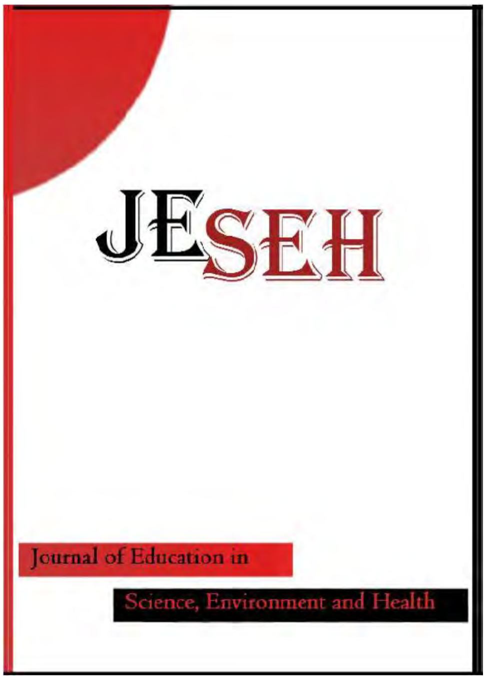

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Abstract

Globally, fewer students are choosing careers in science. In developing countries like Bangladesh, this attrition is often attributed to limited access to laboratories, lack of qualified science teachers, and limited use of student-centered strategies (SCS). Educators are attempting to design professional development programs to empower teachers with innovative teaching methods that will eventually boost enrolment in STEM-related fields. With this end in mind, we designed a six-month-long grant-funded project that equipped five urban schools in Bangladesh with 20 science toolkits. We also provided 20 science teachers and five site coordinators with ongoing professional development to support use of these toolkits with 109 students for inquiry-based learning (IBL). Using an explanatory sequential design, we analyzed quantitative and qualitative data from three surveys. We also used transcripts from interviews with five site coordinators and four Zoom panel presentations to understand the numeric findings. While quantitative analysis with SPSS revealed that teacher-centered strategies (TCS) continue to be widespread in Bangladesh, we noted that the IBL project influenced student outcomes in several ways. The qualitative data confirmed that teachers who receive training and support over an extended period implemented SCS quite effectively. Both quantitative and qualitative findings revealed that a shift from TCS to SCS enhanced students' ability to hypothesize, experiment, and make real-life connections. In this paper, we describe statistically significant differences in the students' knowledge across curriculum type and gender. We also describe the influence of the project on student attitudes.

Introduction

Progress in science and technology is considered the main driving force for the advancement of a country (Organisation for Economic Co-operation and Development, 2012). Empirical evidence over the last few decades confirms that globally, fewer students are choosing higher education and careers in the field of science (Cooper et al., 2020). A similar trend has been observed in developing countries like Bangladesh. The Bangladesh Bureau of Educational Information and Statistics (BANBEIS) reported that students studying science at the secondary level have declined at the rate of 48 percent from 1993 to 2015 (BANBEIS, 2016). Some scholars have attributed declining numbers to culture, limited access to resources (BANBEIS, 2016), and professional development opportunities (Khanum, 2020; Talukder et al., 2021). Others attribute it to pedagogical practices; teacher-centered strategies (TCS), like the lecture method, are still popular in Bangladesh (Akhter et al., 2019; Jony, 2016). Students rarely experience engaging activities in the classroom (Akhter et al., 2019).

Learning some subjects, especially science, without active participation leaves students unmotivated and underprepared to pursue a career in STEM-related fields. A growing number of scholars in developing countries have described the benefits of using inquiry-based learning (IBL), a student-centered strategy (SCS), to attract students toward the sciences (Aulia et al., 2018; Wang & Gao, 2021; Zhao et al., 2021). With this end in mind, we designed and implemented a six-month-long, grant-funded IBL project that would equip the teachers, site coordinators, and students at five urban schools with IBL skills. Grant funding was used to provide each of the five schools with access to four science toolkits for inquiry-based learning (IBL). To facilitate effective use of these toolkits, we provided the 20 teachers (four from each school) and 5 site coordinators (one at each school) with ongoing professional development and support. Participating teachers used these toolkits and the IBL activities they designed with 109 students. Students designed posters to share their findings with students, teachers, and parents. Participating teachers shared the IBL activities they developed in a book and on 'Shikkhok

Batayon,' the largest government-owned educational content website for schools in Bangladesh. Additionally, teachers, students, and site coordinators shared their IBL experience via Zoom with educators in Bangladesh and other countries. In this article, we present a synthesis of literature which informed the design of the IBL project and a study to evaluate outcomes. We describe the context, objectives, and timeline of the IBL project. Next, we describe the four research questions and instruments used to collect data. We present the results, discuss our findings, and invite educators in developed and developing countries to replicate the project (see Machado & Nahar, 2021), with modifications.

Literature Review

In this section, we synthesize research that describes the knowledge, skills, and pedagogy science educators have focused on over the last few decades. Next, we describe how science education is organized in Bangladesh and the factors that impede innovative science teaching practices. We conclude with a description of empirical research that supports a shift from TCS to SCS like IBL.

Essential Knowledge and Skills for Secondary Science Education

There is strong agreement in the scientific community that secondary school students should have a solid foundation in the fundamentals of science, scientific inquiry, and its application in daily life. A few decades ago, the National Science Education Standards (NSES, 1996) described scientific inquiry as "diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (p. 23). Brohi and Munshi (2021) state that the primary purpose of science teaching is to offer knowledge and information about our surroundings. To learn the fundamentals, students must engage in active processes which require capacity to make sense of phenomena and content (Matthew et al, 2019). While Murphy et al. (2021) emphasizes the importance of the inquiry process, Mezirow (1991) states that "making meaning is central to what learning is all about" (p. 11). People are more likely to accept knowledge consistent with their existing knowledge base derived from their own experiences (Kovbasyuk & Blessinger, 2013).

Teaching Strategies for Developing Scientific Literacy

Piburn and Baker (1993) attribute students' negative attitudes toward science to its abstract nature and complexity. Others suggest that teaching methods and curricula contribute to low interest and negative attitudes toward school science worldwide (Tseng et al., 2011). To address such issues, professional organizations have described a variety of pedagogical approaches suitable for secondary students (National Curriculum and Textbook Board, 1996; National Research Council, 1996). Scholars recommend that educators focus on cultivating students' scientific knowledge (Driver et al., 1994), attitudes (Pitafi & Farooq, 2012), and scientific process skills like hypothesis formulation, identification of and controlling variables, and experimentation (Ergül, 2011) with innovative science teaching strategies (Hırça, 2013).

Over the last six to eight decades, science teachers have used a variety of pedagogical approaches to enhance students' science literacy. One popular and widespread pedagogical practice is project-based learning which former science teacher Dewey described as "learning by doing" in his book "My Pedagogic Creed" which was published in 1897. ChanLin (2008) and Karaman and Celik (2008) report that learners who engage in project-based learning performed better in skill development, general ability, and knowledge compilation than those who did not. Mioduser and Betzer (2008) argue that project-based learning helps to increase students' positive learning attitudes toward technology and science (Catherine & Barry 2008). The National Research Council (NRC, 1996) developed a framework for inquiry-based learning. Dewey (1910) also recommended the inclusion of inquiry into K-12 science curriculum. Another strategy for teaching science that became popular in the 1970s is problem-based learning. Problem-based learning, which was first incorporated at the medical school of McMaster University, Canada, was used to analyze patient problems systematically, find solutions, and select the students' own learning goals (de Graaff & Kolmos, 2007). Later, the adoption of problem-based learning expanded into elementary, middle, high, universities, and professional schools (Savery, 2006; Torp & Sage, 2002). The advent of technology has resulted in many different innovative approaches that include the use of SCS. Over the last decade, science teachers have begun to use game-based learning to teach science. The term gamification, which first emerged in 2008, has gained increasing relevance since the 2010s (Deterding et al., 2011; Seaborn & Fels, 2015). Scholars have been investigating how digital games promote learning (Gee, 2007; Lynch et al., 2015; Malone, 1980; Prensky, 2005) motivation and engagement (Gee, 2007; Sheldon et al., 2011).

Recently, educational researchers have begun to study the benefits of replacing physical laboratories with virtual labs (Potkonjak et al., 2016).

Secondary Science Education System and Curriculum in Bangladesh

In many developing countries like Bangladesh students do not have access to innovative teaching strategies for a variety of reasons, including, but not limited to the educational system. Rahman et al. (2010) described the Bangladesh education system as one that consists of several coexisting streams parallel to each other. Within the secondary education system, the curriculum varies. According to Roy et al. (2020),

> The complex education system of Bangladesh …..involves more than 25 types of school providers, offering education from pre-primary to secondary levels, with ten examination boards. Based on the curriculum offered, providers can be grouped under three main streams: (a) public and private schools and madrasas that follow the National curriculum; (b) unregistered and autonomous Quomi madrasas that follow Deobandi curricula; and (c) schools that follow a British curriculum. (pp. 3-4)

Disparities exist across schools in Bangladesh in terms of cost, medium of instruction, curriculum, teaching strategies, and overall quality (Mousumi & Kusakabe, 2017; Nur, 2021). Schools that offer the British curriculum generally serve students of higher socioeconomic status (Mousumi & Kusakabe, 2017; Nur, 2021; Shahidullah, 2017). Conversely, students of lower socioeconomic status tend to enroll in schools with a National Curriculum. Mousumi and Kusakabe's (2017) mixed-method study of 149 students and 30 teachers, parents, and principals in Bangladesh revealed a widespread belief that schools that offer the British curriculum provide better quality education. Using a qualitative approach, Nahar (2021) studied five science teachers at a British curriculum school in Dhaka to examine science teaching standards. She noted that teachers at schools with better facilities and the British curriculum used more innovative science teaching techniques than their counterparts at National curriculum schools.

Barriers to Attainment of Student-Centered Learning in Bangladesh

Like teachers in other developing countries, teachers in Bangladesh may have theoretical knowledge about project-based learning, inquiry-based learning, problem-based learning, game-based learning, and virtual labs; their ability to use these approaches to develop students' scientific knowledge and skills are often impeded by factors that we discuss in this section. This includes the way secondary science education is organized in Bangladesh, the lack of resources, inadequately trained teachers, the lack of quality textbooks, and traditional teacher-centered pedagogical practices.

Lack of Resources

The Bureau of Educational Information and Statistics (BANBEIS, 2016) analysis of data collected from 100 schools and 965 students, science teachers, school heads, education officers, and guardians from across Bangladesh revealed insufficient laboratory resources, trained teachers, and poor-quality textbooks as significant challenges. BANBEIS reported that 15% of schools and 31% of Madrasahs do not have science laboratories. There is considerable disparity between urban and rural schools; only 28.5 % of rural schools have proper laboratory maintenance compared to 43.2% of urban high schools. Students in rural schools have limited access to trained teachers; proportionally more post-graduate trained teachers (44.7%) work at urban and rural government schools. Conversely, fewer rural non-government schools have qualified teachers (10.3%) as compared to their urban counterparts (60%). According to BANBEIS's survey respondents, textbooks are unclear, lack sufficient detail, do not include a glossary, and include illustrations that have errors. Additionally, the curriculum lacks instructions about how it should be implemented in rural settings where resources are even more limited.

Examinations and Rote Memorization

The assessment system at secondary schools in Bangladesh fosters the use of TCS and rote memorization over student-centered learning. Evaluation of students' learning in Bangladesh is driven primarily by the national examination system (Khan et al., 2014; Rahman et al., 2010). Exam results are very important as they are used to determine students' promotion from one grade to another and future study options (Sarkar & Corrigan, 2014). The examinations often include a pool of items taken directly from the textbook, and tests often require answers copied straight from the textbook. This approach propels students to rely almost exclusively on the recommended textbook and rote memorization (Holbrook, 2005; Maleque et al., 2007). Teaching often reflects the washback effect (Tapan, 2010), where teachers mostly prepare students for the exams by encouraging them to practice rote learning. In Al Amin and Greenwood's (2018) mixed method study with 216 secondary school teachers of Bangladesh, 10% agreed that an effective teacher teaches only what will be important for the final examination and that over 30% acknowledged that they did not teach portions of the textbook that they considered less important for the examination. Alam et al. 's (2022) qualitative study, which included head teachers, teachers, and parents of 15 schools in Bangladesh, confirms that students and teachers are dependent on rote memorization for academic success in Bangladesh. Jony's (2016) survey of 100 secondary teachers from different schools in Bangladesh confirmed that this preoccupation with grades and results makes it difficult for students to adjust to SCS.

Limited use of Student-Centered Strategies in many Developing Countries

Scholars have reported limited use of SCS in many developing countries across the world; this may discourage students from pursuing careers in science (Doka et al., 2021, Tsegay, 2015). Schweisfurth's (2011) systematic review of 72 studies in 39 developing countries around the world revealed that:

> Classroom realities in developing country contexts evidently create challenges for LCE. The ideal-typical LCE classroom as envisaged in the doctrine of progressivists based in the rich minority world is far from the lived experience of most teachers and learners in the South… (p. 427)

Empirical and theoretical research on teachers' and students' perceptions about SCS highlight some of the benefits and challenges. Teachers' perceptions greatly influence their use of SCS. Akhter et al. s' (2019) observations and interviews with four secondary biology teachers of Dhaka city revealed that teachers lack knowledge about SCS. Jony (2016) investigated Bangladeshi secondary teachers' perception of SCS through surveys. He noted that nearly half of the sample (44.8%) strongly agreed that teachers need to prepare differently when using SCS. Over 80% of teachers feared losing control of students. They reported that students in Bangladesh are more accustomed to the traditional approach and more focused on grades and the final result. Some feared that SCS would increase students' workload and that it would be difficult for them to adjust to a new system. Schweisfurth (2011) examined teachers' perceptions from a cultural point of view and claimed they might have low expectations of individual students' ability to manage their learning if they are from marginalized communities. Several scholars described students' perceptions of SCS. Widmann and Binaya's (2013) study in Nepal highlighted students' positive responses towards the SCS; students were more likely to like what they were learning when SCS was thoughtfully embedded into instruction. Several scholars identified challenges. The 39 South African student teachers who participated in du Plessis's (2020) study described how difficult it was to maintain discipline when using SCS in large classes. Khanum's (2020) mixed-method study involving 100 undergraduate students and four teachers from Dhaka city revealed that students do not like to talk in front of the teacher; they preferred guidance over autonomy.

Inquiry-Based Learning for Acquisition of Knowledge and Attitudes

In addition to understanding disciplinary content knowledge, students need learning skills - an understanding of how knowledge is organized and acquired. By learning how to solve problems, think critically, apply information, and integrate knowledge, learners can think like experts in a discipline (du Plessis, 2020). Research, however, confirms that students do not automatically acquire these skills (Chiphiko & Shawa, 2014); teachers need to integrate innovative SCS strategies like IBL and project-based learning into the curriculum to facilitate the acquisition of content knowledge and a positive attitude toward science.

Inquiry-Based Learning: Knowledge, Attitudes, Skills

Inquiry-based learning (IBL) can be used to foster deep cognitive capabilities and develop transferable life skills, value clarification, and meaning making in all its complexity. Several professional organizations recommend the use of SCS, like IBL. The National Research Council recommended the use of IBL, which allows students to conceptualize questions and seek possible explanations to respond to their questions (NRC, 1996). The National Science Teacher Association (NSTA) described how IBL promotes scientific content knowledge in students. It goes on to add that:

> Scientific inquiry is a powerful in understanding science content. Students learn how to ask questions and use evidence to answer them. In the process of learning the strategies of scientific inquiry, students learn to conduct an investigation and collect evidence from a variety of sources, develop an explanation from the data, and communicate and defend their conclusions. (NSTA, 2004, para. 3)

In addition to disciplinary knowledge, students need to develop a positive attitude towards science. The scholarly literature confirms that IBL fosters a positive attitude and a high level of student engagement. In his autoethnographic study of 49 seventh-grade students, Frezell (2018) described a close link between hands-on aspects of IBL and students' interest in science. In contrast, he also observed that some students experienced frustration when the lesson seemed to lack structure. Sangkala and Doorman's qualitative study (2019) involving 120 Indonesian high school students confirmed that IBL inculcated a positive attitude that facilitated autonomous learning, content exploration, and finding solutions. A few years later, Postma (2021) examined the effect of IBL on 349 high school students' motivation toward science. She reported a statistically significant difference in autonomous motivation in students who experienced IBL lab activities. Students who participated in the IBL lab activities with enough time, no prior preparation, and no prior assessment showed higher intrinsic motivation than those who were prepared, assessed in the past, and could not get enough time to practice IBL. In short, IBL allows students to enhance their science literacy by performing experiments and investigating phenomena (Gasterland, 2021).

Status of Inquiry-Based Learning in Developing Countries and Bangladesh

Educators in developing countries use IBL for science teaching to varying degrees. Several scholars from developing countries across Asia have reported positive outcomes of IBL on science learning (Dool et al., 2021; Duran & Dökme, 2016; Hastuti et al., 2018; Mulyeni et at., 2019). Pandey et al. (2016) and Zhao et al. (2021) reported a statistically significant effect on students' academic achievement. Abdi's (2014) eight-week experimental study with 40 Irani primary students revealed that students in the IBL group achieved higher scores than those in the control group. Similarly, Zhao et al.'s (2021) reported that 174 fifth-grade students in China had clearer concepts due to IBL. Conversely, some authors described the challenges teachers faced when using IBL in developing countries. For example, Hairida (2016), who conducted a quasi-experimental study with two seventh-grade classes in Indonesia, reported that limited resources impeded implementation of IBL. Hsiao et al.’s (2017) quantitative study with 123 fourth grade students in Taiwan highlighted students' inability to understand the findings of IBL; this could be an obstacle. Huang et al. (2021), who studied students in Beijing and Holland, reported that students need many more opportunities to practice IBL.

IBL gained popularity in Bangladesh in the 1980s. Tapan (2010) reports that the “hands-on practice” focused science curriculum which was introduced in 1982 was not implemented. The country's National Curriculum and Textbook Board (NCTB, 1996) reported that schools could not provide the resources needed to facilitate inquiry in science classrooms. Shahidullah (2017) explained that science teachers rejected IBL because the National Curriculum and Textbook Board (NCTB) of Bangladesh failed to prepare them adequately. Despite these difficulties, all subsequent science curricula included inquiry as an essential part.

Background of the IBL Project and the Related Study

Bangladeshi secondary school students' interest in pursuing education in the science field has been on the decline for decades; this has had a negative impact on the country's advancement in STEM sectors (BANBEIS, 2016). Education leaders, curriculum specialists, and policymakers in Bangladesh are committed to boosting enrollment in the sciences. Scholars have recommended professional development that equips teachers to use low-cost material to design and implement low cost SCS (Akhter et al., 2019; Hossain, 2019). We answered this call to action by designing and implementing the urban phase of a grant-funded IBL project to promote science education in three schools that offered a National curriculum and two that offered a British curriculum in Dhaka, Bangladesh. The six-month-long IBL project (October 2019 to March 2020) was designed to meet the following goals.

1. To provide ongoing professional development to 20 secondary science teachers who worked at five urban schools to equip them with the knowledge, disposition, and skills needed to design and facilitate IBL activities using locally available materials.
2. To provide 100 students with the opportunity to use the provided IBL toolkits to implement a model IBL activity (guided practice), student-led group IBL activity (independent practice), poster presentations, and IBL information sessions via Zoom.
3. To compile science-related IBL activities developed by participating teachers and make them available to the 429,777 teachers of 'Shikkhok Batayon,' the largest government-owned educational content website for schools in Bangladesh.
4. To provide teachers, school site coordinators, and students with an opportunity to share their IBL experience via Zoom with educators in Bangladesh and other countries and a book that includes IBL resources created by participating teachers.

Table 1 presents the six steps that we completed to meet the four objectives described above. The professional development training (step 1) provided teachers with an opportunity to familiarize themselves with the difference between familiar practices like teacher-led demonstrations and IBL, which requires the use of hypothesis testing, manipulation of apparatus, data collection, and analysis to arrive at conclusions. At this session, teachers were provided with details about the four IBL toolbox's each school would receive, instructions on how to create four teams per school (each with a teacher and 5-6 students), and the ways in which teachers should facilitate their teams' use of the toolkit for guided practice with the model IBL activity designed by the project director (step 2) and independent practice using the IBL activity planned by the teacher and students (step 3).

Table 1. Project overview: Urban phase

Program Overview	Timeline
Step 1: Inquiry-Based-based Learning' Training Session	14 - 20 Oct. 2019
Step 2: Use of Model IBL Project & Science Toolkits (Guided Practice)	20 - 30 Oct. 2019
Step 3: Teams Design and Implement their own IBL Activity	31 Oct.-10 Nov. 2019
Step 4: Teams Make Knowledge Public at a Poster Fair	26 Feb. 2020
Step 5: Teams and their Families Attend 'Certificate Award Ceremony'	26 Feb. 2020

We delivered the four IBL toolkits to each of the five schools a few weeks after the project began. During step 2, the 20 teachers used the toolkits and the model IBL project, designed by the project director, to test the hypothesis, manipulate the apparatus, record their observations, analyze results, and draw conclusions. After gaining a working knowledge of IBL, each team designed and implemented their own IBL projects at their respective schools (step 3). They began the process by listing several hypotheses they wanted to test with locally available inexpensive materials; of these, they picked the hypothesis they liked best. Using the model IBL and their teacher as a guide, they used the scientific method to test the hypotheses. For many students, this was the first time they conducted an experiment with locally available material using standard scientific procedures. Next, project participants made their learning public at a poster fair that was attended by 200 students, their parents, and teachers. At this catered event, teachers and students were given certificates and awards (steps 4 and 5). The project director provided ongoing individualized support by phone, school visits, and email. She also used Facebook and Facebook Messenger to provide teachers with encouragement and feedback (steps 1-5).

Upon the culmination of the project, we collected data from participants to evaluate the outcome and improve the program for the rural phase. We administered Teacher Survey B and the Student Experience Survey to evaluate teachers' and students' experiences with different aspects of the project. We also interviewed the five site coordinators (step 6). We hosted four panel presentations via Zoom to share the outcomes of the IBL project with the larger academic community. We posted links to these events on Facebook. Each panel presentation included a cross-section of project participants. On average, approximately 60 to 80 students, science teachers, school leaders, and curriculum specialists in Bangladesh and other countries joined each of the four Zoom sessions (step 6). We used the interview and Zoom session transcripts as additional data sources.

Methodology

We designed this six-month-long study to evaluate the IBL project outcomes and contribute to the limited body of professional development literature that target IBL studies in developing countries in general, and Bangladesh in particular. In this section, we describe the research design, research questions, data sources, instrumentation, and data collection procedures.

Research Design, Questions, and Data Sources

We used a mixed-method explanatory sequential QUAN-QUAL design to study the influence of a professional development program on secondary science students' IBL. The three surveys, which were administered sequentially, elicited both quantitative and qualitative data. We also used the qualitative data from the five site coordinator interviews and four Zoom session transcripts to understand the numeric findings. Table 2 presents four research questions, and the data sources used to answer each question.

Table 2. Data sources of research questions

Research Questions	Items in Survey and Protocol				
	Teacher Survey A	Teacher Survey B	Student Survey	Interview Protocol	Zoom Sessions
1. How did teachers, students, and site coordinators describe the way science is generally taught in Bangladesh?	8		8a - k	1, 2	
2. How did the IBL project influence students' scientific literacy (knowledge and attitudes)?		3	9, 11a -d	4, 5, 7	1-4
3. What challenges did students face, and how did they overcome these challenges?		5, 6	13	3	1-4
4. What influence did the IBL project have on students' motivation and desire to pursue higher studies in science?			6, 7	1, 2	1-4

Instrumentation

We drew on our shared experience of more than 22 years of K-12 teaching experience in Pakistan and Bangladesh (this includes 13 years teaching science in Bangladesh) and 16 years of research design to develop three surveys and an interview protocol. Surveys A and B were administered to teachers. Survey A elicited demographic information and teachers' preferred pedagogy (items 6, 7, and 8). Survey B included items related to the IBL project's success (items 1 and 2) and items related to challenges teachers faced (items 3 and 4).

The 13-item Students' Experience Survey included five items that elicited basic demographic information such as age, gender, and types of curricula. Items 6 and 7 elicited data to ascertain the IBL project's influence on students' future career plans related to science education. Scaled item 8 provided students with an opportunity to describe how often they engaged in different science learning activities prior to the IBL project. Items 9 to 11 garnered data on the knowledge students gained during the project. Item 13 identified the barriers students experienced and how they overcame these.

The interview protocol that we developed for site coordinators included open-ended items (items 1, 2, 3, 4, 7, 8, and 9) and closed-ended items (items 5, 6, and 10). Items 1 and 2 elicited data about general science teaching practices. The rest of the items elicited data about the successes and challenges the site coordinator observed while the project was underway.

Data Collection Procedures

We initially administered Survey A electronically using Qualtrics. Preliminary analysis of data confirmed that we needed to readminister the survey in person along with an explanation of some terms in teachers' native language, Bangla. We did this at the professional development session (step 1). We used Qualtrics to administer Survey B to teachers electronically after step 3 was completed.

Participating teachers sent the link to the Student Experience Survey to their respective students. Only 47 of the 109 students completed the survey (response rate 43.12%); the rest could not be reached due to post-exam absence, shifting location, and the impact of Covid 19 Pandemic. Given that students' perspectives are not represented sufficiently in the scholarly literature, we deemed this number acceptable, especially because the surveys included open-ended responses, which would be triangulated with qualitative data from two other sources. Upon completion of the project, we conducted in-depth semi-structured interviews with the five site coordinators via Zoom. We also used transcripts of the four recorded Zoom sessions as a data source.

Analysis and Findings

We used IBM SPSS statistics version 28 to analyze the numeric items of the survey and NVivo 12 to quantize some of the open-ended survey items. We also used NVivo for typological and interpretative analysis of the five interview transcripts and the four Zoom transcripts (Hatch, 2002). In this section, we begin with demographic information about our participants. Following this, we present analysis and findings, organized by the four research questions.

Participants

We used a purposeful sampling approach to select 109 students, 20 science teachers, and five site coordinators from three English and two Bangla medium urban schools in Dhaka city, Bangladesh (see Table 3). Due to the extenuating circumstances brought on by the pandemic, only 47 students completed the survey.

Table 3. Number of students who completed the survey across school: Organized by curriculum

Curriculum	Schools	Public/Private (approx cost per year *)	Medium of instruction	Respondents per school	Total students per curricular	%
British	A	Private ($1350-1600)	English	18	30	63.5
	B	Private ($2000-2500)	English	12		
National	C	Private ($550-700)	English	02	17	36.2
	D	Private ($320-400)	Bangla	10		
	E	Public (Free)	Bangla	05		

Note. * Information obtained through personal communication with teachers in Bangladesh

The student sample included many more females (n = 32, 68%) than males (n = 15, 32%). More than half of the respondents were 15-16 years old (n = 24, 51%), a third were 13-14 years old (n = 18, 38.3%) and a tenth were 17 -18 years (n = 5, 10.6%). Our findings reflect the perspectives of middle (n = 11, 23.4%), junior high (n = 23, 48.9%), and senior high school students (n = 13, 27.7%). The response rate varied across schools (see Table 3). Proportionately more students completed the survey at the two schools that follow the British curriculum (n = 30, 63.5%) than at the three schools that follow the National Curriculum of Bangladesh (n = 17, 36.2%).

Status of Science Teaching in Bangladesh

Research question one explored participating students' perception of science teaching practices at the five urban secondary schools in Bangladesh. We used item 8 from the Student Experience Survey, item 8 from Teacher Survey A, and the Site Coordinators' interview items 1 and 2 to answer this question.

Table 4. Response patterns to item 8: Students' perception of science teaching in Bangladesh

Students' Perception Regarding Science Teaching		Response Patterns (%) 1	2	3	4
TCS	We listen to teachers give lecture-style presentations	0	6.4	17	76.6
	We read our science textbooks and other resource materials	4.3	6.4	17	72.3
	We memorize science facts and principles	2.1	17	34	46.8
	We take notes during our observations	8.5	23.4	14.9	53.2
	We watch the teacher demonstrate an experiment or investigation	6.4	42.6	23.4	27.7
	We memorize the answers given by the teachers for taking exam preparation	14.9	4.3	31.9	27.7
SCS	We use scientific formulas and laws to solve problems	2.1	14.9	21.3	61.7
	We relate what we are learning in science to our daily lives	0	27.7	38.3	34.0
	We work on problems on our own	6.4	42.6	29.8	21.3
	We explain what we learned to other students and teachers	10.8	34	38.3	17.0
	We do science experiments in small groups	19.1	34	23.4	23.4
	We design or plan an experiment or investigation	25.5	36.2	23.4	14.9

Note. [a] 1 = Never, 2 = Few Lessons, 3 = About Half the Lessons; [4] = Every or Almost Every Lessons

Scaled item 8 in the Student Experience Survey elicited respondents' evaluation of SCS and TCS. The mean and standard deviation scores confirm that, on average teachers use TCS (M = 3.22, SD = 0.47) more frequently than SCS (M = 2.71, SD = 0.66). The large effect size (η^2 = .89) shows that the difference in the mean scores of SCS and TCS is not negligible; proportionally more students reported science teachers' use of TCS.

More students reported that they listened to lecture-style presentations (n = 36, 76.6%) and read textbooks and resource material for every and/or almost every lesson (n = 34, 72.3%) (see Table 4). We used a Kruskal- Wallis test to determine if there was a statistically significant difference across grade levels and type of strategy. We found a statistically significant difference in students' reported access to SCS across three different grade levels (Middle school, n = 11; Junior high, n = 23; Senior high, n = 13), X2 (2, n =47) = 6.46 p = .04. The junior-most group (Middle school) had a lower median score (Md = 12) than the other two groups. The senior-most group (Senior high) had a higher median score (Md = 20) than the group in between (Junior high), which had a medium value of 17. We did not note a statistically significant difference across the three grade levels and TCS. These findings confirm that students of all grade levels reported similar frequency of TCS; however, students of higher grades experience SCS more frequently than students in lower grades.

We used NVivo to engage in typological and interpretive analysis (Hatch, 2002) of students' open-ended responses to item 13 in the Student Experience Survey, teachers' open-ended responses to item 9 in Survey B, and Site Coordinators' responses to interview questions 1 and 2. The qualitative data corroborated the numeric results. Students reported a lack of opportunity to participate in hands-on activities due to limited resources at their school. One student said, "science apparatus handling was challenging as it was new to me" (School A, Student Experience Survey). Another added, "the IBL project was the first-ever science experiment we did on our own...of course with the help of our teacher...following all the lab rules precisely" (School B, Student Experience Survey).

Teachers' comments are consistent with student-reported data. Teachers' responses to item 7 in Survey A highlighted a strong preference for the lecture method (n = 20, 100%). They justified their choice in a variety of ways. Mr. Tapon attributed this preference to cultural norms. He said, "this has been the preferred way to teach in our country. Most students have grown up learning in school through this method. Also, this method is most effective in completing the syllabus or a topic within the allotted time duration of a class period" (School B, Survey B). Others echoed similar sentiments, "It is easy to teach all students in a short time. It is easier to discuss elaborately and easy to manage a large class" (Mr. Kabir, School A, Survey B).

Site coordinators described factors related to resource allocation that propelled teachers to use the lecture method. Mr. Rashid pointed out that class-size could range from '70 to 80 students" and the "lack of science equipment and laboratories" (Site coordinator, School D, Interview, September 23, 2020). Mr. Hunnan noted that teachers "are badly in need of training" (Site coordinator, School E, Interview, October 29, 2020). Ms. Tania faulted school authorities for the lack of SCS. She said:

> Teachers' opinions are not always essential for the authorities. This is a barrier for us. Motivated teachers want to do something for the sake of the student's interest, but we are not allowed to do it. 10 to 20% of teachers always try to do something new, and others do not. (Site coordinator, School E, Interview, September 25, 2020)

Influence of IBL Project on Students' Content Knowledge and Attitudes

The 20 teachers engaged 109 students in two IBL activities during a period of five months. Both IBL activities - the model project designed by the project director and the second one designed by teachers and student-teams included the use of the scientific process. Research question two explored the influence the IBL project had on students' content knowledge in hypothesis formulation, experimentation, and creating real-life connections and attitudes.

We used data from four different sources to answer this question: the five open-ended questions in the Student Experience Survey (Item 9, 11a-11d), open-ended questions from Teacher Survey B (item 3), site coordinators' interview data (items 4, 5, and 7), and four Zoom session transcripts. We present the results in the following four subsections: knowledge of hypothesis formulation, knowledge of experimentation, knowledge of real-world connection, and attitude toward science.

Knowledge of Hypothesis Formulation

Item 9 of the Student Experience Survey required students to formulate a hypothesis. We used NVivo to generate numeric data by classifying each response as 'correct' or 'incorrect.' Next, we used the numeric data to run a series of Chi-Square Tests of Independence to examine the association between categorical dependent variables: hypothesis formulation and categorical independent variables: gender, grade levels, and types of curricula.

1. We noted that 73.3% of the girls formulated hypotheses correctly, compared to only 26.7% of the boys. However, a Chi-Square Test of Independence revealed that gender was not significantly associated with students' formulation of hypothesis (1, n = 47) = 1.051, p = .305.
2. We observed that many more junior high school students formulated hypotheses correctly (n = 16, 59.3%) as compared to their middle school (n = 6, 22.2%) and senior high school counterparts (n = 5, 18.5%). However, the Chi-Square Test of Independence revealed that grade level was not significantly associated with hypothesis formulation (2, n = 47) = 3.34, p = .189.
3. We observed that many more students at schools with a British curriculum formulated hypotheses correctly (n = 22, 81.5%) compared to those at schools with a National curriculum (n = 5, 18.5). We found a statistically significant association between schools' curriculum and hypothesis formulation (2, N = 47) = 8.56, p = .003. The effect size for this finding, *Phi, was* moderate to large, 427.

Site coordinators and teachers were pleased when students showed initiative. For example, Mr. Hannan said he was happy when 'students proposed their own interests for the second phase and explored their hypothesis for IBL' (Site coordinator, School C, Zoom session 4, 26 June 2020). Similarly, Miss Rozina said, 'we were told teachers could design the IBL activity, but my students wanted to design their own project and came up with a number of hypotheses' (Teacher 1, School D, Zoom session 2, 11 May 2020).

Knowledge of Experimentation

Items 11 a and c of the Student Experience Survey required students to briefly describe how they used the scientific method with the two IBL activities. We used NVivo to quantize the qualitative data; we used a 1 for responses that were based on 'limited knowledge' and 2 for responses based on 'advanced knowledge.' Next, we used the numeric data to run a series of Chi-square Tests of Independence to examine the association between categorical dependent variables: experimentation and categorical independent variables: gender, grade levels, and types of curricula. The descriptive statistic revealed a larger number of students from British curriculum schools demonstrated advanced experimental knowledge (n = 23, 76.7%) than in National curriculum schools (n = 7, 23.3%). We noted knowledge of experimentation has a statistically significant association with school curriculum (2, N = 47) = 5.92, p = .015. The effect size for this finding, Cramer's V, was moderate .355. We did not find a significant association between experimentation and grade levels (2, N = 47) = .958, p = .620, and gender (2, N = 47) = 1.051, p = .305.

Teachers and students described the benefits of students' active engagement with scientific experiments. Miss Rabeya said, 'students get little or no scope to do science experiments of their own whereas this project gave them the opportunity to work with freedom' (School C, Survey B). Moonmoon, a Zoom session student-participant succinctly stated, 'We learned how to collect and accurately analyze data, how to handle apparatus correctly, and how to conduct experiments safely' (School C, Zoom session 2, 18 May 2020). Mr. Nazmul was impressed with the students' attitude towards lab activities. He said, 'students realized the necessity of following rules and regulations in the lab. They were capable of figuring out how to go through an investigation to complete it' (School A, Zoom Session 2, 11 May 2020).

Knowledge of Creating Real-life Connections

We used students' open-ended responses to items 11 b and d from the Student Experience Survey to determine if they were able to create real-world connections between topics taught and daily life. We used NVivo to quantize this qualitative data by assigning a 1 to responses that were "unclear or ambiguous" and 2 to responses that were "partially or fully correct." Next, we used the numeric data to run a series of Chi-square Tests of Independence to examine the association between categorical dependent variables: creating connections and categorical independent variables gender, grade levels, and types of curricula. Our data violated the assumption; to address this, we ran a Likelihood Ratio Chi-square Test of Independence. We found that type of curriculum had a statistically significant association with creating connections with daily life (2, $N = 47$) = 6.534, $p = .010$. The effect size for this finding, *Phi*, was moderate .375. A larger number of students from British curriculum schools were able to create connections ($n = 12$, 29.3%) compared to those who followed the National curriculum ($n = 12$, 29.3%).

Students made real-world connections at different stages of the project. This is reflected in the illustrative comments drawn from three different sources.

> Model IBL has shown me that all scientific experiments and knowledge above average is significantly relevant to our surrounding environment since all objects around us obey scientific laws. For instance, I now know that it is better to have raw lemon juice than processed drinks, as it has a higher vitamin C content. (Student 11, School D, Student Experience Survey)

> Students who were confused with the topic in the lecture understood fully. They became more interested in studying physics, increased confidence, and could relate the theory with practical life. (Miss Nilima, School B, Teacher Survey B)

> Students collected information about the advantages and disadvantages of fast food and about homemade food …they found that homemade food is better…and they tried to motivate those students who usually used to eat fast food regularly. So, I think these are the successes. (Miss Tania, Site coordinator, School E, Interview, September 25, 2020)

Attitude toward Science

We analyzed 111 meaning units related to students' changes in attitude. Of these, many references came from Zoom sessions ($n = 73$), and the rest were from interview and survey data ($n = 38$). Students described how curious and enthusiastic they were during the project. During one of the Zoom sessions, Maliha, a student participant, said:

> To be very honest, I could have never imagined that I would spend my free time, my free classes, my break times in the lab at my own will without any instruction from any teacher, and that is because, I guess, we were very curious and excited about it. (School A, Zoom Session, May 18, 2020)

Teachers confirmed that the students were motivated, which in turn inspired them too. For instance, Miss Samia said, 'competition between all participating teams triggered excitement. Moreover, the students try to do better than others' (School D, Survey B). Mr. Shimanto, a site coordinator, described the attitudinal change in students, 'the project enhanced their leadership skills, they were capable of implementing their new ideas' (School C, Interview, December 18, 2020). Teachers and site coordinators also reported a noticeable difference in students' behavior. The IBL project transformed the way students interacted with teachers, used the library, and retained information. Miss Shimin said:

> Students gained a better understanding of the subject matter being taught. They were inspired to work on a particular topic that they wished to learn by asking relevant questions and doing their own research to get the answers. They were motivated to pursue education through this method. (School D, Teacher Survey B).

Students echoed similar sentiments, '... that was the first time I went into my school library for research on something; usually, I go there to gossip with my friends. We spent our free time in the laboratory and computer lab searching online' (School A, Zoom Session 3, May 18, 2020). Miss Shahida reported that students' practical lab experience enhanced content knowledge. She said, 'I observed a difference between traditional learning and IBL. IBL provides a lot of scope for learning. Students gain theoretical knowledge through experiments' (Site coordinator, School A, Zoom Session 2, May 11, 2020). In addition to positive changes, student respondents also described challenges which will be discussed in the following section.

Challenges Identified by Students

Research question three explored challenges students encountered while participating in IBL activities and how they overcame them. We used NVivo for typological and interpretive coding of responses elicited by item 13 of the Student Experience Survey and Zoom session three, which included several student participants. We organized the 53 meaning units related to challenges into four categories. Two categories related to laboratory procedural hurdles: experimentation and observation-interpretation.

In most cases, students described challenges related to experimentation, like the illustrative comment below (n = 31, 66%):

> We had to maintain accuracy, which was a bit frustrating. As we maintained accuracy, it took a long time for us to complete the experiment because the result wasn't coming as it was supposed to. In this case, the blue-black solution took a long time to turn colorless…we had to stir and stir. (Student 10, School B, Student Experience Survey)

They also described challenges related to observation and interpretation, like the illustrative comment below (n = 10, 26.28%):

> The most challenging part, in my opinion, was the part where we had to record data in our record books. Sometimes they were not what we expected them to be, so we had to redo our experiments to find out what's wrong. And those times of data collection were the most challenging. (Student 6, School A, Student Experience Survey)

Some students described communication as a challenge which is very common in developing countries. For example, one said, 'My most challenging part is to talk or speak in English. I'm not good at English, so this is very challenging' (Student 33, School E, Student Experience Survey). Another said, 'it was to think critically' (Student 29, School D, Student Experience Survey). Some overcame problems like this by 'communicating frequently with my teachers, friends, teammates, etc.' (Student 29, School D, Student Experience Survey).

Several students described schedule management as a major challenge; this is reflected in the illustrative comment below:

> It is difficult to manage time for the IBL project after school and coaching time.
> The most challenging part of the IBL project was that the daily routine of the members of our group didn't match, so it was hard to make time for inquiry. (Student 15, School D, Zoom Session 3)

Of the 47 students, 13 reported that they reached out to their teachers for assistance. Others reported they repeatedly tried to solve problems on their own. Their attempt to do this did not go unnoticed. Mr. Rashid said:

> IBL helps overcome the mental inertia of students. They can explore in a learning session and progress at their own pace. Many students gave us a stare like, "you are asking us to do our own thinking?" Is it going to be like this from now onward? This was very interesting to observe and watch them progress. (Site coordinator, School D, Zoom Session 4, June 26, 2020)

Influence of IBL Project on Students' Desire to Pursue Higher Education in Science

Research question four explored students' motivation and desire to pursue further education in science. Analysis of survey item 6 of the Student Experience Survey revealed that many students expressed an interest in pursuing a career in science (n = 41, 87.2%). In the absence of pretest data, we cannot conclude that the IBL project influenced their decision. Nevertheless, multiple teachers described students' renewed interest in science after participating in the IBL project. For example, one of the physics teachers, Mr. Mohammad, said, 'students who were confused with the topic understood fully. They became more interested in studying Physics' (School A, Survey B). Similarly, Miss Akthari said, 'by the end of the IBL project, students became more science-oriented; this satisfied me as a teacher' (School B, Survey B).

Data Quality and Limitations

Given that the second author played a dual role as project director, we employed multiple methods to enhance the validity and reliability of quantitative data and the trustworthiness of qualitative data. A doctoral student with 20 years of teaching experience in Bangladesh validated the three surveys for clarity and readability. We re-administered Survey A in person when it became apparent that teachers had difficulty with electronic surveys and were unfamiliar with the difference between IBL and demonstrations. Machado, in the USA, used Qualtrics to administer Survey B to teachers; she anonymized the data before sharing it with Nahar in Bangladesh. We used Google Forms to collect survey data from students. We converted item 8 of the Student Experience Survey into two subscales. The Cronbach's alpha value of each subscale is TCS (.529) and SCS (.722). Similarly, we enhanced the trustworthiness of qualitative data by transcribing the data ourselves, employing intercoder reliability, creating and using a codebook with fidelity (Hatch, 2002), and using memoing and peer debriefing during the analysis and manuscript preparation phase (Edmonson & Irby, 2008). This study can be improved by addressing the limitations. The internal consistency of some of the subscales in the Student Experience Survey can be improved by adding additional items. The low response rate of survey respondents (43.12%) due to extenuating circumstances is a major limitation of this study. This limitation can be overcome by using incentives to increase the response rate.

Discussion and Implication of Findings

There is evidence to show that teacher-centered practice can change school culture and instructional practice over time when teachers are provided with ongoing training and support (Akhter et al., 2019). The literature confirms that TCS are more prevalent in Bangladesh (Talukder et al., 2021). Scholars attribute this trend to teachers' lack of training (Akhter et al., 2019), students' exam-oriented learning style (Khanum, 2020), and lack of resources (Jony, 2016). There is limited literature to show that teachers receive training over an extended period in Bangladesh. This small, grant-funded project provided 20 teachers, 109 students, and five site coordinators with an opportunity to experience, first-hand, some of the benefits of using SCS over an extended period. Our survey and interviews data confirmed these issues continue to exist at schools that offer a British and National curriculum. Students reported that they had limited opportunities to practice SCS. Both teacher and site coordinators confirmed that teachers were limited by class size, resources, and limited support from authorities. Teachers gravitated toward the lecture method because it helped them build theoretical concepts, maintain discipline, and complete the syllabus in time. Site coordinators indicated that teachers' attitudes impeded their willingness to experiment with SCS. While a large majority of schools, both in developed and developing countries, may not be able to increase resources without government funding and/or grants, administrators can evaluate current teaching practices, develop policies that require student engagement, provide teachers with school-based professional development training, encourage teachers to use SCS and reward outstanding performance.

A wide array of research shows that students in developing countries benefit by engaging in IBL (Abdi, 2014; Wang & Gao, 2021; Zhao et al., 2021). Our findings are consistent with these studies. Our qualitative findings confirm that students appreciated the freedom to learn by exploring content from different sources; laboratory books, online search, etc., and expressed their satisfaction with achievement in content knowledge. Additionally, girls outperformed boys in hypothesis formulation even though it was not statistically significant. Given the low survey response rate due to the pandemic, it is difficult to make a clear judgment about the significance of the results. Nevertheless, the short-term outcomes confirmed that science teachers who receive training and support over an extended period could implement SCS quite effectively.

The literature is inconsistent in terms of the relationship between institutional quality and science achievement. For example, Broer et al. 's (2019) study in Hong Kong, which included high-quality and low-quality schools, showed that students have equal learning opportunities despite socioeconomic disparity. Conversely, Bodovski et al. (2020) and Mousumi and Kusakabe (2017) reported that better quality schools produce higher learning outcomes. Our findings are consistent with Bodovski et al. (2020) and Mousumi and Kusakabe's (2017) findings. We observed that students at British curriculum schools achieved higher scores than their counterparts in National curriculum schools in hypothesis formulation, experimentation, and making connections with real life. As evident from Table 3, inequalities exist. Students who attend British curriculum schools have access to many more resources because parents pay anywhere between $1,350 and $2,500 per year. These resources are used to equip laboratories and libraries. This finding suggests that inequities may exist in terms of both curriculum and instruction. Additional research, with a larger sample size, will shed light on the inequities that exist and the ways in which curricular and instruction can be modified to address this.

Consistent with Aulia et al.'s (2018) study, our respondents displayed positive attitudes towards science. Teachers and site coordinators at both British and National curriculum schools noticed positive changes in students. This included higher motivation, enthusiasm, leadership skills, confidence, and excitement. Kaçar et al.'s (2021) meta-analysis of 30 studies conducted in Turkey from 2000 to 2020 revealed that IBL enhanced the learning of secondary level students more than higher secondary students. Conversely, we found the students' acquisition of content knowledge did not differ across grade levels. This finding is encouraging; it confirms that students in different grade levels can benefit from IBL.

Scholars identified several challenges students face while participating in IBL activities. These included difficulties conducting experiments and dealing with data (Gormally et al., 2009) and frustration in the absence of an appropriate scaffold (Levy and Petrulis, 2012). Consistent with Gormally et al.'s findings, our student respondents experienced some difficulty with laboratory experiments and data collection procedures. Consistent with Levy and Petrulis's findings, our students indicated that these obstacles were directly connected with their lack of exposure to hands-on activities in school. Our students also found it difficult to engage in critical thinking and express their opinions, a limitation that is deeply rooted in Bangladeshi culture. Many of these challenges can be reduced if teachers start to use IBL more frequently.

Gibson and Chase (2002), who surveyed summer camp students from 1992 to 1997 to study the influence of IBL activities on students' motivation to continue with science, reported that students who experience more inquiry activities, especially laboratory experiments, are more interested in choosing science careers. The majority of our survey respondents showed an interest in continuing higher studies in science by the end of the project. Given the small sample size and the lack of a pretest, the findings should be generalized with caution. Schools should consider replicating this study with larger sample size. They should also identify additional ways to encourage students to pursue a career in science.

Both quantitative and qualitative findings revealed that a shift from TCS to SCS enhanced students' ability to hypothesize, experiment, and make real-life connections. It is our hope that the 20 teachers at each of the five participating schools continue to use the science toolkits they received and locally available, inexpensive materials to design and model IBL. Innovative practice can be contagious. We also hope that teachers expand the scope of the IBL projects they design to include additional teachers and students. We also hope that administrators, both in developed and developing countries, use this study and the book chapter that provides additional detail about the professional development we provided teachers (Machado & Nahar, 2021) as illustrative examples to guide the design and implementation of similar long-term projects that foster a higher level of student engagement in science classrooms.

Scientific Ethics Declaration

This project has been approved by the Indiana University of Pennsylvania Institutional Review Board for the Protection of Human Subjects (IRB Number: 19-221 - EXT).

The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors.

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