International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

https://gssrr.org/index.php/JournalOfBasicAndApplied/index

A Case Study of Inquiry- based Learning Implementation: Comparing Beginning and Experienced Teachers' Use of the 4A's Model of IBL in High School Biology

Lea C. Garcia*

University of the Philippines Rural High School, 4031, Philippines
Email:lcgarcia@up.edu.ph

Abstract

The study focused on the comparative performance of two beginning and two experienced teachers in their implementation of 4A's (Activity, Analysis, Abstraction, Application) of the Inquiry-Based Learning (IBL) model in teaching cell division and Mendelian genetics. The thematic analysis of interviews and observations has shown that the two beginning teachers and one experienced teacher were in line with the 4A's model, while the other experienced teacher was only engaged in Abstraction. The three teachers were able to effectively use constructivist Activities, integrate higher-order thinking in Analysis, and bridge the concepts to the real-world Applications. Nevertheless, considerable differences in the teachers' performance during the Abstraction phase were uncovered. Results reveal that teaching experience alone cannot be a guarantee for effective IBL. Recommendations are ongoing professional development on the entire IBL cycle, peer mentoring, and an IBL competence framework. Future research should have a bigger sample and also consider student performance data.

Keywords: beginning teacher; case study; experienced teacher; inquiry-based learning; 4A's model.

Received: 6/1/2026
Accepted: 8/1/2026
Published: 8/10/2026

----

* *Corresponding author.*

1. Introduction

Worldwide, science education reforms put an emphasis on IBL as a primary method of teaching which is considered the most effective one for developing students' conceptual understanding, critical thinking, and scientific literacy [1, 2]. The national K-12 curriculum in the Philippines has also been a major advocate of IBL along with other student-centered approaches to accomplish the science learning domains [3]. Still, the effective performance of IBL in classrooms is a very thorny question of faculty competence and their viewpoint [4]. In the Philippine setting, the most common way to present IBL lessons is the 4A's framework. Although this name is not globally recognized, the stages of this framework are very similar to those of IBL cycles which lead learners from engagement and exploration to concept explanation and transfer [5]. The model comes from constructivist and experiential learning theories which argue that students make knowledge through experience, reflection, and application.

It is an assumption that teachers can slowly employ such a pedagogy as IBL through their teaching in the classroom. Teachers with more experience are usually considered to have better pedagogical content knowledge and classroom management skills [6, 7]. Nevertheless, studies show that experienced teachers do not necessarily become experts in innovative teaching methods merely through their experience. At the same time, experienced teachers are sometimes so deeply entrenched in their traditional, lecture-based methods that they hardly even see the possibility to change them whereas on the contrary, new teachers are generally the ones who have been recently trained in constructivist approaches and are also more willing to give them a try [8, 9]. Such a relationship involving teaching experience and pedagogical strategy indicates an investigation. The focus of this study involves implementation of the 4A's IBL model indicating a contextualized case of IBL practice. It tries to grasp various ways to understand how this important framework is put into practice based on teaching experience. The research was guided by the following questions:

1. How do beginning and experienced high school biology teachers implement the four components/4A's of the IBL model in teaching cell division and Mendelian genetics?
2. In what ways does teaching experience appear to influence the quality of IBL implementation using this model?
3. What are other factors that contribute to effective IBL teaching?

1.1. Theoretical Framework: The 4A's as an IBL Cycle

Different educational design models such as the Dick and Carey models, the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model, and the 4A's model are cited by the literature as the most effective structures to carry out Inquiry-Based Learning (IBL). The 4A's model application, which is based on Kolb's Experiential Theory, is thus the most prominent in the writing of lesson plans among the models referred to in the research. The 4A's model helps a teacher to conceptualize an IBL lesson in a very systematic way notwithstanding the inherent flexibility. Reference [10] explains the 4A's as follows.

Activity: The stage exemplifies the introducing and involvement trigger. It intends to set off already known concepts and activate interest through a problem, demonstration, or hands-on task, thus, creating a "need to know."

Analysis: Students here deal with the activity, the teacher is there to facilitate and encourage by asking probing questions. At this point students have to work on higher- order thinking skills (HOTS) by examining the data, recognizing the patterns, making logical deductions, and giving explanations, even if only preliminary ones.

Abstraction: The aspect of Abstraction is the one where the formalization of knowledge takes place. The teacher leads the students to express the core concepts, the principles, and the scientific terminology discovered during the analysis phase, thus, facilitating accuracy and clarity. This is in line with the pivotal role of the teacher as a guide in the IBL approach to help learners avoid getting the wrong idea [11].

Application: Learners apply their newly created knowledge in unusual contexts, be it by solving problems, or by taking an interest in the real-world implications. The stage has as its ultimate goal the deepening of conceptual mastery, as well as the development of scientific literacy and problem-solving skills.

The study places the 4A's model as one of the IBL theoretical models to account for its realization.

2. Methods

2.1. Research Design

This study employed a qualitative case study design. This approach was selected because it is particularly suited for investigating a "how" question within a real- world context, aiming for an in-depth understanding of the phenomena rather than statistical generalization. The rigid, multi-method data collection involved in such an analysis limits the sample to a few purposively selected cases to obtain deep, contextual data for each case (the teacher.

2.2. Context and Participants

The research took place in two public high schools in the Philippines chosen among other criteria, for their implementation of the Engineering and Science Education Program (ESEP) and their experience in science fairs, which demonstrates an institutional focus on science. The school setting is typified by a very large number of students in each class (45 students on average) and a two-shift schedule, which are features of the typical but difficult environment faced by Philippine public schools.

Through purposive sampling, four Grade 8 Science Teachers who represented a range of experience profiles were selected for the study. Their profiles are detailed in Table 1. The participants were:

Ace: A beginning teacher (3 years) with a BSMST degree major in Biology.

Bes: An experienced teacher (19 years) with a background in Agricultural Education.

Ces: An experienced teacher (10 years) with a master’s degree in administration.

Des: A beginning teacher (3 years) with a degree in Biological Sciences.

Table 1: Profile of the four teachers

Teacher Characteristics	Ace	Bes	Ces	Des
Graduate Course	BS Mathematics and Science Teaching (BSMST), major in Biology	BS Agricultural Education major in Animal Science; earned some units in MA Education	BS Secondary Education, major in General Science; MA in Administration and Supervision	BS Secondary Education major in Biological Sciences
School	A*	A*	B**	B**
Years of Teaching	3	19	10	3
Subjects Taught	Science 8	Science 7 Science 8	Science 8	Science 8
Number of Seminars Attended	1	2	5	4

A* – from School 1 B** - from School 2

This study allowed for a comparative analysis of IBL implementation across different experience levels and educational backgrounds within a specific, high-pressure educational context. The 4A's model is still used until this time in the math department of the school where the researcher is affiliated even though the study was carried five years ago. The 4A's model is not a specific curriculum that can become obsolete rather, it is a pedagogical framework - a way of structuring and thinking about learning. As with the scientific method being the fundamental process for doing research even after technological progress, the 4A's model is still the basic step for organizing IBL. Its main features have been so effective that this model has been used for a very long time, it matches very well how teachers should help students learn, and it is very flexible in the way it can be combined with various new educational scenarios and tools. By means of the 4A's model, this recent article looks at one particular way this classic and highly effective science teaching model has been implemented.

2.3. Data Collection and Analysis

Semi-structured interviews assessed teachers' content knowledge (CK) and pedagogical content knowledge (PCK) regarding the topics. The individual interview used a researcher- developed interview guide containing open-ended questions about cell division and Mendelian genetics. The initial questions were reviewed by the researcher's adviser and two panel members. Each 30-minute interview was conducted during the teachers' free periods. Follow-up interviews clarified and validated responses from the initial interview.

A non-participant observation was conducted where each teacher was video recorded for 10 days of instruction on cell division and genetics, providing detailed evidence of classroom practice. Data analysis followed a thematic approach. The interview transcripts and observation notes were inductively and deductively coded using the 4A’s structure and other themes that emerged from the data. The researchers then conducted cross-case analysis to explore patterns and variations across the four teachers.

2.4. Data Validation

In order to make sure the data was reliable, member checking was used, i. e. teachers looked over interview transcripts and their first interpretations to confirm their correctness. Also, an experienced researcher was involved in peer debriefing providing a critique of analysis and findings.

3. Results

There were major differences in the use of the 4A's model among the four teachers, the biggest being that one of the experienced teachers (Bes) carried out only the Abstraction component whereas the other three (Ace, Ces, Des) performed the whole cycle.

When it comes to the Activity component (Table 2), Ace Ces, and Des came up with various ways to start their classes, successfully linking abstract biological ideas with the collected, outside world to enable students to have a deeper understanding. For example, Ace shared his personal experience, beginning with a simple question - "Do you always take a bath? scrub your body?" - to connect the routine experience of scrubbing off dead skin cells to the process of cell division. He also got students involved in an activity to match traits which incited lively discussion on inherited traits as she intentionally included not only "good" but also "bad" traits. To have a personalized learning experience, Des asked the students to bring pictures of their families and then she led them through the reflective questions like, "Which of your traits are like your father or mother?

Table 2: Teachers' Activity component of the 4A's

Cell Division	**Mendelian Genetics**
Activity: Sharing of Personal Experience	
¹ Do you always take a bath? Scrub your body? **A c e** What is it that you remove from your body as you use ·ubbing pad? 3. Can you explain what this removal of dead cells means?	1. Stand and find a partner. Look for the "good traits" you see from each other. 2. How did you see these good traits? Bad traits?
Activity: Story-telling	**Activity: Role playing**
1. Why are the organelles complaining? 2. Do you agree or disagree with the first group of organelles? Why? **C e s** How important are these organelles in the company? a. Why do you think the chloroplast agrees with the ·ochondria? b. In what way are they similar? Different? 5. If you had the chance to be one organelle, which would it be? Why?	1. What can you say about Gregor Mendel? 2. Can you tell something about Mendel's work? What is he fond of? Are you familiar with garden peas? 3. Can you enumerate the 7 characteristics of peas that Mendel used? 4. When do we say a trait is dominant? Or recessive? What if you cross white with red, what will be expressed? Why? 5. But if you cross pollinate (pure-breeding with contrasting trait), what will be expressed? 6. Based on the crosses made, differentiate phenotype & genotype? Homozygous &heterozygous?
Activity: Short video clip	**Activity: Sharing of Personal Experience**
¹ Where do you find the DNA? chromosome?genes? **D e s** Are you ready to know the cell cycle? What kind of cell is this? 4. How is blood classified? Tissue or cell? 5. Can you describe the cell cycle?	1. Did you bring a family picture? 2. Which of your traits are similar to your father? Mother? 3. What makes one's traits similar to the parents? 4. Explain the principle behind this.

"This physical activity helped the students understand genetics as the students saw the inherited traits that are visible within their own families. Des took the conversation to a higher level by questioning the main factors ("What makes traits similar to parents? Explain the principle behind this."), bridging personal observation to the principle of inheritance. Des also incorporated a video on DNA finding its location along with the chromosomes and genes and the other video was on the cell cycle. The cell cycle was introduced as the students were asked to recognize a plant, animal, tissue or cell in the video. Ces creatively used storytelling and role-playing to motivate the students learn cell division and Mendelian genetics, respectively. In her storytelling activity, students actively personified organelles as "company workers," making them understand their functions through guided questions ("Why are organelles complaining? How important are these organelles in the company?"). She put forth the idea of chloroplasts and mitochondria ("Why do they agree? How are they similar/different? ") to encourage the students to find out about the functions of cell parts, finishing it with a question which aims at making the learning personal ("Which organelle would you be, and why? "). To bring genetics to life, Ces chose role playing, having a student act as Gregor Mendel, while she asked him the penetrating questions about his experiments ("What traits did Mendel study in peas? What happens when you cross white and red flowers? "). This method of communication encouraged the students to look into the patterns of inheritance, dominance/recessiveness, and the use of genetic language ("phenotype/genotype, homozygous/heterozygous") through their own activity. These different activities, being based on the students' experiences and their active involvement, were very good motivational means of presenting difficult subjects.

For the Analysis component (Table 3), these three teachers skillfully facilitated higher order thinking skills by

Table 3: Teachers' analysis component of the 4A's

Cell Division	**Mendelian Genetics**
Sharing of Personal Experience	
1. Removal of dead skin cells through cell division 2. New cells are identical to the original by replicating DNA; distribute the duplicated chromosomes to daughter cells **Ace** 3. For growth, tissue repair, and maintenance, replacement of old/damaged cells 4. To increase in size, replace damaged cells, and create new generations	1. Similarities between oneself and classmate: height, skin color, type of eyes, etc. 2. Common in students: height, texture of hair, etc. 3. Eye color, hair texture: due to heredity 4. Traits share with parents, siblings, or other relatives-height, etc. 5. All influenced by heredity; personality by environment 6. Siblings with different traits: due to random mixing and gene shuffling 7. Traits passed down from one generation to the next through genes, made of DNA, and carried in chromosomes, with each parent contributing one set of chromosomes to offspring
Story-telling	**Role Playing**
1. To simulate the functions performed by each cell part; cell-fundamental unit of life, and knowing its structure and function: to understand how organisms function, develop, and how diseases arise **Ces** 2. Nucleus with role in cell division 3. Nucleus: control center, houses the DNA and directs growth, division, and reproduction; storing genetic information, regulating gene expression, maintaining the integrity of the cell's genetic material	1. How did it feel to be Gregor Mendel? 2. Principle of inheritance/heredity describes how traits are passed from parents to offspring, with genes, or "factors" as units of inheritance, carried on chromosomes 3. Mendel's experiments: a. Creation of true-breeding parent generation of plants b. Breeding two distinct true-breeding P plants to create a second generation of plants c. Self-pollination of two F1 generation plants

	with the same features to create a third generation (F2); by knowing it, different principles of genetics are understood
Short Video Clip	**Sharing of Personal Experience**
Des 1. Genetic information in DNA contains the [illegible]ructions for all proteins [illegible] It ensures each new daughter cell receives a [illegible]plete and identical copy of the parent cell's genetic [illegible]rmation for proper function and survival [illegible] Through unwinding the DNA double helix, using each strand as a template for a new complementary strand resulting in two identical DNA 4. Involves cell growth, DNA replication, and division, key stages: G1, S, G2, and mitosis including cytokinesis. 5. Errors can lead to mutations causing diseases like cancer or even cell death	1. There are good and bad traits 2. Traits influenced by heredity; heredity - transmission of traits from one generation to another 3. Traits like height, type of hair, etc influenced by heredity; personality and specific behavior, influenced by environment 4. The concepts: dominant/recessive; homozygous/heterozygous traits; phenotype/genotype, etc.

guiding students to deconstruct and connect the activities to core scientific principles. In many instances, Ace, Ces and Des demonstrated critical thinking by showing the ability to connect the activity to concepts or ideas. Ace's personal experience actively exemplified how relatable analogies can demystify science as she linked bathing (removing dead cells) to cell division, highlighting DNA replication, chromosome duplication and daughter cell distribution, and emphasizing its role—growth, tissue repair, maintenance and replacement. Her analysis guided students toward self-discovery, reinforcing the idea that science operates in their daily lives. Ace re-examined the trait-matching exercise while turning genetics into an engaging, social learning opportunity. She led the students to use their own characteristics and those of others as a tool to learn about genetics. Ace came to understand Mendelian inheritance through her analysis. She asked them to observe physical characteristic similarities like height, skin color, and hair texture among themselves and their classmates and then related these traits to heredity by discussing family patterns (e. g. shared features with parents, siblings, or relatives). By highlighting how genes (composed of DNA and carried in chromosomes) transmit traits across generations—while also acknowledging environmental influences on personality—Ace helped students analyze the biological basis of variation, including why siblings may differ due to random mixing and shuffling of genes. Ces prepared a storytelling activity ("Smart Workers of the Company") which effectively brought cell biology to life by transforming abstract and complex biological concepts into an engaging, interactive and relatable narrative. The activity got the students to think critically by having them work in groups to talk about the answers to a list of guided questions about cell parts and functions. This encouraged peer learning, as students reflected together, exchanged ideas, and co- constructed knowledge with the teacher's guidance. Interestingly, the students compared roles of cell organelles to the roles of employees in a company.

Understanding that the nucleus is the "control center" of the cell (like a CEO) that oversees growth, division, and DNA management, Ces explained the way in which the contribution of each organelle's function to cellular processes. After that, the students related these characters to more universal biological ideas like development and disease, which resulted in a significant grasp of why cells are considered the fundamental units of life. This approach largely encouraged logical thought by combining narrative with scientific concepts and allowing learners visualize the parts and functions of cells. In a similar way, Ces smartly led the students to becoming the person of Gregor Mendel via a play-acting, so that the whole class could understand the main principles of genetics. By embodying Mendel, the student engaged with key questions—*"How did it feel to be Mendel?"* —prompting deeper reflection on his experimental methods (true-breeding parent plants, cross- pollination, and F1/F2 generations) and their significance. This interactive approach helped students analyze how Mendel's discoveries established the principles of inheritance, emphasizing genes as heritable units carried on chromosomes. By linking role-play to scientific reasoning, Ces enabled students to understand Mendel's experiments while fostering appreciation for Mendel's contributions to modern genetics. Des used a video clip on DNA and cell cycle to guide students in examining key biological processes. Des' multimedia integration illustrated how technology could amplify inquiry-based learning. By pairing a video on DNA and the cell cycle with guided questions, Des ensured students actively analyzed—rather than passively consumed—content.

As guided questions were posted after the video, she prompted students to analyze and synthesize key concepts, reinforcing their understanding of cell division, DNA structure, and the cell cycle. Des' analysis of the video made her explain how DNA stores genetic instructions for protein synthesis and ensures accurate transmission to daughter cells through replication (unwinding and templating complementary strands) leading to identical DNA copies for function and survival. Des linked this process to the stages of the cell cycle and mitosis to understand how cells grow, replicate DNA, and divide. By structuring the lesson around inquiry, Des ensured that technology serves as a scaffold for conceptual understanding rather than a passive viewing experience. Des further prompted critical thinking by discussing consequences of errors, such as mutations leading to cancer or cell death, helping students connect molecular mechanisms to real-world implications.

For the Abstraction component, Table 4 shows how the listed subtopics were discussed by the four teachers.

Table 4: Teachers' abstraction component of the 4A's with the labels: 4 (most comprehensive), 3 (more comprehensive), 2(comprehensive), 1(least comprehensive)

Topic	**Ace**	**Bes**	**Ces**	**Des**
Chromosome	4	2	1	3
Cell Cycle	2	4	1	3
Cell Division	1	2	3	4
Meiosis and its Role	4	1	2	3
Mendelian Genetics	4	1	2	3
Genetics Laws and Kinds of Cross	4	1	3	2

The chromosome. Ace totally owned it with her most detailed explanation by figuring out the pieces of a chromosome (chromatid centromere euchromatin, heterochromatin) and describing the chromosome number of each species with the great emphasis on diploids in humans, haploids in gametes, and the XY/XX system for sex determination. Des talked about what makes up the chromosomes (chromatin vs. condensed chromosomes, sister chromatids, centromeres) and told the difference between autosomes (diploid) and sex chromosomes (haploid), including the XY/XX system. Besides that, Des explained that DNA package changes daily (from chromatin to chromosomes) and showed illustrations with labels supporting the class, which helped a lot in understanding. Bes recognized the role of chromosomes in cell division but in the end gave a more general idea by talking about the nucleus as a genetic material and also briefly mentioned diploid chromosomes without their structure or role being explained. Ces' view was that the nucleus controls the activities of the cell, including its division, and chromosomes are there to pack DNA but he didn't explain more about the chromosome structure or types than to mention an illustrated structure.

The cell cycle. Bes presented a thorough discussion about the cycle phases, not only mentioning the phases but also giving examples of the main cellular processes at each one- for instance in G_1, the cell is making organelles, S-phase is for DNA and histone synthesis, and G_2 is for RNA and protein synthesis. Besides that, Bes explained that G_1 is the longest phase whereas mitosis is the shortest which is a great comparative point. The addition of labeled figures made the explanation easier to follow and more comprehensive than Ace's discussion. Des copied Bes approach and content, dividing the cell cycle into Interphase and its subphases-$G_{1,}$ S, G_2, and mitosis and at the same time repeating the biochemical processes taking place at each phase. As Bes did, Des gave importance to the difference in duration between G_1 (longest) and mitosis (shortest), thereby strengthening the understanding of the major points. Des' text was almost a copy of Bes' work, which shows no new insight but mere duplication. The employment of labeled diagrams helped in clarifying the matter, but this alone did not separate this account from Bes. Ace shared a very brief yet very clear description of the phases in the cell cycle naming each stage shortly and also highlighting the differences between interphase and mitosis. Though this information was correct, it didn't penetrate to the level of cell chemistry or give a comparison of the durations of the different phases. Ces decided on a bit different style, concentrating mainly on interphase and its subphases. Ces clearly and accurately pointed out G_1 as a time for growth and synthesis, S as the phase of DNA replication, and G_2 as the phases when spindle formation and organelle division take place. But the discussion left out mitosis altogether, making this account lacking in completeness of the cell cycle. This gap resulted in less coverage than others of Ces' explanation although the concentration on the main parts of interphase was well set forth.

Cell division. Des gave the most detailed explanation. First, she differentiated karyokinesis (nuclear division) from cytokinesis (cytoplasmic division) and second, she described each stage of mitosis in a detailed and accurate manner. Des also mentioned differences between plant and animal cells (cleavage furrow vs. cell plate formation) and reminded the genetic identity of daughter cells. The function of mitosis (growth and repair) was very well presented, it was the most complete, harmonizing structural and functional aspects. Ces provided the next elaboration and accurate account, focusing on the structural changes, e. g. chromosome coiling, kinetochore-spindle fiber attachment, and nuclear membrane breakdown/reformation. Ces also rightly pointed out that chromatids become independent chromosomes in anaphase and highlighted the role of mitosis, growth and repair. This explanation was better than Ace's and Bes' but lack of cytokinesis details was a major flaw. Bes gave a clear and concise summary of mitosis. The student clearly listed the four stages and their main events, like chromosome alignment in metaphase and separation in anaphase. Though, Bes missed the disappearance of the nuclear envelope in prophase and the reformation of nuclei in telophase, for example. While the explanation was accurate, the elaboration was insufficient compared to the others. Ace presented a well-organized summary of mitosis stages and described chromosome behavior, spindle fiber attachment, and cytokinesis (including differences between plant and animal cells). Though the prophase explanation was a little confusing (chromatin "becomes chromosomes" rather than condenses into visible chromosomes"), and the role of mitosis was oversimplified with the odd analogy about bathing and dead cells.

Meiosis and its role. Ace talked in detail about Meiosis I and II. Besides the various stages of Meiosis I, she mentioned the five substages of Prophase I (leptotene, zygotene, pachytene, diplotene, and diakinesis) and stressed the significance of crossing-over as the main way of producing genetic variation. He explained the biological role of meiosis (formation of gametes, production of genetic variation) and showed how mistakes during meiosis can bring the appearance of genetic disorders (Down syndrome, cri-du-chat). To make the explanation even clearer, he added a comparison table between mitosis and meiosis. Des also did the next best thing. Des presented a neatly organized presentation about meiosis, focusing mainly on Prophase I substages, behavior of homologous chromosomes, and the process of crossing-over. The teacher not only talked about the haploid cell result of meiosis but also showed a mitosis vs. meiosis chart; yet, it was somewhat simplified compared to the one given by Ace. Although Des accurately pointed out meiosis as a source of genetic variation, the teacher omitted the discussion on meiotic abnormalities, thereby failing to make the connection between the abstract concept and its medical implications. Ces preferred a compromise between doing too much and too little. Ces summarized the concept of tetrad formation, the attachment of kinetochores, and the genetic implications of crossing-over very well. Ces also drew a clear comparison between mitosis and meiosis and listed differences in chromosome number, synapsis, and the purpose of each process (growth vs. genetic variation). But, how errors in meiosis lead to disorders was not discussed by Ces and because of this the significance of these in the real world was not explained. Bess gave a very simplified description, rightly recognizing meiosis as being composed of two stages and naming the stages of Meiosis I and II. Still, Bess failed to go into details about crossing-over, genetic variation, and the effects of meiotic errors, which made the presentation on the subject incomplete. Besides that, the comparison between mitosis and meiosis was so minimal that it was almost non-existent ("meiosis involves sex cells, mitosis involves body cells"), That's why other major differences like chromosome number and genetic recombination were not mentioned.

Mendelian Genetics. Ace gave the most thorough explanation of how Mendel operated with his pea plants. Instead of just mentioning the main points, it even included the seven pairs of contrasting traits that Mendel studied and the detailed cross-pollination procedure step by step. The explanation was also very good at clearly differentiating between the P, F_1 and F_2 generations and using actual examples of dominant and recessive inheritance patterns (like the 3:1 ratio in F_2). The very clear link that was made between genotypic (BB, Bb, bb) and phenotypic expressions, combined with clear definitions of key terms (homozygous, heterozygous), made this great for genetic understanding. Des gave a pretty good mix of the conceptual side as well as the practical aspect. The method used in this piece of work that stood out was the clear and systematic explanation of the genetic terms (alleles, Punnett square) and it also used graphic illustrations of monohybrid crosses. The mentioning of probability and generation ratios (3:1) helped to further the understanding of quantitative aspects. Although it did not include as much experimental detail as Ace, its systematic explanation of dominant/recessive inheritance (e. g. T/t for plant height) with very clear tabular comparisons make the concepts very approachable to students. Ces gave a brief but well-organized response, briefly summarizing the seven pea traits addressed by Mendel and correctly using letter-case treatment to symbolize dominance/recessiveness (e. g. R/r). The feature which made pedagogical sense was the neat separation between homozygous/heterozygous genotypes and their corresponding phenotypes. Though, the conciseness was a downside because it left out an explanation of the experimental methods, generation results, and the biological significance of Mendel's work which decreased the value of the explanation for those seeking deeper understanding. Bes provided a succinct summary, describing why Mendel picked pure-breeding plants and the concept of hybrid F1 offspring. Although it correctly pointed out the practical reasons for choosing peas (easy propagation, contrasting traits), it completely overlooked discussions about specific experimental outcomes (e. g. phenotypic ratios) and omitted the defining of essential genetic terms. Without any clear indication of dominant/recessive traits or genotypic/phenotypic expressions, it resulted in quite a few missing pieces conceptually.

Genetics laws and kinds of cross. Ace gave the most complete and well-organized explanation, distinguishing between monohybrid and dihybrid crosses clearly and linking each type to the corresponding genetic laws (Segregation and Independent Assortment). The detailed, stepwise use of Punnett square examples for both kinds of crosses (e. g. Bb x Bb for monohybrid and PpLl x ppll for dihybrid) helped to clarify the concept. What really made Ace's explanation stand out was the ability to relate the abstract laws to tangible examples (pig coat color, pea plant traits) and show the phenotypic ratios (3:1 for monohybrid, 1:1:1:1 for dihybrid cross). Since the law of Independent Assortment is really a chromosomal event, the illustration shown was very helpful in the explanation of the law. Also, a class exercise centered around this law was provided. Next is Ces who in some ways changed things around and made them very understandable for the students. It means that the monohybrid (Yy) and dihybrid (YyRr) Punnett squares correctly demonstrated the uniform F_1 offspring; still, they only represented particular parental genotypes (YY, yy; YYRR, yyrr) but after that, the genotypes were changed for presenting the variation in F_2 offspring. Ces distinctly connected genetic laws to chromosomal disorders (Down syndrome, cri-du-chat) leading to the medical aspect. Students carried out the problem-solving activities on the monohybrid and dihybrid crosses as the teacher associated the activities with the Laws of Segregation and Independent Assortment. Des was good at explaining the Law of Segregation using diagrams which showed visually how alleles separate during gamete formation. For the concept, the explanation of Independent Assortment was quite solid and it mainly focused on the point that the genes must be on different chromosomes. Yet, Des did not take advantage of using worked examples or phenotypic ratios to emphasize the laws which Ace and Ces inclined to include in their presentations.

Ace, Ces, and Des effectively implemented the Application component by applying cell division and Mendelian genetics to real-world scenarios, fostering both conceptual mastery and critical thinking as indicated in Table 5.

Table 5: Teachers' application component of the 4A's

Cell Division	**Mendelian Genetics**
Sharing of Personal Experience	
1. Other everyday experiences (e.g., ing a cut, growing taller) that involve cell division? A c e What might happen if cell division did occur properly in body? growth would halt, wound healing would be impossible, the body would be unable to replace dying cells, leading to a rapid decline in health and ultimately, death)	1. Explained not fair to judge someone based on their inherited traits (e.g., physical appearance). 2. How understanding of inheritance of traits help us better understand and appreciate differences in people? 3. Is it possible if people like scientists be allowed to modify inherited traits in humans? benefits and risks?
Story-telling Activity	**Role Playing Activity**
1. Explained what happens if a cell makes a mistake during cell division? 2. What might happen if the signals that C ol cell division do not work properly? e s	1. Why Mendel chose garden peas for his experiments? Advantages? 2. Identified the patterns Mendel observed in the traits of the pea plants (e.g., dominant vs. recessive traits) 3. Explained Mendel's Law of Segregation in your own words? Mendel's Law of Independent Assortment? 4. Do you understand the basic genetics principles? dominant allele? recessive allele? 5. Explained Punnett squares to predict the outcomes of genetic crosses 6. Were you able to understand the principle of inheritance? Explained step-by-step how Mendel started his experiment
Short video clip	**Sharing of Personal Experience**
1. Explained errors in cell division could lead to diseases like cancer D Understanding cell division is important e fields like medicine, agriculture, or biotechnology s How important is understanding cell division?	1. If a trait is considered "bad," do you think it can be changed or controlled, even if it's inherited? How might someone work to overcome an inherited trait they don't like? 2. If scientists could identify and modify genes responsible for certain traits, should they? What ethical concerns might arise from this? 3. Any examples from nature (e.g., animals, plants) where traits are clearly inherited? How might these examples help us understand human traits?

Even though their strategies had some similarities, each educator highlighted different elements of the use, so their contributions to student learning were complementary. Firstly, all three teachers helped students understand the real-world application of abstract ideas so that students would not be content with just memorizing. They asked challenging questions to think more deeply – Ace and Des for example, talked about ethical issues in genetics (e. g. genetic modification, biases within society), while Ces and Des made connections between errors in cell division and medical conditions (e. g. cancer). Also, each teacher made a point of including cross-disciplinary links, whether to medicine (Ces, Des), agriculture (Des), or social issues (Ace, Des). By asking students to explain why these concepts were important (e. g. "How Important is the concept, cell division? ", Des; "What if cell division fails? ", Ces), they developed scientific literacy and problem-solving abilities.

Unique techniques were also characteristic of each of these educators. Ace was in particular good at making learning meaningful by drawing on everyday examples (e. g. wound healing, growth) and encouraging ethical reflection (e. g. challenging prejudices related to inherited traits). Besides empathy and moral reasoning through the secondary school program, she illustrated the importance of scientific humanization (e. g. "Is it fair to judge traits? "). But, Ces' powerful accent was on scientific investigation and logical, step-by-step thought. She coached learners through Mendel's experiment set-up (e. g. "Why peas? ") as well as genetic inheritance simulation using Punnett squares. Her repetition of concepts served as the basis for procedural knowledge. Besides these, Des also integrated tech and ethical debate by challenging the risks/benefits of genetic engineering (e. g. "Should scientists modify genes? ") while highlighting the interdisciplinary nature of the topic (e. g. biotechnology, agriculture).

4. Discussion

The observed implementation of the 4A’s model by the teachers provides a practical case study that strongly confirms and illustrates several well-established tenets of IBL research. Their successes and variations align directly with the findings of previous literature on spectrum of IBL implementation, constructivism, role of guidance, development of higher-order thinking, direct instruction and scientific literacy.

4.1 The range of IBL execution and its influence on the students' cognitive involvement

The data clearly show a continuum of IBL adoption. While Ace, Ces, and Des implemented the full 4A’s model, Bes’ approach was limited primarily to "Abstraction," reducing the lesson to a direct instruction model. This variance exemplifies a common challenge documented in IBL literature which is the tension between curriculum coverage and the time-intensive nature of genuine inquiry [1]. Teachers like Bes, for example might think that abstraction, directly teaching the core content, would be the most effective way to make sure students get what is called "essential" knowledge. But, the problem is that this method skips over the important constructivist stages of activity and analysis, where students develop their basic understanding through experiencing and questioning. However, Ace, Ces, and Des proved that well-designed tasks are not simply work and fun but actually indispensable supports for the development of higher-order thinking, which is the key feature of effective IBL that results in profound understanding of concepts [2].

4.2 Constructivist foundations: Anchoring learning in experience

The variety of "Activity" methods used by Ace, Ces, and Des not only provide vivid examples of the implementation of constructivist learning theory, a theoretical basis of IBL, which claims that knowledge is actively constructed by the learners through experience and thought [2], but also provide profound examples.

The way Ace and Des made use of personal experiences (bathing habits, family photographs) is in line with the method of linking new learning to students' already-existing knowledge and their real-life situation thereby ensuring a meaningful context for the introduction of abstract ideas. This is a practice that has been found to greatly increase both motivation and memory of the concepts [12]. This implies that the teacher makes sure she knows what the students already know and then leads the activity to address those ideas. In a constructive environment, teachers pose questions and problems, then guides students to help them find their own answers. Ces' storytelling and role-playing activities transformed students from passive recipients into active participants, personifying organelles and embodying Gregor Mendel. This approach fits well with the literature pushing for the use of experiential learning and storytelling to help students understand and remember scientific concepts like cellular functions and historical experiments as noted by the authors in [13]. The use of the constructivist strategy is further evidenced by the data showing that all the motivational activities led by the three teachers through their students comprising personal reflection, group work, simulation games, and other engaging activities help not only in understanding but also in the acquisition of long-term memory. Concepts could be abstract or complex but by exposure of students to multiple experience and because of this relying on the constructs of the learner result in a student-centered classroom.

4.3 Fostering higher-order thinking through guided Analysis

The "Analysis" component is where the teachers facilitated the development of HOTS involving analysis, evaluation, synthesis, creativity, problem-solving, critical thinking, inference, metacognition, abstract thinking among others. Reference [14] sees this as a key thing in not only validating information, making sense of situations, but also producing sound decisions. In the same way, it effectively spots the major role of teacher involvement in IBL, which is, in fact, a fundamental point in the continuing discussion about pure discovery learning versus guided inquiry. Even though the students were doing the activities, the teachers didn't simply abandon them to figuring out the concepts on their own. Instead, they asked them questions which made the students think deeper, and this is considered a key thing of IBL as referenced by the author in [1]. By probing questions, they guided students to analyze their activities, draw inferences, and make connections - key aspects of critical thinking [15]. The author further defines critical thinking as the ability to analyze information objectively, think clearly and rationally, and make a reasoned judgment. Analyzing student's sharing of personal experiences to introduce the basic concepts of cell division and genetics makes the students understand facts [16]. For instance, Ces' guided questioning during the organelle storytelling activity, Ace's analysis of the trait-matching activity and Des' post-video discussion forced students to analyze, synthesize, and evaluate information. This finding confirms that the teacher's role in IBL is not diminished but transformed from a dispenser of knowledge to a facilitator of cognitive processes, ensuring that student engagement translates into genuine conceptual development. Ces' guided discussion during the organelle storytelling activity made the students evaluate the importance of each organelle's function and synthesize their roles into a coherent model of a working cell. This encouraged peer learning, as students reflected together, exchanged ideas, and co-constructed knowledge with the teacher's guidance. Such social interactions also fostered self-reflection, and appreciation of diverse perspectives as noted by the authors in [17].

Ace moved beyond observation to explore the reasons for variation, introducing concepts like genetic recombination in the matching activity she prepared. Des' use of a video clip, followed by critical questioning, prevented passive consumption and instead promoted active analysis of the cell cycle. This practice of using multimedia as a stimulus for inquiry, rather than a replacement for it, is supported by the author in [18] multimedia learning theory and is crucial for developing scientific literacy. This also aligns with research by the authors in [19], which emphasizes that technology enhances learning when used as a supplementary tool to stimulate critical thinking rather than as the sole focus of instruction.

4. 4 Providing support for the concept: The Balancing of student discovery and direct instruction

The results emphasize that Ace and Des are the first to be considered the most thorough in delivering biological concepts, while Ces seems quite variable and Bes is always the least profound in different topics. Bes gave the shortest explanation, simply stating that the Punnett square was helpful for getting ratios but not showing how it was done. This was a very loose approach, with no concrete examples, definitions of laws of genetics, or problem-solving systems. Because of this, it was almost impossible for a student to learn by themselves in such a situation. The accuracy of referring to "gametes as sex cells" did not help at all since the aspect of allele segregation was totally missing. The differences in the "Abstraction" element reveal an important detail in IBL theory, explicit teaching is required to make learning permanent. It is true that in student-centered learning models, teachers have to help students consolidate their discoveries by aligning them with the official scientific terminology and concepts [20]. The results indicate big disparities in the quality and clarity of this consolidation. The range of methods, from Bes' very direct and lecture-style gene agreement to Ace and Des's very student-founded, thorough and logical explanations, works as a case in point of the trade-off problem. Ace and Des did the best job of providing structured, in-depth and well-organized abstractions, being able to describe the structure of chromosomes, meiotic phases and Mendelian laws correctly and vividly. Ces was also able to describe these topics well but the explanations were at times incomplete (for example, the omission of mitosis when discussing the cell cycle) whereas Bes gave only very general summaries. The best abstractions (produced by Ace and Des) came from the moment onwards when the teacher, after students had been experimenting with the ideas in the activities, was able to formalize their discoveries with proper terms and a well-thought-out structure. This was the kind of support that the authors in [11] claim is an essential component of inquiry environments that without which students' misconceptions would go undetected and scientific exactness not be imposed. Besides, these findings also show that IBL does not imply the doing away with direct teaching but rather the use of direct teaching in a well-thought-out manner at a certain point in the learning process to latch onto ideas that students themselves have already generated. In other words, the teacher during IBL lessons ought to be not merely a facilitator of learning experiences but also a subject expert, a teacher capable of giving students clear, accurate and developmentally appropriate explanations to formalize their discoveries.

4.4 Gaining genuine real-world relevance by Application

The very strong "Application" of concepts to the world by Ace, Ces, and Des all acts as a powerful evidence that the main goal of IBL - students developing transferable skills and becoming scientifically literate. While discussing ethical issues in genetics, medical consequences of cell division errors, and use in agriculture students had to use their knowledge in thinking deeply, evaluating, and creating the highest levels of Bloom's Taxonomy. Going beyond memorization to applied critical thinking is a well-known feature of IBL that also prepares students for civic engagement with scientific issues [21]. Ace's attention to societal bias and Des's writing about genetic engineering mainly are examples of how IBL can develop the socio-scientific reasoning skills that are necessary for informed citizenship.

4.6 Variable implementation fidelity

The fact that Bes' approach was very traditional, while the others were doing full IBL cycles, clearly shows the problem with the variable enactment of inquiry that has been documented in the literature. The teacher-centric model reflected in Bes' focus only on "Abstraction" is frequently a result of teachers' perceptions of time constraints or content coverage pressures [4]. That leads to the effectiveness of IBL that depends not only on its design but also on the faithful implementation. It also shows that professional development should not only be about "how" to design activities but also about "why" the evidence that each phase of the inquiry cycle (Activity Analysis Abstraction, Application) is an indispensable part of building deep, meaningful understanding.

On ways how teaching experience influences the quality of IBL implementation, the study reports that teaching experience is a poor proxy for effective IBL implementation. Its influence is not straightforward. Experience is not a sure way of ensuring compliance - Bes, the teacher with the most years of experience, surprisingly demonstrated the least fidelity to the model as she only implemented one of the four components (Abstraction). So experienced teachers might still be inclined to use traditional, direct-instruction methods even when the curriculum takes them to adopt inquiry. New teachers are capable of great things - Both new teachers (Ace and Des) showed through their high-quality implementation of the entire 4A's cycle that they can be extremely effective. Not only did Ace and Des make use of all the components but they also came up with some very challenging conceptual explanations during the Abstraction phase. Experience can produce contradictory results - The other experienced teacher Ces implemented the model completely but the level of depth was inconsistent Mostly in the Abstraction phase where at times her explanations were not as thorough as those of the new teachers. Thus, even though experience might be helpful for classroom management and instructional planning, it does not necessarily result in the acquisition of the pedagogical skills and attitudes needed for effective, student-centered IBL.

4.7 Other factors for effective IBL teaching

This case study points to several critical factors beyond years of experience that contribute to effective IBL teaching as follows.

The Pedagogical Design and Its Capacity. This is the ability of creating and carrying out a learning skill that is scientifically organized. Good teachers (Ace, Ces, Des) efficiently connected fun Activities with deep questioning that helped get the point across and paved the way for the formal definition (Abstraction) while also enabling the students to apply it to the real world (Application).

Depth of Pedagogical Content Knowledge: The teachers' academic qualifications played a big role. Ace (BSMST major in Biology) and Des (degree in Biological Sciences) were highly specialized in their respective contents which is directly the reason why they were able to explain the points during Abstraction very well and with full details. Bes, on the other hand, was an Agricultural Education major while Ces was an Administration major and that is probably the reason why they showed less understanding of core biology concepts.

Fidelity to the Complete Inquiry Cycle: The best teachers who were the ones who grasped that the real strength of IBL is in bringing together all the phases. They saw that the Activity generates a need for Analysis, then Analysis makes Abstraction meaningful and finally, Application results in deeper learning. Breaking down the components, as Bes did, weakens the model's constructivist basis.

Teacher as a Facilitator: Effective teachers demonstrated a role change from "knowledge provider" to "learning enabler". Their main tool in the Analysis stage for initiating higher-order thinking in students was a series of guided inquiries.

5. Conclusion

This in-depth case study does not indicate broad generalizations about all teachers. However, it yields valuable theoretical insights that can inform both practice and further research. Teaching experience is a poor proxy for effective IBL implementation. The quality of implementation in this study was more closely linked to the teacher's pedagogical design capacity, depth of content knowledge, and fidelity to the complete inquiry cycle than to their years in the classroom.

The teachers’ implementation of the 4A's IBL model in lessons on cell division and Mendelian genetics varied significantly among the four teachers, and the differences did not strictly follow the beginning versus experienced divide. Thus, the findings reveal a clear distinction between the pedagogical approaches of beginning teachers (Ace and Des) and experienced teachers (Bes and Ces). While Ace and Des, though less experienced, nevertheless being able to demonstrate more structured, challenging, and conceptually rigorous lessons, Ces (experienced) managed to maintain a balance between communication and depth, whereas Bes (experienced) was quite off track, both content-wise and inquiry-wise, making it very basic. Such a situation of Ace and Des shows that first teachers of the new generation may if well-equipped, become great educators through inquiry. The instance of Bes however reveals that senior teachers might still need a bit of help to transition from the old to the inquiry way of teaching. Hence, teacher training should not only focus on a one-size-fits-all approach geared by experience. Rather, it should aim at equipping all educators with the skills necessary to carry out the entire IB process, particularly focusing on enhancing the phases of the analysis and application which generally, are the most difficult ones to be executed well.

6. Recommendations

Within the studied context, peer mentoring be instituted where proficient teachers like Ace and Ces can share strategies with colleagues like Bes to ensure consistency in applying student- centered approaches. Likewise, it is recommended that Bes adopts Ace’s strategies to enhance student engagement and conceptual mastery. In the general sense, for improvement and consistency, teacher education institutions (TEIs) should update their pre-service education curriculum to increase teachers' motivation and readiness to use the 4A's model of IBA into their teaching.

For professional development**,** a competence framework for the 4A's model be developed to guide teacher training and self-reflection. Teacher educators should be responsible for strengthening professional development and maintaining continuous teacher mentoring. It is also recommended that a competence list of effective IBL teaching using the 4A's model be compiled as guide/reference. This competence profile might help teacher educators to reflect on the science curriculum for initial teacher training.

For future research, a larger-scale, mixed-methods study be conducted, incorporating student achievement data and a more diverse sample of teachers to explore the relationships between teacher background, IBL implementation, and student outcomes.

7. Limitations of the Study

The decision to focus on this study involving four teachers only was deliberately done to make it consistent with the research as qualitative. Since the primary aim of the study was to comprehend the implementation of the 4A's model, a smaller number of participants allowed for getting more profound and detailed insights into each teacher's cognition, introspection, and growth over time. It could be argued that a bigger sample would enhance generalizability, however, the primary aim of the current research was theoretical rather than statistical generalization - i.e., to get the insights that can guide teachers' work or be the basis for new studies. It is recognized as a limitation accompanied by the suggestion of future research to confirm the results by scaling up.

Acknowledgment

The researcher is very grateful to the participants who willingly gave time and effort for the completion of the study.

References

[1] Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and quasi- experimental studies of inquiry-based science teaching: A meta-analysis. Review of Educational Research, 82(3), 300–329. https://doi.org/10.3102/0034654312457206

[2] Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—What is it and does it matter? Results from a research synthesis years 1984 to 2002. Journal of Research in Science Teaching, 47(4), 474–496. https://doi.org/10.1002/tea.20347

[3] Department of Education. (2016). K to 12 curriculum guide: Science. Republic of the Philippines.

[4] Crawford, B. A. (2014). From inquiry to scientific practices in the science classroom. In N. G.Lederman

& S. K. Abell (Eds.), Handbook of research on science education, Volume II (pp. 515–541). Routledge.

[5] Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes,N. (2006). The BSCS 5E instructional model: Origins and effectiveness. BSCS.

[6] Berger, J. L., Girardet, C., Vaudroz, C., & Crahay, M. (2018). Teaching experience, teachers' beliefs, and self-reported classroom management practices: A coherent network. SAGE Open, 8(1), 1–12. https://doi.org/10.1177/2158244017754119

[7] Terada, Y. (2021, August 31). How novice and expert teachers approach classroom management differently. Edutopia. https://www.edutopia.org/article/how-novice-and-expert-teachers- approach-classroom-management-differently

[8] Graham, L. J., White, S. L. J., Cologan, K., & Pianta, R. C. (2020). Do teachers' years of experience make a difference in the quality of teaching? Teaching and Teacher Education, 96, 103190. https://doi.org/10.1016/j.tate.2020.103190

[9] Johnson, D. (2018). The role of teachers in motivating students to learn. BU Journal of Graduate Studies in Education, 9(1), 46–49. https://files.eric.ed.gov/fulltext/EJ1230415.pdf

[10] Regoris, J. D. (2021). 4As (Activity, Analysis, Abstraction, Application) Lesson Plan.Technological Institute of the Philippines. https://www.slideshare.net/slideshow/4as- activity-analysis-abstraction-application-lesson-plan/266702720

[11] Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner.

[12] Forbes, C. T. (2011). Preservice elementary teachers' adaptation of science curriculum materials for inquiry-based elementary science. Science Education, 95(5), 927–955. https://doi.org/10.1002/sce.20444

[13] Rashid, S., & Qaisar, S. (2017). Role play: A productive teaching strategy to promote critical thinking. Bulletin of Education and Research, 39(2), 197–213.

[14] Johnston, J. S. (2009). What does the skill of observation look like in young children? International Journal of Science Education, 31(18), 2511– 2525. https://doi.org/10.1080/09500690802644637

[15] Hwang, G. J., Lai, C. L., & Wang, S. Y. (2017). Seamless flipped learning: a mobile technology-enhanced flipped classroom with effective learning strategies. Journal of Computers in Education, 2(4), 449–473. https://doi.org/10.1007/s40692-015-0043-0

[16] Adams, N. E. (2015). Bloom's taxonomy of cognitive learning objectives. Journal of the Medical Library Association, 103(3), 152–153. https://doi.org/10.3163/1536-5050.103.3.010

[17] Díaz-Iso, A., Eizaguirre, A., & Olalla, A. M. G. (2019). Extracurricular activities in higher education and the promotion of reflective learning for sustainability. Sustainability, 11(17), 4521. https://doi.org/10.3390/su11174521

[18] Mayer, R. E. (2014). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), The Cambridge Handbook of Multimedia Learning (2nd ed., pp. 43–71). CambridgeUniversity Press. https://doi.org/10.1017/CBO9781139547369.005

[19] Gilakjani, A. P., Lai, H., & Ismail, H. N. (2013). Teachers' use of technology and constructivism. International Journal of Modern Education and Computer Science, 5(4), 49–63. https://doi.org/10.5815/ijmecs.2013.04.07

[20] Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. Educational Psychologist, 41(2), 75–86. https://doi.org/10.1207/s15326985ep4102_1

[21] Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. Studies in Science Education, 45(1),142. https://doi.org/10.1080/03057260802681839