day-to-day response to the COVID-19 pandemic, technology played a major role in educators' and school systems' responses to the COVID-19 pandemic. In a cross-case analysis aimed at understanding the partnership between undergraduate STEM student mentors of color and middle school and high school teachers, Kier and Johnson [13] found that the partnerships coupled with relevant support technologies resulted in high quality-connected learning for middle and high school students. In their review Amunga et al. [14] found that most institutions used synchronous and asynchronous technologies to support STEM education during the pandemic, and a few institutions also relied on more sophisticated technologies like Virtual Reality. They also reported how the pandemic and associated technology use further raised concerns around access and equity in STEM education. Febiyanti et al. [15] studied the impact of using

videos in PBL on 4th grade students' listening comprehension skills using a quantitative pre- and post-design. They saw a significant increase in students' listening comprehension skills when using video technology. Gupta [16] used students' academic results, artifacts from PBL activities and surveys to assess the impact of learning technologies in PBL settings and found positive outcomes for student knowledge attainment for both theoretical and practical concepts. In Ufnar et al.'s [3] survey of Primary Investigators of 115 STEM outreach studies during the pandemic, 80% of them were able to leverage technology to offer learning opportunities to students in response to the pandemic.

3. Method

3.1 Context and Participants

The data for this paper comprises interviews conducted with teachers between the peak of the pandemic in May 2020 to the tail end of the pandemic in January 2022. In total, we conducted 27 interviews with teachers over Zoom or phone calls when internet connectivity did not support Zoom calls. The first set of interviews were conducted in May 2020, with an aim to understand how the teachers and their schools were responding to the pandemic in their teaching. The second set of interviews were conducted a year from the first interviews in May and June 2021. By the time of the second interviews, all schools had moved back to in-person instruction, and we were interested in understanding how the teachers and schools were transitioning back to teaching using a PBL approach. Finally, the third and final set of interviews were conducted in December 2021 and January 2022, when most schools across the world were back to "normal" in terms of in-person instruction and no mass-testing requirements. The focus of these last set of interviews was to understand what had persisted from pandemic-time teaching, and what aspects of pre-pandemic teaching had made their way back to schools.

For the first set of interviews, we spoke with

eleven teachers across four schools in three different states in the United States. For the second and third set of interviews, we were able to interview eight of the original eleven teachers whose institutional contexts we share in Table 1. All teachers we interviewed, and their associated schools were part of a larger project focused at bringing PBL education to high schools across the United States. Authors on this paper and other colleagues on the project team worked with the teachers in different capacities to support the teachers and their schools in transitioning their traditional teaching to PBL teaching across the school. All names used in Table 1 are pseudonyms and the study was approved by the human subjects ethics review board of Massachusetts Institute of Technology with a compliance agreement at Boston College.

3.2 Analysis

The analysis for this paper was conducted by the three authors of the paper over several rounds of both inductive and deductive coding. We started the qualitative analysis by going over three interviews each to look for themes relevant to our areas of interest for the broader research study. These areas included teachers' PBL practices, use of technology, and responses to the pandemic. Based on each researcher's inductive coding, we created a codebook that contained 17 different codes covering four broad themes. These themes included DISRUPTION (disruption caused to education by the pandemic), PROJECT BASED LEARNING (teachers' PBL practices), RELATIONSHIPS (impact of the pandemic on relationships between teachers and students), and TECHNOLOGY (use and novel adoptions of technology).

For the study we share in this paper, we focus on three research questions:

RQ1: What changes to teaching made in response to the pandemic in PBL high schools have persisted?

RQ2: What aspects of teaching from before the pandemic have returned in PBL high schools?

RQ3: What role has technology played in changes

Table 1. Teacher participants' institutional contexts, grades taught, and years of experience

School type	Name	Grade Level Taught	Years of experience
Urban public Charter	Leslie (LM)	10	5
	Nancy (NW)	9	10
	Riley (RD)	9	12
Rural public	Andrew (AC)	9 to 12	14
	Ramona (RW)	9 to 12	unknown
Urban public charter	Daisy (DR)	9	7
	Jon (JC)	9	5
Suburban public charter	Elliot (EM)	9 to 12	4

to teaching and learning over the course of the pandemic in PBL high schools?

To answer the research questions, we analyze quotations from the teacher interviews that were coded by at least two researchers under the following codes:

Parent code: DISRUPTION (DIS)

Sub-parent code: DIS - Stickiness (STI)

Code: STI- changes that stuck (RQ1)

Code: STI – back to normal (RQ1)

Parent code: TECHNOLOGY (TECH)

Code: TECH -novel adoption (RQ3)

Code: TECH - embracing affordances (RQ3)

In the findings section below we explain our shared definitions for each of the codes and example quotations under unifying themes to answer the research questions.

4. Findings

4.1 RQ1: What Changes to Teaching Made in Response to the Pandemic in PBL High Schools have Persisted?

To answer RQ 1, we use findings from our interview data which were coded by at least two researchers as the code “STI-changes that stuck.” In our code-book, this code refers to instances of teachers explicitly discussing changes made in response to the pandemic that have persisted into the later stages of the pandemic. Below we share quotes representing themes of how teachers have expanded their use of technology to support learning, as opposed to learning about technology in itself. We also share teacher quotes representing how a major change that has persisted is that they and their schools are attempting to adopt more practices that are truly meaningful to them and the students. This includes changes in school schedules and grading policies.

4.1.1 Technology as a “Tool” as Opposed to an End in Itself

Andrew shares how while during remote teaching, students were learning about different technologies, and now that they are back at school in person technology (electronics) cannot be the sole focus of learning, but instead support learning.

“But I think that cannot be the focus of it. We made electronics kind of the focus of distance education. You have to, that’s how you deliver it. But I don’t think that worked really well. So, I think we can still use it, but it has to be like a tool we use, it can’t be the master we serve. So hopefully we still continue.”

“I mean, human interaction is powerful. It really is. So hopefully we still have those experiences, but we could

use the technology just to enhance it, not take the place of it because it’s not going to do that.”

Daisy echoes Andrew’s sentiment and shares how something that has changed for her from the first time we interviewed her in May 2020 to the time of our last interview (December 2021/January 2022) is how she thinks about technology more as a tool as opposed to something we were forced to use during the pandemic, “so I definitely think that that changed a little bit for me of like, How can we approach this using technology as a tool?”

In a similar vein, Leslie shares an example of how grading on Zoom helped her develop strategies for giving clear and effective feedback to her students, and she continues to use those strategies since the students are still using iPads for their work.

“My students still scored at the state average of our AP exam, which is, I’m really proud of them because a lot of places in the state of Tennessee had in person school and I taught exclusively over zoom. But I feel like I really narrowed down how to give good, applicable, and then not all consuming for me. I figured out how to fit it into my own schedule and time, how to give good writing feedback virtually. And since our kids work largely on iPads, that is a skill that has translated directly over to this school year.”

4.1.2 Doing what is truly meaningful

Leslie shares how the pandemic has made her rethink what she includes in her class as content. She is prioritizing what is meaningful for the students and honoring that individuals have a finite capacity to learn. She shares below how she is honoring her students’ time and interests.

“And I think just really honoring student time and student bandwidth. I think I’ve watched them feel so burnt out from zoom and COVID and uncertainty and housing insecurity and so many things that I feel very attentive to, I have a high bar of what I expect you to be able to do, but I won’t waste any of your time in helping you get there, if that makes sense.”

“And not that before I was like, oh yeah, let me waste your time. But I feel like I’ve paired down what’s truly more meaningful and just honoring their capacity to carry that load. So yeah, that’s something I think with teaching really specifically, I helped with.”

4.1.2.1 Changes in School Scheduling

One of the ways several teachers share how they and their school systems have enacted doing what is truly meaningful to them and their students is through changes in their school scheduling. For example, Nancy below shares that having extra time to plan during the peak of the pandemic has made them dismiss their students earlier to have additional planning time.

“I will say, we found a very flexible schedule online that we were able to adapt to where we had a lot of time built in for planning and meeting with each other. Now

we've started to incorporate that more into our school day. We've actually made the kids leave earlier now. They leave at 2:30 instead of 3:00 or 2:55, so that we can have office hours and have extra planning time. Because we realize the value of that. And we were missing that. We're like, 'Hey, we have more time to plan and do stuff.' Now we're scrambling. So now it's more intentional time about team building within the community of teachers."

Similarly, Riley shares how her school has kept the practice of having virtual or asynchronous meetings that fit better in everyone's schedules and also help teachers be better prepared for the week.

"Another thing actually, going back to something we're doing still, is virtual or asynchronous staff meetings. So instead of physically gathering together once a week, we're sending out a running document with like some key points. Teachers get that on Sunday night, to kind of set up the week for them. We had a meeting just now, but that is more if we really need to make sure that we are explaining something together; we're framing things for everyone in the same way, we'll have those."

4.1.2.2 Grading policies

Another aspect in which the teachers share that they changed their practices to bring more meaning into learning and be student-centered is their grading policies. For example, Ramona shares how instead of an increasing penalty to late work, she has changed the policy such that students are able to submit the work even if it is late so that they actually learn the material.

"I have become more flexible, I think, and this sounds really trivial in the grand scheme of things. But as a result of COVID and in an effort to adjust to students' lifestyles, I changed my late work policy because know it used to be one day late, 10% off every day after that. But I noticed after a certain point they just stop. They don't want to turn it in. I would rather have something than nothing. So I changed now they have a week past the due date to get it turned in and they can get full credit. So they get to prioritize what is important? What do I need to do today? What can wait two days to get done?"

"So they have one week to turn something in; after that, they don't receive full credit for it. So that gives them kind of leeway and they just have to be able to adjust and monitor their time."

Similarly, Riley shares that in support of their students and to help students move past low points that almost everyone experienced during the pandemic she and her colleagues established grade floors so that they do not carry a bad performance in one quarter with them for the rest of the school year. She shared how this practice for inspired by Joe Feldman's [17] book titled *Grading for Equity*

"Second semester, we established a grade floor for all of our students because we found that there was just such a drop off and that students were getting in these holes. A lot of us read *Grading for Equity*, and were

really thinking about that question of what's a research-based way to approach this idea of motivation, student motivation? A lot of students who were at really bad places one quarter. The next quarter they were ready to go, and they had potentially not turned in any work first quarter, so they all have zero. How do you dig yourself out of that hole?"

4.2 RQ2: What Aspects of Teaching from before the Pandemic have returned in PBL High Schools?

To answer RQ2, we share quotations from the teachers' third interview that are codes as "STI – back to normal" by at least two researchers. This code represents teachers discussing aspects of schooling and instruction from before the pandemic that have returned, or they discuss a desire to go "back to normal." An overarching theme we see here is the teachers and students' desire to use less technology and screens in their classrooms as evidenced by wanting to go back to using paper and pencil and reading physical books. Teachers also share how they are happy to be able to do in-person activities again after social distance education had limited such endeavors. For PBL high schools, it is essential for students to be able to connect with the communities that their projects are situated in, and the teachers share how they have started going on field trips and visits again.

4.2.1 Less Technology Please! Back to Paper and Pencil

Andrew shares how him and his colleagues always thought that students would like to use more technology in the classroom, and so when they started using learning management systems (LMS) like Google Classroom and Canvas they thought that the students would appreciate this switch. Instead, the students requested for them to move assignments back to paper and pencil.

"Something that we always thought as old people, is kids like to use technology. They're more adept at it than we are. They pick it up quicker than we do. And so we thought learning management system. We had Google last year, last two years. We have Canvas this year, but we thought students will like to receive their work on Canvas. They'll like to turn it in on Canvas. They'll like for us to communicate with them."

"They don't. They are now begging for paper and pencil. They're like, 'Can we just have this on paper?' And I remember about a month into the school year, and I was like, I can bring this to you on paper or I can send it to you. And they're like, 'To paper, please. Please paper.'"

Elliott shares how he too has had enough of screens for a while and would much rather prefer that his students read from physical books as opposed to digital copies of the texts even though he makes them available. He shares, "I do still like to use the books in the classroom. I have classroom sets now

of like most of our texts. I'm like, 'All right, the readings are here. There's a digital copy, but please grab the book.'" Daisy shares how she and several of her colleagues feel the same way. She tells us, "It's funny because some teachers are like, 'I'm not using computers at all.' Because they just feel like we've been on them too much."

4.2.2 *Let's do more things in-person*

Daisy's quote below represents a sentiment that we saw throughout our longitudinal interviews with the teachers. Teachers missed being able to check-in on their students and see how they were doing as it is difficult to tell through a screen or even behind a mask how a student is doing. Below she shares how she appreciates being able to get to know and care for her students in person.

"And so when kids don't know you, that makes it a little bit more difficult, but yeah, definitely been able to get to know all of the kids a lot more and learn a lot more about their style and just also just their mental health in general and where they're at."

"It's much easier to be able to see those things in person. And you can see their triggers, whereas on a screen and their screen's off. I can't see that; a kid might be having a legitimate panic attack. I had a kid who have one like two days ago and I wouldn't have known if we were on a computer. So, it's just one of those things where I can check in with people, physically looking at them a lot more and whatnot. And kids can also come get help from me a lot easier. I think it's just easier for them to maybe come up and ask than it was to send a Zoom request to me."

Similarly, Jon shares how in teaching his students about different botanists and zoologists using a PBL pedagogy he decided to do a nature writing unit for which they went around in the neighborhood with their clipboards, taking notes and readings. He expresses how important it is to be in person for these types of human-centered activities.

"This year, it's been much different. When I was thinking about project-based learning, the first thing that came to mind was, 'Oh, let's do a nature writing unit, we're going to read these different naturalists, and then we'll go out around the neighborhood and we'll walk around with our clipboards and our field notes, and we'll read outside.' And kind of construct the whole unit around reading in these different environments. And I think that is for sure a reaction to how can we do something that's really dependent on us all being together and able to go somewhere together. So that's happening."

Since our partners in this study are high schools and an important activity several students participate in when in high school is touring colleges and working towards being admitted to colleges. Andrew below shares how being able to visit colleges in person like the "before times" has brought a positive change back to normalcy for the school and students. He

shares, "we did take our seniors on five college visits, which nobody got a college visit last year. They were virtual. Well, I don't know what you can tell by school by virtual, but so we have intentionally done those things."

4.2.3 *We Are Going Places Again*

Riley shares how at her school they have deep partnerships with local universities and communities for students to work on their projects. She shares how the pandemic impacted the authentic relationships that are imperative to doing this kind of work.

"Some of our teachers carried on with projects, and they were reaching out to local universities like the [university name]. Our environmental science class was focusing on environmental racism and dealing with pollution in a particular neighborhood in [city name]. I think the authentic connections weren't happening as much through hands-on experiences, as much as through community partnerships."

"We also use a lot of independent study projects, just figuring out how we could have high expectations and authentic learning with our limitations. Independent studies was the way that we addressed that in many ways. Now, I think our approach has been, I used the word 'tentative' earlier. I think we're tentatively getting back into full range menu of different PBL strategies."

Further she shares how it has been difficult to figure out the logistics of such trips upon the return to being able to visit community sites. She shares, "one of the things that's been slower to develop is getting students out of the classroom and out into the community; chartering buses and getting them around the city and things like that."

Jon and Elliott both share how their schools are back to being able to do field trips with the students for PBL lessons. At Jon's school, students often do internships with local businesses and organizations as part of PBL apprentice learning and these setups were slowly gaining traction again.

"So, we got the green light to do the field trips with freshman, so they're out every Thursday for quarters two and three. Tenth graders and eleventh graders did not get a green light to do full-on internships, so we're trying to do these design thinking projects here at the school, but incorporating some field trips involved in that, but it's not like they're out every week."

Elliott shares how he thinks that his school and district's approval to be able to take students on field trips is a much-needed change after the experiences everyone had in the pandemic. He shares below plans to take students to the Everglades (National Park with grasslands in the United States) and a sensory garden.

"We are able to do field trips again now, they cleared us just at the beginning or the midway through October."

"So we have our juniors and seniors are doing an

overnight trip to the Everglades in January. And so, I started in the planning for field trips for the sensory garden and stuff that they're going to start next semester. And I think that's awakened some students. Like, 'Oh, we get to go on field trips again.' I'm like, 'Yes, we're going to go places.' And I think we need to do that to really make this better."

4.3 RQ3: What Role has Technology Played in Changes to Teaching and Learning over the Course of the Pandemic in PBL High Schools?

As we shared in some quotes in response to RQ 1 and RQ2 above, an important aspect to understanding post-COVID teaching and learning is the role that technology has played. We hear different often understandably contradictory themes when it comes to teachers' use of and sentiments towards technology. Where sometimes they share how adopting new technologies has paved the way for them to learn new software and hardware technologies that assist their teaching past the pandemic, other times they share a yearning to go back to paper and pencil and the importance of doing things in person. This dualism is understandable and aligned with many individuals' reaction to technology use in general – where it makes doing several activities easier, it often takes away the human and material relationships we have with people and things [18, 19]. In this section we share examples of technology use that have persisted for teachers we interviewed. We share quotes from the third of our longitudinal interviews that have been coded as either "Tech: novel adoption" or "Tech: embracing affordances". The first are instances of teachers discussing the use of a brand-new technology in the school. The second are instances of teachers discussing embracing old technologies in new ways. This means using technology more frequently in the classroom and/or using older technologies in new ways.

4.3.1 Learning Management Technologies

Daisy below shares that prior to the pandemic she was mostly using paper to teach statistics and probability. The switch to using Google Classroom and Nearpod has stuck with her as she finds it efficient to develop lessons using them and the students are accustomed to using these tools and have continued using them.

"I don't use paper really at all anymore, which is funny because years past and honestly, if I was teaching predominantly statistics and probability and we were doing that, I probably would be using more paper, but my class really lends itself to being on a computer. So, I'm really thankful for having had the experience, even though it wasn't a good time, because I have been able to pick up some of those skills that we can use in here to keep everything online. So, I very rarely use paper. The most I use is Post-it notes with students. Everyone uses

Google Classroom. A lot of people are keeping Nearpod. So, at one point we were letting some kids opt out and still work from home, which was impossible to keep up with because we have one planning period and we have two Preps that we prep for . . . I know I still was leaning on Nearpod at the beginning of the year to create basically two lessons, one for in person. And then one that I could have kids doing at home. And a lot of students were like, 'Oh it's very easy for me to keep up with.' So, that was really good. And I definitely wouldn't have had the skills that we didn't have in virtual school."

Jon has also been using Google Classroom and Google Drive and enjoys the ease that they bring to the task of distributing materials to students.

"I think Google Drive and Classroom as a way to distribute materials, but I'm using them much more. I think I've just learned that I don't . . . It's been a replacement for physical copies or work that we would do. I just have learned, 'Oh, this is a lot easier to distribute things this way.'"

A similar tool to store and share content in an organized way that Elliott has been using is eCampus. He appreciates that he is able to share the material with his class when he may not be around.

"I've been using eCampus as always. It's where everything is stored. It's just so convenient. Especially when kids are sick or like I got two. So, I mean, and my daughter's got a fever right now. So, if I have to be home and stuff, I post an announcement. Ask them like, 'Hey, here's what you got to do.'"

Riley shares how at her school, they are using a lot more of Padlet and Flipgrid. Padlet allows teachers to share related content through different "walls." Flipgrid is an app that can be integrated into other LMSs and be used for sharing and commenting on videos.

"As a school we're using Padlet a lot more. Padlet was something that I think no one had really been using. There's another, Flipgrid, was another one that we started using a lot more. Teachers are still using Padlet, still using Flipgrid."

4.3.2 Content And Task-Specific Technology

Ramona shares how of all the different technological tools she tried, she continued to use the ones that seemed most applicable for what her students were learning like PhET which can help simulate laboratory exercises.

"I chose to use were the ones where I saw a larger engagement level in my students, or I felt like it was more applicable, and they were learning more from it. Like the PhET, for example, give them access to lab simulations and programs that we just can't get in real life. So that helps them branch out their learning a little bit."

Ramona also shares how she uses online quizzing applications to help engage her students. She shares "I use Quizziz and Kahoots. They're very similar,

but I use Quizzis and help them like practice answering questions, but it makes it so game like that they are more engaged than anything else.”

Below Elliott shares how he thinks his move from paper-based to online rubrics standardizes his grading and while it may take some work to set it up initially, the standardization and ease it affords make it worth the time.

“I’ve tried to be more in using the technology or at least in following through with grading, especially. I did have like a paper thing where I would list all their assignments and like check off where everyone was at with the standards. And what I’ve tried to be more consistent with is having the rubrics online and using the online to do it. I did see the single point rubric and I’ve started to use that a lot.”

“And so, I found that to be really successful and much easier. It’s more time consuming, but I’ll have the standard that I want them.”

Jon has been using an audio editing application to help his students edit their podcasts. He was concerned about the learning curve, but the students picked it up quickly and he plans on continuing to use it as students learn skills around working with audio that can be used elsewhere as well.

“Soundtrap is an audio . . . It’s basically like Garage-Band lite. And we use that for a bunch of podcasting stuff last year. I was really concerned about how complicated it was going to be to teach that stuff virtually, but kids picked it up pretty quickly. So, I definitely have planned on introducing that much earlier this year, just because in addition to a podcast I think there’s so many other applications for it, just knowing how to record audio, how to edit audio.”

Perhaps the software most ubiquitous during the pandemic was Zoom for videoconferencing and several teachers shared how helpful it was to connect with students but also individuals who would not be able to visit in person in a regular year, but the students were able to engage with them over Zoom. Below Ramona shares her experiences and hopes of being able to continue making such online connections.

“Zoom meetings, we can meet with people all over the world now. We can share things that we didn’t have access to before. I don’t want to see that disappear. I don’t want us to stop using it just because we don’t

need it anymore. So, my hope is that we find that nice balance between in-person face-to-face relationships and communication, but also utilizing the very best of technology and getting contact with people and resources that we wouldn’t have before.”

5. Discussion

In the above findings we share quotes from longitudinal interviews we conducted with teachers teaching hands-on courses at PBL high schools across the United States during the COVID-19 pandemic. We answer three research questions, the first to understand what changes they made in response to the pandemic have persisted, the second to understand what practices have reverted back to the prior-pandemic times, and thirdly the role that technology has played in pandemic-time teaching and after during the transition to post-pandemic teaching and learning. In response to the first question regarding what has persisted we hear evidence for new technologies that teachers and students learned to support pandemic-time teaching have persisted to be used as tools for better teaching and assessment. We also hear narratives of teachers using the transition back as a moment to do what is most meaningful for their students, which includes changes in scheduling and grading policies. In response to the second question regarding what practices from before the pandemic have made their way back to schools, teachers share how they are happy to be able to have the choice to not use screens for everything, being able to connect with their students in person, and support students in going on field trips. Finally, regarding how technology has impacted post-pandemic teaching, teachers share how they and their students have learned new technologies and developed new habits to bring them into their workflows. They have adopted both new learning management systems to plan and deliver content, and content and task-specific technologies like those for simulated labs and running online quizzes. In Table 2, we share a summary of the above findings to depict how the teachers’ practices and perception of PBL and technology use in education have evolved from

Table 2. Evolution of teachers’ practices and perceptions

Practices and perceptions of:	During the pandemic	That have returned to the earlier times	That have persisted after the pandemic
Project-Based Learning	Teachers moved projects online using content and task-specific technology	Teachers are doing more enrichment activities and partner visits in person	Teachers are doing more of what they find meaningful for their students e.g., scheduling and grading
Technology	Teachers shifted to using new technologies like learning management systems	Teachers are looking forward to using less technology and more paper when relevant	Teachers are using technology as a means for education as opposed to technology being the goal

during the pandemic to after, including what has returned to the earlier times and what has persisted.

Below we share a discussion on overarching themes that we see in responding to the aforementioned research questions.

5.1 *The Dichotomy of the Promise of PBL for Social Distance Education*

While several researchers and practitioners had recognized the potential of PBL for social distance education [8, 12], we see how while the open-ended and self-directed nature of this learning approach suited pandemic-time learning well, there were some concerns with its suitability as well. As in our study the teacher Andrew shares, the pandemic afforded opportunities to use technology as a tool to teach and learn better. Several teachers shared examples of technology they had adopted in the pandemic for PBL teaching that they continue to use like Soundtrap for John, Zoom for Ramona, and Google Classroom for Daisy. However, at the same time PBL requires authentic connections with communities and people in which the projects are situated, and personalized connections between teachers and students. As we learn for Daisy how difficult it was to check in on her students over computer screens, from Jon how connecting with the community and world around was important from his students to learn well, and for Riley about how her students needed to be able to connect with their community and partner universities to work on their PBL independent study projects. Hence, while the pandemic left us better off with respect to knowing and using technologies, authentic connections that life post the pandemic has afforded are also a welcome and necessary aspect of PBL.

5.2 *An Ethic of Care: Teachers do more than Deliver Content*

While that of a minority, an opinion that has been present in popular culture and exacerbated by the pandemic is that technology will replace or reduce the need for school teachers [20–22]. As we see in several of our narratives and other work reporting on schooling from during the pandemic [23, 24] this is far from the truth. While technology can provide several useful ways to deliver content, manage learning environments and even perform specific tasks, the role of a schoolteacher, and in our case teachers facilitating PBL, is much broader than these tasks. Teachers are often one of the few adults in students' lives who see them every working

day and know how they are doing [25], teachers care about their students and this ethic of care is what keeps several of them in the profession despite experiencing burnouts [26], and teachers are able to personalize education for students by upholding values of equity [12]. In our narratives we see similar sentiments shared by Daisy when she shares how much better it is to see how her students are doing in person, when Leslie shares her approach to honoring students' interests and capacity, and Riley shares her and her colleagues' practices to bring more equity to grading practices. The pandemic and its aftermath have shown us the important role that teachers play in young peoples' lives that go way beyond delivering content and performing specific tasks that emerging educational technologies can assist with.

6. Conclusion

In this paper, we share experiences of teachers who had started a journey to transitioning their curriculum to PBL prior to the pandemic. The pandemic brought forth a unique set of challenges to which teachers and schools responded in creative and unprecedented ways. While we the authors do not think that the pandemic as a whole was welcome in any part, it is interesting to see what impacts the pandemic made to teaching and which changes have persisted. There is no doubt that teachers will go above and beyond their official obligations to support students and we see evidence for the same throughout the narratives we share above. Teaching hands-on STEM course content in PBL settings also invoked its own set of challenges given the traditional reliance of such work on labs, classroom technologies, and more recently authentic connections and work with local communities. The teachers and students value human connection no matter how much new and emerging technologies may support part of their teaching processes. In answering three questions around what has persisted, what has gone back to pre-pandemic times, and what role technology has played, we hoped to elucidate not just the pivots teachers made to accommodate pandemic-time learning but also how the pivots may shape the future of STEM PBL education.

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Avneet Hira is an assistant professor and founding faculty member in the Human-Centered Engineering Program with a courtesy appointment in the Department of Teaching, Curriculum, and Society at Boston College. Her research, which is in engineering education, focuses on the affordances of technology, humanistic design, and engineering epistemology. She received an NSF CAREER award in 2023 for her work on promoting belonging and preventing harm in informal engineering learning environments.

Emma Anderson is a learning scientist at the Scheller Teacher Education Program | The Education Arcade at the Massachusetts Institute of Technology. Her research centers around science, art, making, and play with a focus on

increasing agency for teachers and students in formal and informal learning environments. Anderson is a former environmental educator who taught science lessons in urban kindergarten through 6th-grade classrooms and spent summers leading campers around the woods.

Peter J. Woods is an assistant professor of learning sciences at the University of Nottingham. His research focuses on what and how people learn through creative production, with an emphasis on the situated technologies and cultural contexts that influence this praxis. Recent publications can be found in *Information and Learning Sciences*, *Teaching and Teacher Education*, and *Critical Studies in Education*. Woods is also a former high school math teacher who taught at a small, arts-based, and PBL focused charter high school.