semester 1

Science - I

COURSE GUIDE

Associate Degree in Education/
B.Ed. (Hons.) Elementary

2012

Higher Education Commission

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Higher Education Commission

Foreword

Teacher education in Pakistan is leaping into the future. This updated Scheme of Studies is the latest milestone in a journey that began in earnest in 2006 with the development of a National Curriculum, which was later augmented by the 2008 National Professional Standards for Teachers in Pakistan and the 2010 Curriculum of Education Scheme of Studies. With these foundations in place, the Higher Education Commission (HEC) and the USAID Teacher Education Project engaged faculty across the nation to develop detailed syllabi and course guides for the four-year B.Ed. (Hons) Elementary and two-year Associate Degree in Education (ADE).

The syllabi and course guides have been reviewed by the National Curriculum Review Committee (NCRC) and the syllabi are approved as the updated Scheme of Studies for the ADE and B.Ed. (Hons) Elementary programs.

As an educator, I am especially inspired by the creativity and engagement of this updated Scheme of Studies. It offers the potential for a seismic change in how we educate our teachers and ultimately our country's youngsters. Colleges and universities that use programmes like these provide their students with the universally valuable tools of critical thinking, hands-on learning, and collaborative study.

I am grateful to all who have contributed to this exciting process; in particular the faculty and staff from universities, colleges, and provincial institutions who gave freely of their time and expertise for the purpose of preparing teachers with the knowledge, skills, and dispositions required for nurturing students in elementary grades. Their contributions to improving the quality of basic education in Pakistan are incalculable. I would also like to thank the distinguished NCRC members, who helped further enrich the curricula by their recommendations. The generous support received from the United States Agency for International Development (USAID) enabled HEC to draw on technical assistance and subject-matter expertise of the scholars at Education Development Center, Inc., and Teachers College, Columbia University. Together, this partnership has produced a vitally important resource for Pakistan.

PROF. DR SOHAIL NAQVI
Executive Director
Higher Education Commission
Islamabad

How this course guide was developed

As part of nation-wide reforms to improve the quality of teacher education, the Higher Education Commission (HEC) with technical assistance from the USAID Teacher Education Project engaged faculty across the nation to develop detailed syllabi and course guides for the four-year B.Ed. (Hons) Elementary and two-year Associate Degree in Education (ADE).

The process of designing the syllabi and course guides began with a curriculum design workshop (one workshop for each subject) with faculty from universities and colleges and officials from provincial teacher education apex institutions. With guidance from national and international subject experts, they reviewed the HEC scheme of studies, organized course content across the semester, developed detailed unit descriptions and prepared the course syllabi. Although the course syllabi are designed primarily for student teachers, they are useful resource for teacher educators too.

In addition, participants in the workshops developed elements of a course guide. The course guide is designed for faculty teaching the B.Ed. (Hons) Elementary and the ADE. It provides suggestions for how to teach the content of each course and identifies potential resource materials. In designing both the syllabi and the course guides, faculty and subject experts were guided by the National Professional Standards for Teachers in Pakistan 2009 and the National Curriculum 2006. The subject experts for each course completed the initial drafts of syllabi and course guides. Faculty and student teachers started using drafts of syllabi and course guides and they provided their feedback and suggestions for improvement. Final drafts were reviewed and approved by the National Curriculum Review Committee (NCRC).

The following faculty were involved in designing this course guide: Zubaida Kifayat, F.G. Elementary College for Women, Skardu; Bilqees Batool, F.G Elementary College for Women, Skardu; Alia Ayub, Sardar Bahadur Khan Women University, Quetta; Kifayat Khan, Hazara University, Haripur; Waheed Akbar, Hazara University, Mansehra; Mohammad Shaban, GCET Rawalakot; Shahida Iqbal Nizami, GCET (F) Muzzafarabad; Anwar ul Haque, GCET (M) Muzzafarabad; Dr. Abdul Ghaffar, GCET Faisalabad; Muhammad Altaf, GCET Lala Musa; Riazalai Gorai, GCE (M) Gilgit; Muhammad Nasir Khan, GCE (M) Gilgit; Muhammad Iqbal, GCE (M) Gilgit ; Asghar Ali Khan, GCET Kasur; Khalid Mahmood, GCET Shahpur Sadar; Tahseen Lateef, GECE (M) Lyari; Ali Asghar Khaskheli, GECE (M) Hyderabad; M. Faheem Kausar, GCEE Quetta; Rubina Masood, GCEE Quetta; Parveen Ashraf, GCET (F) Rawalakot; Shahnaz Bibi, GCET (F) DG Khan; Naeema Rasool, GCET Bahawalpur; Muhammad Siddique

Kalwar, GECE (Male) Sukkur; Naureen Mumtaz, University of Education, Lahore; Bushra Bano, GCEE (F) Sibbi; Banafsha Khan, GCEE, Pishin; Fouzia Ghias, Fatima Jinnah Women University, Rawalpindi; Liaquat Hussain, Gomal University; Zubair Ahmed, University of Sindh; Mumtaz Hussain, F.G Elementary College for Women, Skardu; Liaqat Ali, F.G Elementary College for Women Skardu; Dr. Rafaqat Ali Akbar, IER University of Punjab; Muhammad Nadeem, RITE DI Khan; Muhammad Sharif, RITE(M)Kohat ; Humaira Abbasi, University of AJK; Safia Khatoon, GECE(W) Hyderabad; Ch. Khalid Mahmood, GCET Shahpur Sadar.

Subject expert guiding course design: Bettina Dembek, Senior Curriculum/ Instructional Design Associate, Education Development Center.

Date of NCRC review: 3 March 2012

Reviewers: Dr. Rizwan Akram, University of the Punjab, Lahore; Dr. Parveen Munshi, University of Sindh; Dr. Rehana Masroor, Allama Iqbal Open University; Dr. Nabi Bux Jummani, International Islamic University.

Table of Contents

Syllabus

SCIENCE I

SCIENCE I

Year/semester

Year 1, Semester 1

Duration (hours)

48 hours (16 weeks)

Credit value

3 credits

Prerequisites

Matriculation (with a science subject)

Course description

This course will refresh and strengthen Student Teachers' subject-matter knowledge. It lays a foundation for the pedagogical content knowledge also required to effectively teach general science in primary school. The course covers core concepts in physical science, life science, and earth science. Also covered are the teaching strategies and instructional approaches that best support the development of conceptual understanding of science.

Science I in semester 1 is followed by Science II in semester 3. Both courses integrate science content with science pedagogy and skill building instead of teaching them separately. Both content outcomes and process outcomes have been listed. This division in the objectives between content and process is primarily one of convenience. It allows outcomes to be adequately represented in a written document. In the classroom, content and process should always be addressed simultaneously. After completing Science I and Science II, the prospective Student Teachers will be well prepared to implement the National Curriculum in primary grades 1–5.

The Science I and Science II course materials are designed to prepare prospective primary teachers to teach inquiry science in grades 1–5. The (pedagogical) content knowledge is chosen accordingly. Prospective science teachers who want to teach science in lower secondary grades (6–8) should deepen their science knowledge further by attending additional science classes offered in year 3 and year 4 of the B.Ed. (Hons.) program.

Course outcomes

After completing this course, Student Teachers will be able to:

- describe the interdependence of ecosystems and the organisms within and how changes affect populations and the equilibrium of a system. Relate evolutionary forces to the diversity of ecosystems and of the species within them
- identify the effects of human activities and naturally occurring changes on ecosystems and the consequences of those changes

- begin to see the Earth as a system consisting of major interacting components that consistently undergo change. Physical, chemical, and biological processes act within and among them on a wide range of timescales
- describe physical and chemical properties and physical/chemical processes with a special focus on the change of state of matter and how this change relates to energy
- develop an understanding of common misconceptions about matter and particle theory
- describe a chemical reaction in the context of a rearrangement of atoms and also in the context of the formation of a new substance with new properties
- investigate the relationships among force, mass, and motion of an object or system
- apply various models to science teaching while recognizing their limitations. Prevent potential misconceptions that could result from the use of some widely used models
- read, record, and analyse data and present that data in meaningful ways.

Teaching-learning framework

Throughout this course, pedagogy is interwoven with the content development. Faculty will model inquiry teaching to Student Teachers in order for them to experience first-hand the learning and teaching of science in an inquiry way. Thoughtful discussions will follow such hands-on experiences to clarify the applied methods and expected learning. These reflections are essential because it is through these discussions that Student Teachers will gain essential pedagogical content knowledge. They will also learn how to apply this knowledge to their science teaching in elementary grades upon graduation. Discussions, reflections, and applications of pedagogical science content knowledge are critical components of Science I (and Science II). Each task prepares Student Teachers for their own teaching and enables them to modify activities to best meet the needs of their individual classrooms. For this reason, a substantial amount of time is dedicated to the teaching of specific science content in each unit of the course.

In addition to content and pedagogical content knowledge, this course is also designed to help Student Teachers develop science thinking and process skills.

After completing this course, Student Teachers will be able to:

- begin to apply inquiry to the teaching of science at the elementary level
- identify, adapt, and modify investigations that lead to conceptual understanding
- begin to design science investigations around core concepts
- begin to understand the need for learning progressions
- recognize common misconceptions and be able to respond with appropriate remediation
- use open-ended questions to assess children's conceptual understanding
- provide children with exciting science experiences that extend their natural fascination with the world and help them learn the science skills and concepts they will need in later schooling and in life
- reflect on their teaching to develop a personal approach to the teaching of science.

Semester outline

UNIT 1:	Course Overview
	Unit one gives an overview of the course and the key models, theorists, and debates in child development. Development is seen as an holistic process.
Week #	Topics/themes
1	Course overview Science in personal and social perspective The nature of science and scientific investigation (observations and inferences) Teaching of science: reflect upon the way Student Teachers learned science and how they want to teach science when they graduate

During this unit, Student Teachers will:

- discuss the nature of science and contrast science to other ways of knowing about the world
- understand the differences among results, conclusions, and inferences
- describe how science is a process rather than a product
- provide examples for the impact of science in daily life and the environment.

UNIT 2:	Populations and ecosystems
Week #	Topics/themes
2	Basic needs of living things Interdependencies of living things (symbiotic relationships)
3	Ecosystems and habitats Population growth: survival and extinction
4	Ecosystems and habitats Population growth: survival and extinction

During this unit, Student Teachers will:

- investigate the interdependence of living things (including humans) in an ecosystem
- investigate how changes in environments affect plants and animals (including humans)
- explain how adaptive characteristics of a species affect its chance for survival or possible extinction
- describe factors that limit or support the growth of populations within an ecosystem
- analyse data collected over time and explain how disruption in one part of an ecosystem can repeat throughout an ecosystem
- begin to identify the unit's underlying core science concepts for children in elementary grades
- design age-appropriate, inquiry-based activities and identify learning outcomes.

3 UNIT 3:	Diversity and adaptations
Week #	Topics/themes
5	Diversity of living things Systems of classification
6	Adaptations for survival Evolution and diversity
7	Teaching 'diversity and adaptations' in elementary grades

During this unit, Student Teachers will:

- describe the diversity of living things
- explain how adaptive characteristics of a species affect its chance for survival or possible extinction
- explain how evolution has resulted in diversity among living things
- observe fossil records and interpret them for evidence of adaptation, environ mental change, and extinction
- explain why we use classification systems and how classification systems are applied
- begin to identify the unit's underlying core science concepts for children in elementary grades
- design age-appropriate, inquiry-based activities and identify learning outcomes.

4 UNIT 4:	Earth: The blue planet
Week #	Topics/themes
8	Earth: an inhabitable planet Weather and seasons Categorizing the world by continents, biomes, vegetation zones, climate zones, etc. Introduction to maps; reading and creating simple data charts
9	Constant changes on Earth: rock cycle Rivers (erosion/sedimentation) Earthquakes and volcanoes
10	Teaching 'diversity and adaptations' in elementary grades

During this unit, Student Teachers will:

- describe the diversity of living things
- explain how adaptive characteristics of a species affect its chance for survival or possible extinction

- explain how evolution has resulted in diversity among living things
- observe fossil records and interpret them for evidence of adaptation, environ mental change, and extinction
- explain why we use classification systems and how classification systems are applied
- begin to identify the unit's underlying core science concepts for children in elementary grades
- design age-appropriate, inquiry-based activities and identify learning outcomes.

5 UNIT 5:	Force and motion
Week #	Topics/themes
11	Relationship among force, mass, and motion of an object Interaction of objects as it relates to force and linear, constant motion Graphing of motion and basic calculations of speed and average speed
12	Non-linear motion and accelerated motion (laws of motion) Graphing of non-linear and accelerated motion
13	Teaching 'force and motion' in elementary grades

During this unit, Student Teachers will:

- articulate and demonstrate the principles of motion and forces and apply them to examples of interactions between objects
- investigate the relationships among force, mass, and motion of an object or system
- conduct investigations to determine the position and direction of a moving object (and represent its motion on a graph)
- draw free-body diagrams that list all the forces acting on an object and the resulting direction of motion
- analyse the motion of objects by the established relationships known as the laws of motion
- begin to identify the unit's underlying core science concepts for children in elementary grades
- design age-appropriate, inquiry-based activities and identify learning outcomes.

6 UNIT 6:	**Properties of matter**
Week #	Topics/themes
14	Physical properties of matter, including melting point, boiling point, hardness, density, and conductivity Atoms, molecules, mixtures, elements, and compounds Introduction to the periodic table
15	States of matter: solid, liquid, gas (examples of water) Introduction to models and their limitations in science teaching
16	Teaching 'properties of matter' in elementary grades

During this unit, Student Teachers will:

- describe the diversity of living things
- explain how adaptive characteristics of a species affect its chance for survival or possible extinction
- explain how evolution has resulted in diversity among living things
- observe fossil records and interpret them for evidence of adaptation, environ mental change, and extinction
- explain why we use classification systems and how classification systems are applied
- begin to identify the unit's underlying core science concepts for children in elementary grades
- design age-appropriate, inquiry-based activities and identify learning outcomes.

Textbooks and references

Target Science: Physics by Stephen Pople

Target Science: Chemistry by Michael Clugston and Rosalind Fleming

The Teaching of Science in Primary Schools by Wynne Harlen

Inquiry: Thoughts, Views, and Strategies for the K–5 Classroom – National Science Foundation

Ready, Set, Science! Putting Research to Work in K–8 Science Classrooms – National Research Council

Taking Science to School: Learning and Teaching Science in Grades K–8 – National Research Council

Lederman, N., and Abd-El-Khalick, F. 'Avoiding De-Natured Science: Activities That Promote Understandings of the Nature of Science'.Retrieved from:

➢ http://toolbox.learningfocused.com/data/0000/0014/2125/Teaching_the_NatOSci.pdf.

'A Science Prototype: Rutherford and the Atom'. Retrieved from:

➢ http://undsci.berkeley.edu/lessons/pdfs/rutherford.pdf.

Understanding Science is a website that communicates what science is and how it works:

➢ http://undsci.berkeley.edu/index.php.

For an easy-to-understand illustration of Newton's laws of motion, refer to:

➢ http://teachertech.rice.edu/Participants/louviere/Newton/.

For information about Bloom's Taxonomy, refer to:

➢ http://www.odu.edu/educ/roverbau/Bloom/blooms_taxonomy.htm.

Course assignments

Suggested assignments are included in the unit guides of the course. Some are short-term assignments and some take several weeks to complete. A mixture of individual and group assignments is also provided.

These assignments are designed to deepen Student Teachers' learning and allow them to research and apply their knowledge to topics of personal interest. All the assignments count towards the final grade.

Examples of assignments include the following:

- Conduct an investigation on a science topic and present your findings and conclusions.
- Develop hands-on activities around a core science concept for an elementary grade.
- Write an editorial for a local newspaper on a relevant science topic stating an opinion supported by evidence.
- Plan and conduct a science activity with a group of children using the inquiry approach.

Grading policy

The university and its affiliated colleges will determine the course grading policy. The policy should be shared with Student Teachers at the beginning of the course. It is recommended that at least 50% of the final grade be determined by coursework completed by Student Teachers. Coursework may include work completed in assignments in or outside the classroom.

UNIT 1

COURSE INTRODUCTION

Unit Overview

In this first week of Science I, Student Teachers are introduced to teaching science in elementary school. They enter this course with diverse personal experiences and varying levels of science background and skills. This first week provides them with an overview of the content that will be covered in Science I. It also introduces them to skills and methods that are important for science and science teaching.

In Science I, Student Teachers study science content to deepen and expand their previous science understanding. The content is from the four science disciplines: biology, earth and space science, physics, and chemistry. All the units (2–6) follow a consistent pattern: the first two weeks provide prospective science teachers with learning opportunities to refresh and expand their own science understanding. The third week of each unit is dedicated to the teaching of science concepts in the elementary grades.

Throughout Science I and Science II, the teaching of science to prospective science teachers should model an inquiry approach. Ample opportunity should be provided for hands-on experiences, discussions, and reflections.

For most incoming Student Teachers, this inquiry approach represents a change to how they experienced science. Most incoming Student Teachers are used to reading textbooks and solving problem sets in which only one defined correct answer is teacher verified. Being asked to make observations, develop questions and hypotheses, and discuss ideas and thoughts with one another is probably new to most of them. This may require some getting used to. As you teach incoming Student Teachers, it is important to model that new behaviour and encourage them to make the transition to an inquiry classroom with you. As a starting point, you can pose open-ended questions of a higher-thinking order (e.g. using verbs of Bloom's Taxonomy) that allow for various possible answers and discussion. Good questions can make Student Teachers think for themselves and want to know more rather than reciting a fact. Those kinds of questions invite them to listen carefully to one another, to build on their peers' ideas, or to challenge them if they disagree. Science should not be presented as a discipline with a finite number of facts that need to be memorized. Rather, it is a discipline that is constantly changing as new discoveries are made. New theories are established, and old ones are revised or dismissed. Treating science like a pure delivery of facts rather than a process of inquiry does not do it justice. Instead, it sets the wrong tone for the course and for all future science teaching and learning across all grade levels.

The appeal and fascination of science and science teaching lies in inquiring about the natural world, learning how to study, and making sense of all the wonderful phenomena happening around us. Good science teaching uses this natural motivation and should be practiced throughout all grade levels.

This introductory week of Science I should also be used to set a culture of trust and collaboration in the class. Student Teachers with more advanced content knowledge should see themselves as mentors. They are partners in the process of learning and teaching science rather than Student Teachers who know it all and always answer the more difficult questions. Each one of them should have ongoing chances to participate actively in all tasks and discussions. All contributions should be treated with respect and should not be dismissed or immediately marked as wrong. Even a 'wrong response' can start a thorough discussion about a concept. If Student Teachers learn to respond in full sentences and argue their point with their peers, they engage in the process of science. Developing science skills is as crucial as studying science concepts and should be given as much attention. You will find ample examples throughout the unit guides on how the two are related and how to teach them in an integrated way.

In addition, this course combines basic ideas about the history of science, science in personal and social perspective, and science and technology. The ideas in each of these areas are not separated out in the units or dealt with individually. Instead, they are integrated, where appropriate, into the flow of the units.

Learning outcomes for this unit

Student Teachers should be able to:

- discuss the nature of science and contrast science with other ways of knowing about the world
- understand the differences among results, conclusions, and inferences
- describe how science is a process rather than a product
- provide examples for the impact of science in daily life and the environment.

Unit 1/week 1: Introduction

(**Sessions 1–3**)

Suggested activity for session 1

Introductions

In the first session, provide Student Teachers with an overview of the course and the expectations. Address any questions or concerns they might have. Use the remainder of the class to get to know your Student Teachers better and set the stage for the rest of the course.

You might want to begin by asking Student Teachers some of the following questions:

- What are your expectations for the course?
- What is your science background?
- What interests (scares) you in science?
- What do you think science is?
- Do you think it is important to learn/teach science in (elementary) school? Why?
- Are there differences (similarities) between teaching science and, for instance, teaching Urdu? Explain your opinion.
- How did you experience science in school? What do you remember fondly? What do you wish were different?

The common link among all these questions is that there is no one correct answer. They allow everyone to participate and state their opinions. They are personal questions and require no prior knowledge. However, some Student Teachers might respond using prior knowledge to better explain their points. Facilitate this conversation by trying to involve all of them as much as possible. If a small discussion develops—for instance, when two Student Teachers make two opposing statements—invite the rest of the class to think about the two statements and give their opinions. The point of these conversations is to learn more about the Student Teachers and their backgrounds. These discussions also set the tone for all future sessions. Forming an opinion, an observation, a fact, an inference, a hypothesis, and so on and defending your own statements or critiquing your peer's should be essential parts of each session. Get Student Teachers used to the idea that these science sessions should be filled with lively conversations. They should not expect you to be the only person who asks questions and verifies responses. Instead, they should also ask questions and answer one another's questions. Several answers can be requested and discussed for a single question.

Suggested activity for session 2

Observations vs. inference

Tell your Student Teachers that in today's session they will all become detectives. Their task is to carefully study three figures that show footprints at an unknown location. Then they need to come up with a possible explanation for what might have happened at that location.

Make sure each Student Teacher can see Figure 1 (see Course resources at the end of the guide for the three figures). Ask them to spend two minutes in silence carefully studying the figure to determine what kind of a story it might tell. Tell them that every detail might matter and that there might be more than one solution. Also tell them that this figure is the first of three figures. Each of the following figures will include the previous, so they do not need to copy the figures into their notebooks.

After a couple of minutes, ask each Student Teacher to write down what might have happened at that location. Make sure that all of them write a story because the stories will be used in a discussion later in the session. If they have troubling starting their story, prompt them by saying: what do the shapes look like? What might they represent? Emphasize that there are no wrong or right answers.

When most Student Teachers are done with Figure 1, reveal Figure 2 and ask them to continue their stories. Remind them not to talk to each other.

After another couple of minutes, display Figure 3 and ask them to finish their stories and conclude what happened.

When all Student Teachers have finished writing down their stories and conclusions, ask them to turn to their neighbour and share the story. Tell them to discuss each story and decide on one story and conclusion. If they can't agree on one story, that is also acceptable, but they must be prepared to discuss what they agreed on and what they didn't and to state their reasoning. (Note that people typically write the following story: two birds approached each other over the snow or land, and they had a fight. The big bird ate the smaller one and went on its way. The shapes represent the tracks left by walking birds.)

Ask for volunteers to present their stories and conclusions. Be sure not to judge any of their presentations. Comment only on the stories by focusing on evidence that Student Teachers use to support their stories. For example, if they say that the tracks are of wolves, ask them what evidence they have for this observation (rather than saying that the observation is wrong). After the first presentation, ask the rest of the class to judge the proof of evidence used for the presentation. They should state whether they agree or disagree with the explanation they heard. Then ask the rest of the class: does anybody have a different story that would explain the footprints? Could something else have happened?

End this session by leaving Student Teachers thinking about what happened at that location and realizing that several different scenarios are possible.

Suggested activity for session 3

Debriefing of observation vs. inference

Begin this session by showing Figure 3 again. Remind Student Teachers of the different stories and conclusions they heard previously. Ask them to consider the following questions and discuss them with their partner (you might want to ask one question after the other rather than showing them all at once):

- How did you know that the shapes in the picture were bird prints? Did they really stem from birds?
- How did you decide on your ending—for instance, that one of the birds ate the other? Are there any other possibilities? For example, is it possible that one flew away while the second stayed?
- How do you know that the tracks were made at the same time? Is it possible that one set of tracks was made a number of years before the other set?
- What do you conclude from this activity regarding the nature and characteristics of observation in science?

After Student Teachers have had enough time to discuss each question with their partner, ask them to report to the class. Have the class discuss the presented answers, especially if they see things differently or would like to add something.

Finally, ask Student Teachers to think about what this simple activity could teach them in respect to science. What main ideas can they deduce from this activity?

NOTE: make sure all Student Teachers understand the difference between observation and inference. In this situation, observations are descriptive statements about natural phenomena that are 'directly' accessible to the senses (or are extensions of the senses) and about which several observers can reach an agreement easily. For example, an observation is that Figure 1 shows some black markings with a similar shape (one larger than the other) that are organized into two merging pairs. Student Teachers might have concluded that the tracks were left by birds; however, that is no longer an observation or a conclusion but an inference. Although it is a well-founded inference, because it is likely that these tracks were made by two birds, it is not the only explanation for those tracks. Other explanations, such as the notion that the tracks were made by other creatures or objects that left similar-looking tracks, cannot be ruled out based on the evidence available. Be sure to discuss all possible inferences. You could also debate what it would take to prove that those tracks were made by a bird. The bottom line is that scientists can look at data and draw different conclusions. The quality and amount of evidence that supports these conclusions determines which conclusions are more credible. This short activity should provide a concrete example for future discussions about scientific phenomena in which Student Teachers need to carefully observe and then draw conclusions. Being able to differentiate between a fact and an inference is a crucial skill for all Student Teachers moving forward.

End this session by explaining that scientists make similar inferences as they attempt to answer questions about natural phenomena. Even though their answers are consistent with the evidence available to them, sometimes no single answer (or story) can explain that evidence. Often, several answers are possible. Even in today's ongoing science research, many unresolved mysteries are still being discussed.

Tell Student Teachers that in the next 15 weeks, they will engage in ongoing studies of science phenomena. Their skills in observations, discussions of conclusions, and inferences will be put to the test. Science is based on evidence; it is empirical in nature. Therefore, a necessary condition for constructing scientific ideas is to always have credible evidence when you are presenting ideas or hypotheses. If sufficient evidence is not provided, everyone in the class should feel called upon to challenge the statements made and engage in scientific discourse about the topic.

Additional resources

Target Science: Physics by Stephen Pople

Target Science: Chemistry by Michael Clugston and Rosalind Fleming

The Teaching of Science in Primary Schools by Wynne Harlen

Lederman, N., and Abd-El-Khalick, F. 'Avoiding De-Natured Science: Activities That Promote Understandings of the Nature of Science'. Retrieved from:
- http://toolbox.learningfocused.com/data/0000/0014/2125/Teaching_the_NatOSci.pdf.

'A Science Prototype: Rutherford and the Atom'. Retrieved from:
- http://undsci.berkeley.edu/lessons/pdfs/rutherford.pdf.

Understanding Science is a website that communicates what science is and how it works:
- http://undsci.berkeley.edu/index.php.

For an easy-to-understand illustration of Newton's laws of motion, refer to:
- http://teachertech.rice.edu/Participants/louviere/Newton/.

For information about Bloom's Taxonomy, refer to:
- http://www.odu.edu/educ/roverbau/Bloom/blooms_taxonomy.htm.

UNIT 2

POPULATIONS AND ECOSYSTEMS

Unit Overview

After providing Student Teachers with an overview of what to expect in Science I, this is the first day of teaching actual science content. The course begins with two units on life science. Each provides Student Teachers with an easy entry into observable and less abstract science concepts.

The objectives of this first unit are:

- to engage Student Teachers in experiencing inquiry science first-hand
- to make them comfortable with the discipline
- to eliminate any concerns or fears they may have about science.

In this unit, Student Teachers begin their study of life science using a macroscopic approach. They explore ecosystems and get a sense of how unity and diversity carry through all of biology. They also examine the basic needs of living things and their interdependencies. In addition, they learn to explain how some species thrive and populations grow but others become extinct.

Student Teachers first examine how organisms are interconnected with each other in an ecosystem and also with the nonliving components in their environment. They explore the concept of an ecological niche. They find out how niches help increase diversity within an ecosystem and maximize the number of populations that can live in the same ecosystem. They analyse the factors that affect population size and how populations change over time. They explore the effects that changes to ecosystems have on populations and the equilibrium of the system. Finally, they identify the effects of human activities and naturally occurring changes to ecosystems, as well as the results of those changes.

To teach life science in elementary grades, Student Teachers should have a detailed discussion about how to best introduce young children to, for instance, the concepts of ecosystems and population (growth). Often, older children have misconceptions about natural selection, adaptation, and evolution. You can prevent misconceptions by carefully scaffolding the learning experience throughout children's schooling. It is important to begin laying a solid foundation in children's conceptual understanding during elementary schooling. As a result, it will be easier for them to understand more complex and abstract concepts later on. Therefore, the third week of every unit develops and deepens this kind of pedagogical content knowledge, which is essential for an elementary grade science teacher.

Learning outcomes for this unit

Student Teachers should be able to:

- investigate the interdependence of living things (including humans) in an ecosystem
- investigate how changes in environments affect plants and animals (including humans)
- explain how adaptive characteristics of a species affect its chance for survival or possible extinction

- describe factors that limit or support the growth of populations within an ecosystem
- analyse data collected over time and explain how disruption in one part of an ecosystem can repeat throughout an ecosystem
- begin to identify the unit's underlying core science concepts for children in elementary grades and design age-appropriate, inquiry-based activities and learning outcomes.

Essential core vocabulary

Biotic and abiotic factors, interdependency, biological niches, ecosystems, biomes, species, population, population growth and pressure, carrying capacity, survival and extinction, food chains/webs, dynamic equilibrium

In this unit, Student Teachers should develop a good grasp of the definitions of these key words and use them correctly when they communicate. Inaccurate, colloquial, or careless use of language in science instruction often causes misunderstandings, which can lead to misconceptions. Throughout your teaching, try to model accurate use of scientific terms and encourage your Student Teachers to do the same.

Student Teachers should understand that an *ecosystem* is a community of organisms and their environment and that these *biotic* (living) and *abiotic* (nonliving) *factors* are interrelated. They may have a one-sided view of the relationship between the biotic and abiotic factors of ecosystems. They may believe that the activity of organisms does not affect their living conditions. They might also believe that some species are important to an ecosystem and that others are not. They may think that these less important populations could be changed or removed without affecting the rest of the ecosystem. It is important for Student Teachers to grasp the idea that all components of an ecosystem are interdependent, even if they are not directly linked. When Student Teachers design and create model ecosystems, they must apply their new understandings about the resources needed to maintain life and the interrelationships between biotic and abiotic factors. They also often think of populations as always growing or declining. Investigations where Student Teachers analyse patterns of population change over time should show them that populations actually vary around an average size. Examining carrying capacity and limiting factors will help them realize that resources are not unlimited and that populations cannot grow in size indefinitely.

Unit 2/week 2: Basic needs of living things and interdependencies in ecosystems

(Sessions 1–3)

This week, Student Teachers examine how organisms in an ecosystem are interconnected with each other and also with the nonliving components in their environment. They study a specific habitat and determine the interactions among the organisms living there. They also identify the components needed for life to exist.

Suggested activity for session 1

A hands-on inquiry activity

If possible, take your Student Teachers outside to a patch of natural land that is not sealed by brick or asphalt. You don't have to go far away from the classroom. A grass patch, tree, or brush area on campus or next to a road will do.

Start by asking Student Teachers what they expect to find on that patch of land. Make sure they list living and nonliving things from a microscopic to a macroscopic level.

Divide the class into small groups. Then instruct each group to choose a 1 square-metre patch that they will carefully explore. If your Student Teachers are not used to open-ended inquiry explorations, provide them with guidance. For example, make the borderlines of their plot visible by using a string or drawing a line. Also, help them develop a strategy on how to fully explore the plot for all living and nonliving things and record their findings. If possible, don't prescribe everything for the entire class. Instead, let different groups develop their own strategies.

In these first sessions, set the stage for a course of science that is defined by open-minded explorations. Encourage Student Teachers to ask questions that they then try to explore and answer. Let curiosity, thoughts, and proof be the driving forces. It is not about being right or wrong; rather, is about forming good questions, developing an exploration strategy, and making conclusions based on recorded observations and data. Encourage Student Teachers to question each other and not to shy away from asking critical questions. Set the tone for a rich science course that fosters inquiry and scientific discussion rather than lectures. Be a model to them, so when they teach science, they can use this approach. In a nutshell, help Student Teachers build knowledge rather than just taking in knowledge. Learning through experience and reflection will last a lifetime. It will also help convey the beauty of the natural world and science overall.

If your Student Teachers struggle with the inquiry approach, provide some guidance by asking the following questions for them to explore:

- Do you expect your plot to have many different kinds of organisms or just a few? List as many different kinds that might live in your ecosystem.
- How do you think the living and nonliving components interact with each other?
- List at least five resources that living organisms use in this plot.
- What factors might determine what kinds of organisms live in each plot?
- Do you think your plot will be the same tomorrow? Next month? Next year? Explain your response.

While Student Teachers work in their respective plots, circle among them. Remember not to correct or evaluate them at this point. Instead, encourage them to work with one another. Working together and thinking about the prior knowledge that each of them brings to the task should allow them to develop a strong strategy and a good data-collection method. You can initiate a conversation with them by asking the following questions:

- What are you doing?
- What is your plan?
- What are you observing?
- How are you recording your observations and findings so you can share them with the other groups?
- What do you expect to find?
- Has anything surprised you?

Make sure all groups record their observations so they can share them with the rest of the class in the next session.

Suggested activity for session 2

Debriefing of the hands-on inquiry activity

Ask each group to report their findings from their patch of land. You might want to gather all their findings on a flip chart or board. This will provide the class with a complete overview of what was found in the larger patch of land.

Have Student Teachers discuss the methods that different groups used, discuss the commonalities and differences of their findings, and explain how they might group their observations. Continue to encourage rather than evaluate or correct. If applicable, discuss strengths and weaknesses of different groups' methods. Have the Student Teachers do most of the talking rather than having them wait for you to tell them. Science doesn't have the answer to everything, and the science process is ongoing. Invite them to learn how to engage in the process. They begin by exploring, drawing conclusions, and having scientific discussions with one another rather than just learning facts.

As a second step, have Student Teachers categorize all their findings, for instance, by grouping them into living (biotic) and nonliving (abiotic) things found in their plot. Have them summarize their findings by answering the following questions:

- What did you find most often?
- What were rare cases?
- How many species did you find? Perhaps provide Student Teachers with resources that will help them classify their findings.

End this session by introducing Student Teachers to the concept of ecological niches. Explain how niches help increase diversity within an ecosystem. Discuss the interrelationships and how to maximize the number of populations that can live in the same ecosystem. At this point, you might want to expand the discussion from the plot of land that they explored to any other niche or ecosystem that they can think of. Take them from a local, shared experience and discuss more global 'species-rich' ecosystems. For example, you could discuss the rainforest and contrast it to scarcer ecosystems found in harsher places, such as at a high altitude, in the deserts, in the deep oceans, and so on. Have Student Teachers work in pairs for this exercise. Have them identify conditions that lead to highly diversified ecosystems and conditions that are not so favourable to survival.

Suggested activity for session 3

Conclusion and transfer: An imaginary ecosystem reacts to a change

In this final session of the week, ask Student Teachers to create a concept map of an imaginary ecosystem in some area of Pakistan. Have them work in pairs to map out all the species of that ecosystem that they would like to include (considering flora and fauna). Tell them to list all biotic and abiotic factors that play a role. Also, tell them to start small by picking a small area and just one species (for instance, a mammal). Then they can start creating all the interactions this species has with all the other organisms that live in that ecosystem. Make sure Student Teachers do not forget the abiotic factors. If they struggle with this open-ended assignment, discuss some simple food chains with them and then move on to food webs.

Next, have Student Teachers introduce an event that causes a change in the ecosystem (it can be a small change, such as a milder than usual winter, or a catastrophic one, such as a fire). Have them answer the following questions:

- How does this event affect the dynamic equilibrium of the ecosystem in the short and long term?
- What are the consequences?
- What could be corrective measures (human or natural) that would help the ecosystem return to its dynamic equilibrium? Student Teachers need to hypothesize here, but tell them to be prepared to explain their reasoning.

Even when an event or a change causes damage to an ecosystem, it can often recover over time to a system that was similar to the original one. However, certain major disasters can cause such damage to an ecosystem that it cannot recover. Human activity, in particular, can alter the biotic and abiotic components, resulting in major changes to the overall system. These changes often affect the biodiversity of the ecosystem, especially, but not always, when the food web is disrupted.

The design of a model ecosystem requires Student Teachers to apply the understandings that they identified this week. These include the resources needed to maintain life and the interrelationships among biotic and abiotic factors within ecosystems. They should also show an understanding of how water, oxygen, and carbon dioxide support life in an ecosystem based on prior knowledge from their schooling.

This activity will end the first week. In the second week, Student Teachers look closer at populations within an ecosystem. They will identify how those populations naturally increase and decrease as they respond to factors that limit or support growth. This will provide an opportunity to create and use data charts and construct graphs. These are also essential skills for all science teachers.

As Student Teachers explore the effects of natural and man-made changes to ecosystems, they will rely on their earlier experiences of analysing how events in one part of an ecosystem can affect the entire ecosystem. Provided that there is time, you might want to analyse more complex patterns affecting population change at the end of next week.

Unit 2/week 3: Dynamic ecosystems and populations

(**Sessions 4–6**)

In week 1, Student Teachers explored their own plot of land, a tiny section of an ecosystem. They should have catalogued the organisms that live in it and the physical environment that provides the resources organisms need to survive. These resources include water; soil; the appropriate temperature; gases, such as carbon dioxide and oxygen; organic and inorganic nutrients; sunlight; and shelter. They should have observed that organisms in an ecosystem may cooperate or compete for these resources and that these interactions can vary. They ended the week by creating a concept map of their sample ecosystem and hypothesized how it might react to change.

This week, Student Teachers further explore the complex interdependence and interactions of organisms in an ecosystem and how ecosystems adapt to changes.

Suggested activities for sessions 4–6

Populations and ecosystems

Student Teachers first explain their understandings of the interrelationships in ecosystems and then explore the concept of an ecological niche. They describe how niches help increase diversity within an ecosystem and maximize the number of populations that can live in that ecosystem.

Student Teachers then explore populations by examining the factors that cause natural populations of organisms to increase or decrease in size. To describe the dynamics of population growth, they analyse complex patterns of population size. Then they determine how populations change over time. By analysing data and creating and interpreting graphs, they understand the importance of population patterns and use this knowledge to predict future trends. By using graphs of population data, they can calculate the carrying capacity for a population in an ecosystem. They analyse the effects of mutualistic relationships, such as symbiosis, parasitism, and commensalism by interpreting data and graphs and carrying out simulations. By the end of the week, Student Teachers understand that the population size an ecosystem can support depends on the resources available. They also understand that certain factors limit the growth of populations.

The analysis of population trends leads to a study of change in ecosystems and dynamic equilibrium. Student Teachers learn that ecosystems are dynamic, not static, and that populations of organisms and their physical environment adjust constantly. They explore the effects that changes have on populations. They then determine factors that add to an ecosystem's stability, particularly how feedback loops keep an ecosystem in equilibrium.

As a conclusion to this unit, Student Teachers investigate the effects of human activities (such as pollution, habitat destruction, or urbanization). They examine naturally occurring changes to ecosystems (such as natural disaster, disease, population increase, or depletion of food) and the short-term and long-term results of those changes.

As an extension, you could provide Student Teachers with the following 'long-term' research project: what happens to an ecosystem when a major event—such as a raging fire, volcano, or typhoon—destroys large parts of the ecosystem? Determine what happens in an ecosystem that is wiped clean by a cataclysmic event and develop the ecological succession.

Unit 2/week 4: Teaching populations and ecosystems in elementary grades

(**Sessions 7–9**)

This week, you should prepare Student Teachers for teaching science in elementary school. It is essential to support them in making the transfer from their own science study to becoming a science teacher in the elementary grades. Many teaching strategies and the pedagogy learned in this course are transferable to teaching at elementary grades. However, the content, activities, and learning objectives must be adjusted to reflect age differences and prior knowledge.

Suggested activity for session 7

Establishing content for elementary grade science

Explain to your Student Teachers that this week you will switch from teaching them content that enhances their science understanding to discussing how they will foster the science learning of children in elementary grades.

Ask your Student Teachers to think about the past two weeks and the content covered. Have them work in pairs and jot down ideas on how they could teach the topic of populations and ecosystems to children. Ask these questions: what kind of science topics do you think are important to teach in grades 1–8? What kind of principles and concepts need to be established as a foundation for learning science in high school and beyond regarding evolution, genetics, adaptation, and so on?

The possible answers are almost endless. This is not the time to approve or correct their ideas. Rather, have your Student Teachers discuss their ideas with each other and explain their reasoning. Interject only if the discussion wanders too far off the topic of physical science and matter. Record their ideas on the board or on a poster so that everyone can refer to them in the next session.

Next, have your Student Teachers consult Pakistan's National Curriculum for General Science in grades 1–8 and determine if they have missed any relevant topics that they want to add now. You might want to form groups for different grade levels, for instance, grades 1–3, 4–6, and 7–8. Focus the discussion on only science concepts that relate to population and ecosystems.

Suggested activities for sessions 8–9

Designing activities for elementary grade science

As early as grade 1, children are establishing an understanding of populations and ecosystems. The National Curriculum supports this notion, for instance, in themes such as 'Things around us: Plants and animals' (grade 1) and 'The natural environment' and 'Plants/animals' (grade 2). In grade 3, the National Curriculum lists 'Habitats' and 'Changes in living things', but ecosystems and populations are also included in themes such as 'Conservation of natural resources' and 'Food and feeding'.

For grades 4–8, the National Curriculum addresses ecosystems and populations in the listed content of life science. It also takes a systems approach that allows children to explore and learn about the connections between living and nonliving organisms in an ecosystem, a food chain, and so on. Developing a conceptual understanding of these topics requires the teaching of those connections. Definitions and simple recall knowledge will not allow children to master this deeper understanding.

Have Student Teachers choose a specific topic and grade level that they will discuss in depth in a smaller group. Their task is to identify age-appropriate activities for teaching their concept of choice to children in elementary grades. Remind them to use hands-on inquiry activities if possible and to make them intriguing. Provide these questions: what kind of question could children in elementary grades investigate? What kind of challenge could they solve, and what concept would they learn as a result? What kind of learning outcomes can you expect at that age level?

If Student Teachers struggle to come up with activities or lessons that they can teach in elementary grades, you might want to provide them with some of the following ideas. However, they still need to develop a specific lesson for a specific grade.

Populations

Children in elementary grades can observe living things through three different lenses: *individuals, populations,* and *communities*. Thus, they examine the features and behaviours of *individual* organisms (e.g. how organisms move). As they get older and their skills and knowledge develop, they can document different observations, such as the growth and decline of groups of individuals of the same species (*populations*). They can observe and record how populations of many species interact with one another (*communities*). In addition, they can track interactions between living and nonliving factors, which creates a picture of the whole ecosystem. Children learn how to make their observations increasingly more specific and to recognize the difference between observations and inferences. As they note changes in their mini-environments and discuss them as a class, they are challenged to explain why those changes occurred. Students learn that they must tie their explanations to evidence.

Ecosystems

If possible, elementary school children should observe as much as possible in the real world. With such concrete and observable science topics as ecosystems and populations, this can be easily done. Every effort should be made to take the children outside the classroom for first-hand observations. Children can just observe a tiny area of soil, a tree, some grass, and so on. These encounters are essential in building curiosity for studying the natural world. Also, these experiences get children ready to develop essential skills necessary for more advanced science topics.

If possible, children in elementary grades should visit a local environment (such as a pond). They should study the two main components of that ecosystem: the organisms that live there (biotic factors) and the physical environment that supports them (abiotic factors). Then they return to the classroom with samples to set up a mini-environment based on the actual study site. With very young children, you should limit the area of observation and the tasks. Just observing one species and its interactions could be enough.

Older children in elementary grades could set up terrestrial and/or aquatic mini-environments. They could then study how communities of organisms interact with one another and with the physical environment to survive. They could brainstorm how to build the best possible mini-environment, focusing first on abiotic factors before they add biotic components. The teacher can guide their experiment with the following questions:

- What do organisms need from the physical environment? (e.g. light, water, gases, temperature, and space.)
- How much of those physical resources does the species need? For instance, could too much light be a problem? What is the best amount of light?
- Do resources change from day to day or from season to season and affect the behaviours of the organisms?

Through these investigations, children should begin to see how to model the real world inside for closer observation but how these models will have limitations.

Suggested learning progressions for 'populations and ecosystems'

In all of the preceding activities, it is important that Student Teachers understand the expectations for children in elementary grades. Although science content can and should be taught to young learners, it needs to be age appropriate and concrete and include hands-on inquiry. Whenever possible, young learners should experience the real world first-hand rather than studying images or models inside the classroom. Curiosity and fascination can build a strong foundation and motivate children to pursue a science career.

A child in grades 1–3:

- *Builds an awareness of the basic needs of living things. Investigates and identifies resources (light, water, nutrients, and air) that plants need to survive.* Investigates and identifies resources (food, water, and air) that animals need to survive.
- *Determines how an organism's habitat provides for its basic needs.* Observes and explains that there are a variety of local environments (e.g. field, forest, dessert, marsh, river). Provides examples of how an organism depends on other organisms and its environment to meet its basic needs.
- *Identifies physical characteristics that enable an organism to survive (e.g. legs for moving, sharp teeth for eating, a hard shell for protection).* Provides examples of diverse structures (e.g. wings, legs, fins) that serve similar functions (e.g. movement).
- *Observes how organisms interact with their environments to meet their needs.* Identifies potential sources of food (in the case of animals), shelter, water, air, and light within a particular organism's habitat. Describes how organisms interact with other organisms and with nonliving things in their habitat. Examines and records how organisms react to changes in their habitat. Explains that some animals eat plants for food, others eat other animals, and some eat both plants and animals.

A child in grades 4–6:

- *Investigates how changes in environments affect plants and animals (including humans).* Observes and describes how organisms can cause changes (helpful and damaging) in their environments. Provides examples of situations that cause some plants and animals to change their behaviour to survive and reproduce, die out, or find new locations to live. Describes how growth, death, and decay are important aspects of living systems by providing evidence from readings and observations.
- *Illustrates the interdependence of organisms in an ecosystem.* Discusses and provides examples of how all organisms depend on plants. Recognizes that some organisms depend on dead plants and animals for food. Identifies micro organisms as necessary components in all ecosystems. Describes and explains that the world has many different environments (e.g. rainforest, desert, plains, wetlands). Identifies factors in the ecosystem that allow or prevent an organism from surviving and reproducing. Provides examples of how an organism's behaviour is affected by the environment (e.g. availability of food sources, change in the number of predators).
- *Examines and describes the flow of matter and energy in living systems.* Illustrates, with examples, food chains and webs that show the flow of matter and energy in an ecosystem. Explains that (most) living things depend on food and oxygen for growth, repair, and energy. Discusses and provides examples of how all organisms depend on the Sun for food and energy.

A young adult in grades 7–8:

- *Explains how adaptive characteristics of a species affect their chance for survival or extinction.* Assesses through observations and investigations the reproductive advantage of different trait variations in various environments. Provides examples of situations in which an environment changed, the adaptive characteristics of a species were insufficient, and the species became extinct. Investigates and describes conditions that can result in extinction. Observes fossil records and examines them for evidence of adaptation, environmental change, and extinction.
- *Analyses the functions of and relationships among producers, consumers, and decom posers in ecosystems.* Categorizes organisms according to the function they serve as consumers, producers, and decomposers. Determines through investigations the raw materials plants need to photosynthesize. Explains why photosynthetic organisms are called producers. Investigates and explains the importance of decay in an ecosystem. Describes the flow of energy and matter through food webs for various ecosystems. Identifies sunlight as the original source of energy for most ecosystems. Identifies the two main interconnected global food webs (i.e. one that includes microscopic ocean plants and the other that includes land plants).

A note about prior conceptions

When considering the essential elements in an ecosystem, it is common for children and Student Teachers alike to focus mainly on organisms and overlook all of the abiotic factors. For example, when creating a pond mini-environment, children may think chiefly about putting organisms in water without considering other parts of the pond system, like mud. In addition, children may not think carefully about abiotic factors. For example, they may know that their environment needs light, but don't know how much. The mini-environments give children an opportunity to experiment with a number of abiotic factors in various ways. As children investigate how much light or how much mud is needed, they begin to explore and understand what those factors provide.

In terms of biotic factors, it is common for children to believe that some species are important to an ecosystem and others are not. They might also believe that these lesser populations can be excluded, changed, or removed from their mini-environments without any problems occurring. Children often miss the complex connectedness among populations within an ecosystem; they do not see that all organisms play roles and are interdependent. Instead of viewing ecosystems as organized wholes, they view them as a collection of individual organisms. The interconnected roles of producers, consumers, and decomposers can be illustrated well in a food chain/food web activity.

The mini-environments also provide an opportunity for children to switch their focus from individuals to populations. Children often do not realize that when an individual organism is eaten by a predator, this may be helpful for the rest of the prey population. For example, when a beetle is eaten, the situation is unfortunate for that beetle, but the rest of the beetle population now has fewer beetles competing for food, space, and so on. Children can begin to learn that the survival of a species depends on the health of the population, not the individual.

Finally, research suggests that children are often familiar with several types of environments and a variety of plants and animals, but they do not have an organizational structure that puts them together. This adds to children's difficulties in conceptualizing ecosystems as organized wholes. Thus, as children compare many different ecosystems, the goal is for them to organize their thinking into systematic categories. For instance, types of ecosystems have particular 'characters' because of their biotic and abiotic components.

Additional resources

University of California Museum of Palaentology. 'Ecosystems of the world'.
➢ http://www.ucmp.berkeley.edu/exhibits/biomes/index.php.

The Franklin Institute: Resources for Science Learning. 'Neighborhoods'.
➢ http://www.fi.edu/tfi/units/life/habitat/habitat.html.

NASA. 'Probing the Impact of Climate Change on Wildlife, Ecosystems'.
➢ http://www.nasa.gov/topics/earth/features/climate_partners.html.

Teachers' Domain. 'Ecosystems'.
➢ http://www.teachersdomain.org/resource/clim10.sci.life.eco.restoration/.

Teachers' Domain. 'Analyzing an Ecosystem'.
➢ http://www.teachersdomain.org/resource/lsps07.sci.life.oate.ecosystem/.

Gallegos, L., Jerezano, M., and Flores, F. (1994). 'Preconceptions and relations used by children in the construction of food chains'. *Journal of Research in Science Teaching,* 31(3), 259–272.

Grotzer, T., and Basca, B. (2003). 'How does grasping the underlying causal structures of ecosystems impact students' understanding?' Journal of Biological Education, 38(1), 16–29.

Zubrowski, B. (2006). *Investigating pond organisms: An exploration of pond life and its environment.* Neo/SCI.

UNIT 3

DIVERSITY, ADAPTATION, AND EVOLUTION

Unit Overview

This unit builds on the content of unit 2 and focuses on why there is such a variety of species in Earth's flora and fauna. In the previous unit, Student Teachers learned that in a healthy ecosystem, the populations of species are stable and the interdependencies among the species are balanced. The ecosystem behaves like any other system: any change in one part of the system affects others. If the change is substantial enough, the ecosystem can become unbalanced, resulting in drastic changes. In this unit, Student Teachers build on that knowledge and explore the importance of biodiversity to survival and adaptation. They are also introduced to the abstract world of DNA and biomolecules. They will begin to understand evolutionary processes on a molecular level.

The process of evolution is the underlying principle of biological science. It explains the unity and diversity of life and the adaptation of organisms to their environment. This course is not designed to deal with specific science topics in depth. However, it is important that by the end of this unit, Student Teachers develop a conceptual understanding of the basis of evolution: that is, the key to evolution is the selection of naturally occurring variations in populations. They should recognize that organisms with favourable trait variations that develop randomly are more likely than others to survive and have offspring.

In the first week, Student Teachers explore natural selection as the mechanism for evolution in concrete terms. They begin by identifying how the structures of organisms are related to their functions. They then use morphology and embryology to explain how to categorize organisms into different groups. They explore how adaptations—as a form of evolutionary change—happen; how adaptations are related to the environment; and how adaptations provide the basis for natural selection. They examine how structural and functional adaptations determine whether organisms succeed in their interactions with other organisms and their environment. They learn how adaptations have evolved over time and how they have led to the variety of life on Earth.

In the second week, Student Teachers connect their understanding of natural selection, evolution, and classification of organisms to the concept of species. They examine the criteria used to identify species and the biological factors that determine whether two populations will interbreed. They hypothesize how natural selection can lead to speciation. They begin to relate their understanding of DNA mutations to the expression of new characteristics. They learn how these new traits can enable an organism to be better suited to its environment. They also explore evidence that all existing species are related by descent from common ancestry. They examine how climatic events and evolutionary forces have shaped the living world. In addition, they study the role of extinction in creating niches for new species.

Finally, Student Teachers compare their understanding of biodiversity that they gained exploring their plot of land in unit 2 to their newly developed understanding at the end of this unit.

The third week develops and deepens the Student Teachers' pedagogical content knowledge. This helps teachers to successfully introduce young children to the diversity of all living things.

Learning outcomes for this unit

Student Teachers should be able to:

- describe the diversity of living things
- explain how adaptive characteristics of a species affect its chance for survival or possible extinction
- explain how evolution has resulted in diversity among living things
- observe fossil records and interpret them for evidence of adaptation, environ mental change, and extinction
- explain why we use classification systems and how classification systems are applied
- begin to identify the unit's underlying core science concepts for children in elementary grades
- design age-appropriate, inquiry-based activities and learning outcomes.

Essential core vocabulary

Natural selection, adaptation, evolution, classification, speciation, variation, biodiversity

In this unit, Student Teachers should develop a good grasp of the definitions of these key words and use them correctly when they communicate. Inaccurate, colloquial, or careless use of language in science instruction often causes misunderstandings, which can lead to misconceptions. Throughout your teaching, try to model accurate use of scientific terms and encourage your Student Teachers to do the same.

Please note that the everyday usage of the terms *adapt, adaptation,* and *fitness* can cause some confusion about the concept of adaptation and natural selection. In every-day usage, individuals adapt deliberately. This may lead Student Teachers to believe that adaptation is a conscious process to fulfil some need or want. But in the theory of natural selection, populations change, or *adapt*, over generations, inadvertently. This is an important point for Student Teachers to understand.

Unit 3/week 5: Biodiversity, natural selection and adaptation
(**Sessions 1–3**)

In this first week, Student Teachers learn that adaptive characteristics of a species affect its chance for survival or possible extinction. As they explore adaptation, they draw on their experience to provide examples of:

- biological adaptations that enhance survival and reproductive success in a particular environment
- adaptations, such as changes in structures
- behaviours
- physiology.

Student Teachers may have some difficulty understanding natural selection. The reason is that natural selection requires the integration of two distinct processes in evolution:

- the random occurrence of new traits in a population
- the non-random effects of these new traits on survival.

Student Teachers may view natural selection as a process that perfects organisms. However, it is actually the simple result of variation, differential reproduction, and heredity. Alternatively, they may misinterpret natural selection as a random process because the genetic variation that occurs in a population is the result of random mutation.

Be very clear when choosing your words. Continue to emphasize that selection acts on that variation in a non-random way: genetic variants that aid survival and reproduction are more likely to become common than variants that don't.

Throughout this unit, keep an eye out for any indication that Student Teachers might be developing either of these two common misconceptions.

Suggested activities for sessions 1–2

Species: Darwin's finches

Begin by asking Student Teachers where they think the biodiversity on Earth comes from. Have them use the knowledge they learned in unit 2 about ecosystems, resources, and populations. Also, ask them why some ecosystems have a large number of different species and others only have a few.

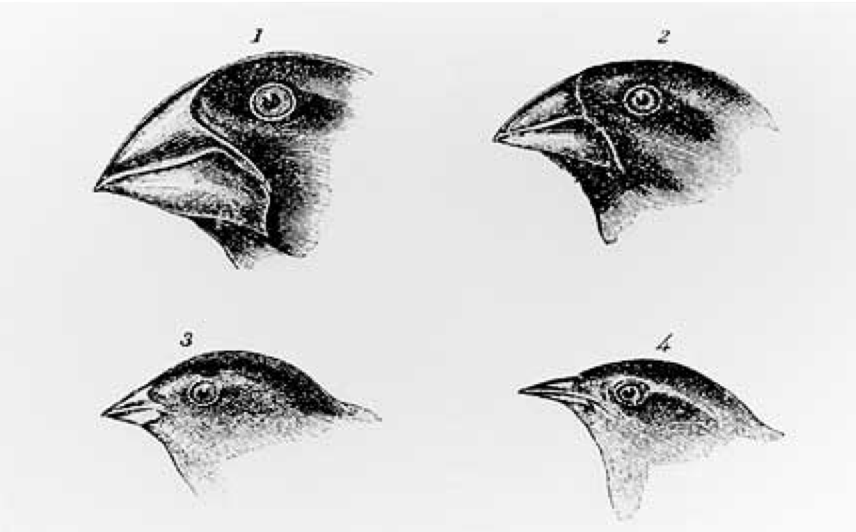
Have them use their records of what they discovered in their plot of land in unit 2 and use their catalogue of the living things they found. Then introduce them to Carolus Linnaeus, a Swedish scientist who in the eighteenth century developed a classification system based on structural features. His classification system is still being used to bring order to the enormous diversity of living things. It is also used to define relationships among different organisms and identify new organisms as they are discovered. Give Student Teachers an example of how a local species found on their plot of land would be catalogued using Linnaeus' taxonomy (species, genus, family, order, class, phylum, and kingdom).

Tell them that this week they will focus on 'species' and ask them what kinds of species they know. Collect their answers on the board; push them to go beyond mammals. If Student Teachers mix up species with sub-species (or breeds/races), do not correct them at this point. Instead, show them a sheet of different cat or dog breeds and ask them how many different *species* are displayed. Tell them that organisms of the same species are capable of interbreeding. Then discuss what they have identified as species before so they can correct their responses if needed.

Introduce your Student Teachers to Darwin and his study of the finches of Galapagos. You might want to spend a little time discussing Darwin and his life. Then talk about what he did on his ship the *Beagle* before focusing on his famous work on the finches of Galapagos.

Provide your Student Teachers with an image of Galapagos finches and their beaks (you can use the one provided below or a similar one that you have in a textbook). Tell them that these are all different species of finches found on Galapagos; however, they are all descendents of a finch found in South America.

Next, divide the class into at least three or four groups and assign each group one of the finches. Have each group research its habitat, identify its primary food, and describe its beak. Good examples for this task are the large ground finch (1), vegetarian tree finch (2), woodpecker finch (3), and cactus ground finch (4).



Four different species of finches found on Galapagos:
(1) large ground finch (2) vegetarian tree finch
(3) woodpecker finch (4) cactus ground finch

Invite each group of Student Teachers to research its finch species in great detail. Ask the groups to provide a summary that contains a description of:

- the characteristics of the finch's beak
- the finch's habitat and environmental conditions found on that island
- the finch's preferred food source.

Ask Student Teachers to hypothesize about what has happened on Galapagos over time. How did so many species of finches develop on the Galapagos Islands? Make sure they draw on information they have gathered about the finch's ecosystem and its biology. Also, have them use their understanding of species and evolution to explain how the amazing diversity of finch species might have occurred.

Ask each group to present its findings and hypothesis. Make a summary on the board about the similarities and differences found. Discuss how each group's findings can explain Darwin's theory that natural selection is the mechanism of evolution. Then talk about how natural selection is an example of the unity and diversity of life.

As an outcome of this brief study, your Student Teachers should be able to hypothesize that the finches settled on different islands for a reason: the distances between the islands were so vast that they could not easily fly away from the islands they settled on. Therefore, because they were isolated on separate islands, they could not mate with finches on other islands. Over time, the finches on different islands developed different beak sizes and shapes that were best suited to the kinds of foods found on their island.

The result was speciation (the development of one or more new species from an existing species) of the original ancestral finch. Over time, 13 different species of finches developed.

Suggested activity for session 3

Debriefing Darwin's finches: The history of evolution

Use this session 3 to have Student Teachers read about Darwin's ideas on evolution. They should also learn how his scientific work was the basis for criticism but also new research. Have them research the following questions and share their findings with the class:

- Was Darwin right?
- Was he wrong?
- What new discoveries have helped scientists understand better how species evolve?
- What's the current thinking?

If possible, allow Student Teachers access to the Internet or any other resources available.

There is no need to go into great detail on evolutionary theory in this session. However, it is important to show how scientific thinking progresses over time. Student Teachers should understand that certain facts get questioned and may be revised based on new findings. They need to realize that scientific knowledge is never complete and that the quest of understanding the natural world is ongoing. Learning about Darwin and his concept of evolution illustrates the interacting roles of evidence and theory in scientific inquiry. This information demonstrates how scientists' work is influenced by their societal and cultural beliefs and how scientific thinking builds on earlier knowledge.

This is also a good time to discuss with Student Teachers the difference between science and other ways of knowing. Or, depending on your Student Teachers' background knowledge and ability, you might continue the discussion and progress to genetically modified produce, cloning, and so on.

The next week will provide more basic insight into molecular processes and genetic mutations.

Unit 2/week 6: Evolution and speciation
(**Sessions 4–6**)

In week 2 of unit 2, the goal is to help Student Teachers distinguish between *evolution* (the historical changes in life forms) and *natural selection* (the mechanism for these changes). It is strongly suggested that you allow ample time in units 2 and 3 to make sure that they first recognize the diversity *and* relatedness of species. Then they can move on to study natural selection as an evolution mechanism. This progression may help avoid some misconceptions.

Some Student Teachers might have difficulty understanding that population changes are the result of the survival of a few individuals that preferentially reproduce. They instead might believe that populations change over time because of the gradual change of all individuals in that population. They do not realize that changes are caused by the increase in the proportion of individuals that have advantageous characteristics. To realize how natural selection can account for evolution, Student Teachers must understand the important difference between the selection of an *individual* with a certain trait and a change in the proportions of that trait in *populations*.

Student Teachers who believe that evolution is the process in which species respond to environmental conditions by changing gradually over time think that the environment (rather than random processes and natural selection) causes traits to change. They believe that acquired traits can be inherited and that variability is not important in evolution. It is very common for children and Student Teachers alike to believe that organisms develop new traits because they need them to survive. They think that *adaptation* refers to individuals deliberately developing new traits in response to the environment. Confusion about these topics may be due to the everyday usage of the terms *adapt, adaptation,* and *fitness*.

This week, Student Teachers learn how similar internal structures and chemical processes in different organisms can infer shared ancestry. They use simulations, data from primary sources, and fossil records to hypothesize how evolutionary paths diverged from a common ancestor. They draw on these understandings as they examine the biochemical evidence for common ancestry in this unit.

Student Teachers study how organisms are grouped based on evolutionary relationships or DNA similarities. They build on their understandings of classification from the previous unit. Recall that in unit 2 they used biological classification systems to interpret degrees of relatedness among species. They should be aware that the selection of naturally occurring variations in a population leads to great species diversity. They should also know that extinction of a species can occur when the environment changes and the adaptive characteristics of a species are insufficient to allow its survival.

Unit 3/week 7: Teaching populations and ecosystems in elementary grades

(Sessions 7–9)

Explain to your Student Teachers that this week, you will switch from teaching them content that enhances *their* science understanding to discussing how they will foster the science learning of young pupils in elementary school.

Suggested activity for session 7

Establishing content for elementary grade science

Ask your Student Teachers to think about the past two weeks and the content covered. Have them work in pairs and jot down ideas on how they could teach the topic of diversity and adaptations to children. Ask these questions: what kind of science topics do you think are important to teach in grades 1–8? What kind of principles and concepts need to be established as a foundation for learning science in high school and beyond regarding evolution, genetics, adaptation, and so on?

The possible answers are almost endless. This is not the time to approve or correct their ideas. Rather, have your Student Teachers discuss their ideas with each other and explain their reasoning. Interject only if the discussion wanders too far off the topic. Record their ideas on the board or on a poster so that everyone can refer to them in the next session.

Next, have your Student Teachers consult Pakistan's National Curriculum for General Science in grades 1–8 and determine if they have missed any relevant topics that they want to add now. You might want to form groups for different grade levels, for instance, grades 1–3, 4–6, and 7–8. Focus the discussion on only science concepts that relate to diversity and adaptation.

Suggested activities for sessions 8–9

Designing activities for elementary grade science

As early as grade 1, children are establishing their understanding of diversity and adaptation. The National Curriculum supports this notion, for instance, in themes such as 'Things around us: Plants and animals' (grade 1) and 'The natural environment' and 'Plants/animals' (grade 2). In grade 3, the National Curriculum lists 'Habitats' and 'Changes in living things'. Diversity and adaptation are also included in themes such as 'Conservation of natural resources' and 'Food and feeding'.

For grades 4–8, the National Curriculum includes diversity and adaptation in topics such as 'Living things and their environment', 'Environment and interactions', and 'Environment and feeding relationships' (grade 7), building towards the concept of 'Heredity in organisms' (grade 8). Taking a systems approach to studying the environment, its makeup, and the role of individual species in it allows for an easier transition when discussing topics such as the concept of adaptation and the cause of diversity in natural systems.

For suggestions on diversity and adaptations listed in the following section, begin by using ideas generated by Student Teachers that you recorded in session 7. Have them choose a specific topic and grade level that they will discuss in depth in a smaller group. Their task is to identify age-appropriate activities for teaching their concept of choice to children in elementary grades. Remind them to use hands-on inquiry activities if possible and to make them intriguing. Provide these questions: what kind of question could children in elementary grades investigate? What kind of challenge could they solve, and what concept would they learn as a result? What kind of learning outcomes can you expect at that age level?

If Student Teachers struggle to come up with activities or lessons that they can teach in elementary grades, you might want to provide them with some of the following ideas to build upon.

Adaptation and survival

Building on the previous unit, children identify the features and behaviours of organisms that help them survive in their particular habitats. They can conduct a field study to survey the plants and animals in their own areas (for example, the school yard or a local aquatic system such as a pond, a river, or tide pools). By studying the habitats and its inhabitants, children begin to develop an understanding of the complex interdependences of living things, including the important role of plants and microorganisms.

Children should explore how various species satisfy their needs in the environments in which they are typically found. They can examine the survival needs of different species and consider how the conditions in particular habitats can limit what kinds of living things can survive. Their studies of interactions among organisms within an environment should start with relationships they can directly observe.

They then look for adaptations that give species an advantage in meeting their needs. For instance, they can examine the beaks of birds as an example of an adaptation for obtaining food in different ways.

Older children can also focus on variation in structure and function among the species and their various reproductive strategies. They can begin to differentiate between inherited traits and those that are not inherited. They can also examine how specific behaviours can help an organism survive.

Children can begin to look for ways in which organisms in one habitat differ from those in another and consider how some of those differences are helpful to survival. The focus should be on the consequences of different features of organisms for their survival and reproduction.

They can broaden their study of habitats (for instance, habitats found in the mountainous areas, the plains, or along the coast) and compare and contrast ecosystems nationwide or even globally. They can also view nature films to see a great diversity of life in different habitats. (There are many good videos and resources on adaptation and survival online. For some examples, see the additional resources section.)

To guide children in their activities of exploring the big idea of adaptation and survival, they should be able to answer the following questions:

- How do the environmental conditions of specific ecosystems determine which plants and animals live there?
- What features enable certain plants and animals to thrive in specific environments?
- What adaptations help local plants and animals live in their habitat?
- In the end, children should conclude that the structures and behaviours of living things must enable them to meet their basic needs, or they will not survive.

Although younger children will not understand evolutionary details, they can observe the structures and responses that enable an organism to thrive in its respective environment. The concepts of natural selection and evolution will be explored in later grades.

Children may confuse adaptations of a species with methods that an individual organism may use to 'adapt' to an immediate situation. In science, an adaptation is a specialization in the design of structure, form, or function that has evolved to suit an environment.

Suggested learning progressions for 'diversity and adaptations'

It is important that Student Teachers understand the expectations for children in elementary grades. Although science content can and should be taught to young learners, it needs to be age appropriate and concrete and include hands-on inquiry. Whenever possible, young learners should experience the real world first-hand rather than studying images or models inside the classroom. Curiosity and fascination can build a strong foundation and motivate children to pursue a science career.

A lot of the following suggestions are similar to those listed in the previous unit on ecosystems and populations. To some extent, studying ecosystems and populations leads to the more complex and abstract topic of adaptation and diversity.

A child in grades 1–3:

- *Examines characteristics of plants and animals and describes how those characteristics help the organism to live.* Identifies physical characteristics that enable an organism to survive (e.g. legs for moving, sharp teeth for eating, a hard shell for protection). Provides examples of diverse structures (e.g. wings, legs, fins) that serve similar functions (e.g. movement).
- *Describes structures of plants and animals that help them meet basic needs in different environments.* Describes structures of animals and how those structures help the animal live in a particular environment. Describes structures of plants and how those structures help the plant live in a particular environment.

A child in grades 4–6:

- *Compares and contrasts structure and function among different organisms.* Observes, investigates, and explains the functions of different parts of plants (e.g. seeds, leaves, flowers). Identifies examples of plant structures that serve the same function but differ in appearance (e.g. seeds, leaves, flowers). Compares and contrasts structures that animals use to obtain food and protect themselves. Identifies examples of structures in animals that serve the same purpose but differ in appearance (e.g. bird beaks). Draws conclusions about the functions of plant and animal structures seen in fossils.

- *Builds an awareness of variations and similarities in organisms.* Illustrates through simulations how different variations of a structure (e.g. bird beaks) are suited to specific functions (e.g. cracking seeds, digging for worms). Describes that internal and external cues influence the behaviour of organisms. Identifies variations and similarities in the behaviour of organisms. Classifies animals according to various organizational schemes and recognizes that the organizing schemes can vary according to purpose.
- *Investigates adaptations of structures that carry out essential functions.* Provides examples of adaptations in structures that carry out essential life functions after studying various organisms and ecosystems (e.g. radulae in snails, gills in fish, cilia in rotifers).

A young adult in grades 7–8:

- *Explains how adaptive characteristics of a species affect their chance for survival or extinction.* Assesses through observations and investigations the reproductive advantage of different trait variations in various environments. Provides examples of situations in which an environment changed, the adaptive characteristics of a species were insufficient, and the species became extinct. Investigates and describes conditions that can result in extinction. Observes fossil records and examines them for evidence of adaptation, environmental change, and extinction.
- *Differentiates between inherited physical traits and those that are not inherited in animals or plants.* Discusses that when plants/animals reproduce, both biological parents pass on information that determines characteristics of the offspring. Lists physical characteristics of animals that are caused by interaction with the environment and those that are inherited. Explains that learned behaviours are not passed on to the next generation.

Additional resources

Teachers' Domain. 'Masters of Disguise'.
➢ http://www.teachersdomain.org/resources/tdc02/sci/life/colt/disguise/index.html.

Teacher's Domain. 'Animal Defenses'.
➢ http://www.teachersdomain.org/resources/tdc02/sci/life/colt/defense/index.html.

ScienceNet Links: Learning Activity G4.3.2. 'Pond 1: Pond Life'.
➢ http://www.sciencenetlinks.com/lessons.cfm?BenchmarkID=5&DocID=77.

National Geographic. 'Critter Cam'.
➢ http://animals.nationalgeographic.com/animals/crittercam/.

Holt Biology by Johnson & Raven. (2004.) Chapter 15: Populations. Section 1: How Populations Grow. p. 319–325.

Holt Biology by Johnson & Raven. (2004.) Chapter 16: Ecosystems. Section 1: What Is an Ecosystem? p. 339–344.

Holt Biology by Johnson & Raven. (2004.) Chapter 17: Biological Communities. p. 361–381.

Holt Biology by Johnson & Raven. (2004.) Chapter 18: The Environment. Section 2: Effects on Ecosystems. p. 390–395.

UNIT 4

EARTH –THE BLUE PLANET

Unit Overview

Unit 4 shifts to earth science. In units 2 and 3, Student Teachers studied biological systems—such as ecosystems—on a relatively tangible scale, noticing interactions and interdependencies. In this unit, Student Teachers continue their study of systems. Unit 4 introduces them to systems on a greater scale (in terms of distance but also in regard to time). They learn to see Earth as a system with interactions of its geosphere, biosphere, atmosphere, and hydrosphere. In Science I, the focus is mainly on the atmosphere and hydrosphere. In addition, the idea of heat transfer is introduced to explain some of the air and water movement on Earth.

In the past two units, Student Teachers familiarized themselves with the biosphere and its flora and fauna. In this unit, they investigate air and water as the components of the atmosphere and hydrosphere. They will understand how the hydrosphere plays an essential role in making Earth habitable. They will also study how the water cycle is part of a system. They explore how processes in the hydrosphere and atmosphere shape Earth's landscapes and life overall. By providing them with a more holistic view of Earth and its systems, Student Teachers should be well prepared for further study of earth science concepts in Science II.

In the first week, Student Teachers study the water and air on and above the surface of Earth. They consider the impact of radiant energy from the Sun on the Earth's systems as a whole as it heats Earth's water and air. In this context, you can introduce climate, weather, and the seasons.

In the second week, the focus is on how Earth's landscape undergoes constant change. Picking up on the water theme, you can explore erosion and sedimentation in the context of rivers or along coasts. (Science II, unit 4 discusses the theory of plate tectonics in greater detail.)

The goal of this unit is to choose very tangible and specific concepts that manifest themselves in Pakistan's landscapes and that Student Teachers can observe first-hand. After this unit, they should have a good understanding of the physical landscape of Pakistan as it can be seen today. They should be able to speculate how it might have been formed. In this unit, it is also important to convey an understanding that systems undergo constant change. Some changes can happen quickly and can be observed; other changes occur very, very slowly. Gradual changes are more difficult to comprehend because they can't be as easily observed, and tools must be used to collect evidence. Introducing Student Teachers to such ideas provides them with a vital foundation. This groundwork helps them as they continue to deepen their conceptual understanding of the physical world around them.

It is important for Student Teachers teaching life science in the elementary grades to discuss in detail how to best introduce young children to the environment that surrounds them. This knowledge will help children discover all the fascinating aspects of Earth (and the universe). It is also important to show young children how unique and special Earth's systems are. Children will then grow up with a better understanding of the intricacy of Earth's systems. Also, they will develop a better appreciation for the uniqueness of Earth and understand how (man-made) changes in any part of the system contribute to an ever-changing Earth. It is critical that you begin laying a solid foundation in children's conceptual understanding during elementary schooling. As a result, it will be easier for them to understand more complex and abstract concepts later on. Therefore, the third week of every unit develops and deepens this kind of pedagogical content knowledge, which is essential for an elementary science teacher.

Learning outcomes for this unit

Student Teachers should be able to:

- recognize that the abundance of water on Earth makes Earth unique and habitable
- describe and give examples of ways in which Earth's surface is built up and torn down by natural processes
- explain how weathering and erosion reshape landforms by eroding rock and soil in some areas and depositing them in others
- investigate landforms and identify constructive and destructive forces that led to their formation
- begin to identify the unit's underlying core science concepts for children in elementary grades
- design inquiry-based activities and learning outcomes that are age appropriate.

Unit 4/week 8: Earth: The habitable planet

(**Sessions 1–3**)

This week focuses on the hydrosphere and atmosphere: the water and air on and above Earth's surface that make it habitable for life as we know it. By creating models, conducting research, and designing and carrying out investigations, Student Teachers explore the key concepts addressed in this unit. Those concepts include the water cycle, the nature of the atmosphere, and the radiant energy from the Sun, which creates convection currents of wind and water that drive weather patterns and climate. In their investigations, Student Teachers examine the impact of pollution and natural changes in the hydrosphere and atmosphere that occur now and in the past.

Suggested activity for session 1

The water cycle and weather/climate in Pakistan

One way to introduce Student Teachers to the water cycle is by together defining the hydrosphere. Then divide them into small groups and have them brainstorm all the sources of water on Earth's surface. Have them begin with the local area and expand the scope from there. Ask them to create a concept map on which they list all the sources of water in their area. Student Teachers will probably begin with the obvious rivers and lakes, but if they stop there, prompt them with the question: what happens to the raindrops that fall on the landscape? They should be able to complete the concept map with clouds, most soils, underground water, and so on.

Use this initial concept map as an introduction to the water cycle. If possible, provide Student Teachers with websites, readings, diagrams, and other resources. They should identify and simulate the processes by which water:

- becomes part of the atmosphere via evaporation, sublimation, and transpiration
- condenses or precipitates out of the atmosphere
- flows through the geosphere via surface runoff, infiltration, and percolation.

In the second part of this session, provide Student Teachers with data on temperature and precipitation in different areas (or cities) of Pakistan. Work with the data and have them create and interpret graphs to answer these and other similar questions:

- Where is the wettest/hottest area in Pakistan?
- Where the driest/coldest area in Pakistan?
- Why do you think these areas are like that?

Also, look at seasonal fluctuations and have Student Teachers speculate why they think the weather is different. End this session by creating averages of precipitation and temperature data over several years to decades. Then use these averages to introduce the concept of what constitutes climate data (long term). Working with temperature and precipitation data is an excellent opportunity to also discuss statistical concepts, such as averages, trends, and anomalies. Discussing these data in the context of Pakistan's weather allows for an easy transition to explore the difference between weather and climate.

It's not important for Student Teachers to explain in detail nuances of the weather/climate across the regions in Pakistan. However, they should be able to hypothesize that the topography of the country plays an important role in the type of weather/climate.

Suggested activities for session 2

Precipitation and seasons

Student Teachers next investigate the troposphere and what influences local weather. From their water cycle investigations, they should understand that water is present in the atmosphere in the form of water vapour and clouds. They then learn about the composition of clouds. They learn how the characteristics of clouds and their role in weather vary depending on their altitude and the amount of water they hold. They investigate the factors included in weather (e.g. air temperature and pressure, cloud cover, humidity, and precipitation) and those that cause weather to change (e.g. changes air pressure, movement of air masses). Try to find ways to tie these concepts to local examples. Use similarities and differences among different locations to illustrate, for instance:

- how altitude influences temperatures
- how mountain ranges can influence precipitation (in particular, the effects of prevalent wind directions).

You may also choose to introduce Student Teachers to maps showing climate zones (and vegetation zones etc.). Perhaps introduce them to terms such as *arid, semi-arid,* and *humid*. Then show them the consequences of these climate conditions on the landscape and the impact on local agriculture. You can discuss several relevant subthemes in greater detail, but it will be impossible to cover them all. Therefore, it is best to focus on covering the 'big-picture concepts' to lay a solid foundation. This will allow them to continue a more detailed study in Science II or on their own.

Whichever preceding suggestions you use, reserve some time to explore concepts that are traditionally the source of misconceptions. In particular, the question of what causes precipitation and what causes the seasons can reveal persistent misconceptions.

Precipitation

What are clouds? When does it rain? These can be good questions to start a conversation in which Student Teachers can share their prior knowledge. Listen carefully to their explanations. Encourage them to discuss each other's ideas and to expand their thinking. Their longer statements, not short phrases, can reveal existing misconceptions.

Student Teachers may hold many preconceptions about the hydrosphere and atmosphere. In particular, they might have a certain idea about water in its gaseous state (vapour) and the processes by which it changes from liquid to gas (evaporation) and gas to liquid (condensation). In the next unit on properties of matter, they spend more time on the states of matter. However, at this point, it is important to begin to discuss some of the common misconceptions, such as the following:

- The atmosphere is mostly oxygen
- All clouds are cold, and therefore, their presence makes the air cold
- Clouds are water vapour
- Heat causes water to break up into hydrogen and oxygen—that is, water is destroyed when it evaporates
- Air pressure increases with an increase in altitude

Make sure Student Teachers understand that water evaporates from lakes and rivers *and* that moisture evaporates everywhere (moist ground, plants, humans, etc.). Water remains in the air until it precipitates. (If Student Teachers are weak on physical science concepts, teaching what happens on the molecular level when water changes state might be too hard to convey at this point. States of matter is covered in unit 6, 'Properties of matter'). However, if many of them show signs of misconceptions, take the time to have them do an experiment. Let them evaporate some water by placing some wet, dark clothes or tissues in the sun or onto a heater. Then have them observe that the water contained in the cloth evaporated without being seen and that it is now in the air of the room.

Do not use the demonstration of boiling water and showing the white steam. This can lead to the misconception that clouds are water vapour when in fact clouds are primarily water droplets and/or ice crystals.

Seasons

To explain what causes the seasons, most Student Teachers will describe a model that they probably saw in primary school of the Earth rotating around the Sun on an elliptical path. The common misconception is that the warmer summer months are caused by the Earth being closer to the Sun during that time. This misconception may stem from their personal experiences with heat sources, such as radiators or ovens, where the closer you get, the warmer it gets. They do not understand that the Sun is so far away that this difference in distance on the elliptical path versus the overall distance to Earth is almost negligible. Therefore, the change in seasons is due to the tilted Earth axis. Earth is tilted either towards the Sun or away from it, which changes the angle at which the Sun's rays hit the Earth's surface.

If Student Teachers struggle with this idea, spend time experimenting with the Sun's rays on a surface at various angles. Besides changing the angle, also investigate how different land surfaces heat or cool more quickly depending on their properties (different types of land and water). At a minimum, they should conclude that the steeper the angle is between the Sun's rays and the surface, the higher the temperature. (You could expand the activity to show that the colour and material of the surface also make a difference.) Then transition back to the model of Earth rotating around the Sun. Show the effect of the tilted Earth axis as it exposes the surface to the Sun's rays throughout the year and one rotation. To test their understanding, ask them to explain why the southern hemisphere's coldest months are July and August and its hottest months are December and January.

Suggested activity for session 3

The blue planet

Conclude this week by discussing the uniqueness of the conditions that we find on Earth. Talk with Student Teachers about how these conditions enable life as we know it. Begin by building on the topics covered this week, such as Earth's atmosphere and hydrosphere and the climate that makes Earth inhabitable. Have them draw on their prior knowledge from previous lessons and create a list of items that are unique to Earth and are conducive to life. You can inform them that Earth is often described as an ecosystem. Then ask: what makes this ecosystem so special? What could be factors that result in change? They should be able to apply what they've learned in unit 2 to this greater scale of considering Earth as a whole. At this point, it is more important for them to gain an understanding of systems and how one change can cause another change than present a response that includes many details.

You can extend this discussion by asking Student Teachers to discuss what would happen to life if:

- Earth was closer/farther away from the Sun
- Earth's temperature was different
- Earth's axis wasn't tilted
- Earth didn't have an atmosphere.

In this discussion, Student Teachers should apply what they have learned so far this week. They should begin to hypothesize using scientific reasoning. It's not that important for them to mention or even understand all the consequences of the previously mentioned scenarios, but they should engage in a discourse with one another, form hypotheses grounded in facts, and challenge each other to deepen their arguments. During this semester and Science II, Student Teachers will deepen their scientific understanding of natural phenomena. You might want to revisit these questions as you teach the course(s).

If there is time, you may want to compare and contrast Earth to the other planets in the solar system. For example, you could compare their size, position to the Sun, features, and surface conditions.

Unit 4/week 9: Shaping Earth's landscapes

(**Sessions 4–6**)

In the second week, explore how water contributes to form and shape the landscapes. After having discussed the water cycle, it is a natural transition to take a closer look at Pakistan's rivers, deltas, and coastlines, as well as plate tectonics.

In week 1, Student Teachers learned how essential water is for life on Earth. This week, they look at how water shapes the geophysical features and contributes to an ever-changing landscape. Week 1 introduced them primarily to large distances in earth science by looking at the solar system. Week 2 should introduce the scale of time and how the Earth's surfaces have changed over hundreds or thousands of years.

Water and erosion (or deposition/sedimentation) are just a couple of concepts that would naturally fit into discussions this week. You could also cover the rock cycle in this context. Rivers transport large amounts of rocks and sediments downstream. Therefore, Student Teachers could follow the 'journey of a rock,' which is similar to what they did with water in week 1.

Unit 4/week 10: Teaching planet Earth in elementary grades

(**Sessions 7–9**)

This week should be dedicated to preparing Student Teachers for their teaching of science in elementary school. It is essential to support them in making the transfer from their own study of science to becoming a teacher of science in the elementary grades. Many teaching strategies and pedagogies learned in this course are transferable to teaching at elementary grades. However, the content, activities, and learning objectives must be adjusted to reflect the difference in age and prior knowledge.

Suggested activity for session 7

Establishing content for elementary grade science for planet Earth

Start this session by explaining to your Student Teachers that this week you will switch from teaching them content that enhances *their* science understanding to discussing how they as teachers will foster the science learning of young pupils in elementary school.

Ask your Student Teachers to reflect on the past two weeks and the content covered. Have them work in pairs and jot down ideas about how they could teach the topic of planet Earth to children. What kind of science topics would be relevant to teaching in grades 1–8? Which principles and concepts do they need to establish as a foundation for learning science in high school and beyond regarding the role of Earth's hydrosphere? What main ideas or concepts should be covered with these young children?

As the Student Teachers discuss what they could teach at the elementary grades, facilitate those conversations. Possible answers are almost endless. This is not the time to approve or correct offered ideas. Instead, have them discuss the ideas with each other and provide feedback. Have them explain their reasoning. Only interject if the discussion wanders too far off the topic of earth science. Record their ideas on the board or on a poster so that you can refer back to them in the next session.

Also, have your Student Teachers consult Pakistan's National Curriculum for General Science in grades 1–8. Have them analyse whether they have missed any relevant topics that they want to add now. You might want to form groups for different grade levels, for instance, grade 1–3, 4–6, and 7–8. Again, focus the discussion on only science concepts that relate to earth science.

Suggested activities for sessions 8–9

Designing activities for elementary grades

Pakistan's National Curriculum lists earth science themes as early as grade 1. The list includes the following themes:

- Exploring the neighbourhood
- Using maps
- Identifying Earth as one part of a greater universe
- Understanding what causes day and night
- Recording weather data
- Discussing the seasons and climate in different locations of Pakistan

Basic teaching of these concepts should begin in early elementary grades and increase in complexity as children grow older.

Begin by using ideas generated by Student Teachers in session 7 that you recorded. Have them choose a specific topic and grade level that they will discuss in a small group and elaborate on. Their task is to identify age-appropriate activities that teach their concept of choice to children in elementary grades. Remind them to use hands-on inquiry activities if possible and to make them intriguing. Ask the following questions: what kind of question could children in elementary grades investigate? What kind of challenge could they solve, and what concept would they learn as a result? What kind of learning outcomes could be expected at that age level?

Earth science is another science discipline that encompasses many different fields and sub-themes. In order to interest young children in earth science, it is essential to provide as many hands-on experiences as possible. As in biology, providing young children with local examples and having them explore the world around them (physical geography of their town and surroundings, the weather, the resources needed to survive, the stars above them, etc.) will trigger their curiosity. Helping them explore their environment in a structured way allows for deeper learning.

The Student Teachers should come up with a range of ideas and activities to fascinate young children. Showing children the beauty of the natural world around them will entice them to want to learn more about it. This curiosity, resulting exploration, and basic understanding will lay the foundation for more complex and abstract concepts in later years.

If Student Teachers struggle to come up with activities or lessons that they can teach in elementary grades, you might want to provide them with some of the following ideas to build upon.

Seasonal changes

Young children in early elementary grade should know that the Sun is the major source of light and heat on Earth. As discussed in the previous biology units, they should have explored their natural environment and learned how life depends on the availability of water, food, air, and shelter. Based on this prior knowledge, children can take the next step and study how seasonal change affects life. They could observe (and record) evidence for seasonal change (temperature and rainfall). Based on their collected data and observations, they can make connections about:

- how the seasons affect human activity
- how humans' use of Earth's resources changes during each season.

For instance, they can connect the growth of plants and crops in the fields and the birth of baby animals with the weather and the change of seasons. (Refer also to Science II, unit 4.)

Day and night

Children in the lower elementary grades can observe and record the Sun's position over the course of a day to document the east-west path of the Sun. In a long-term experiment, they can add the movement and changes of the Moon to their Sun observations. You could also briefly introduce them to the night sky and have them conduct initial observations of stars and planets. At this point, they are too young to learn about the scientific reasons for these phenomena. Their observations and the knowledge that there are regular patterns in appearance and apparent motion form the foundation for a real understanding of the solar system. A continuation of these concepts in the middle school grades and beyond will build on this foundation. (Refer also to Science II, unit 5.)

Suggested learning progressions for earth science: Planet Earth

In all of the preceding activities, it is important that the Student Teachers understand the expectations for children in elementary grades. Science content can and should be taught to young learners, but it needs to happen in an age-appropriate, concrete, and hands-on inquiry way. They can be expected to observe, for instance, how the weather or the seasons change. They should learn how weather affects them or the environment and document their observations and thinking. But in lower elementary grades, they are too young to understand or even explain why, for instance, the seasons change. You can expect these explanations later when children have had the opportunity to deepen their science knowledge and thinking skills. Through carefully developed learning progressions, you will prepare them for more abstract ideas and complex situations. Please refer to Science II, unit 4 to learn more about how these complex topics, such as seasons, plate tectonics, or the universe, can scaffold over time.

A child in grades 1–3:

- *Investigates how weather can change from day to day.* Identifies basic weather features (e.g. temperature, wind, rain, clouds). Describes changes in weather based on observations.
- *Identifies patterns of seasonal changes in weather.* Observes and records seasonal changes in weather (e.g. temperature, wind, and precipitation). Describes changes (if any) in weather patterns over the seasons after gathering long-term data.

- *Recognizes humans' dependence on earth materials.* Indicates how people use Earth's resources (e.g. as building materials, as sources of fuel, for growing food and obtaining water). Observes and describes the properties of Earth's resources and determines how people use them.
- *Gains an understanding of how some earth materials are created and change.* Compares how sand and soil are formed based on investigations. Categorizes sand and soil in different ways (e.g. grain size, colour, texture, water-holding capacity).
- *Recognizes that the Sun is the major source of light and warmth on Earth.* Identifies day and night as a repeating pattern. Investigates and describes how the Sun warms the land, air, and water.
- *Compares the apparent path of the Sun and Moon across the sky.* Observes safely, records, and describes the apparent daily changes in the Sun's and Moon's position during the day (i.e. east-west motion, point of rise/set). Describes the Sun and Moon's apparent daily motion as similar.
- *Builds awareness that our Sun is a star among other stars in the universe.* Provides examples of how the Sun is necessary for life on Earth. Explains that our Sun is a star that gives off a tremendous amount of heat and light.

A child in grades 4–6:

- *Realizes that some Earth processes are rapid and some are slow.* Compares rapid Earth processes (e.g. volcanic eruptions, earthquakes) to slow ones (e.g. formation of metamorphic rock).
- *Develops an understanding of the importance of water as an earth material.* Identifies major sources of water on Earth. Verifies that water can be found under ground, on the surface of Earth, and in the atmosphere.
- *Investigates landforms and relates a combination of constructive and destructive forces to their formation.* Identifies major features of Earth's surface. Describes and examines constructive forces (including volcanic eruption and sediment deposition) that change landforms. Describes and examines destructive forces (including weathering and erosion from waves, wind, and water) that change landforms. Observes and explains that weathered rock, along with organic materials from decomposed plants, animals, and bacteria (and possibly pieces of living organisms), make up soil.
- *Describes and gives examples of ways in which Earth's surface is built up and torn down by natural processes.* Examines and differentiates the geological processes that build and/or change features of the Earth's surface. Explains how weathering and erosion reshape landforms by eroding rock and soil in some areas and depositing them in others. Describes how forces over time lead to the formation of sedimentary rock.
- *Examines components and relationships in the solar system.* Describes common objects (e.g. Sun, planets, moons) in the solar system. Observes safely, records, and describes the yearly pattern of the Sun's apparent path (e.g. seasonal change in length of day/night, changes in point of sunrise/set, changes in noon altitude). Identifies the predictable monthly pattern of the Moon's phases (new, crescent quarter, gibbous, full). Demonstrates and explains that the rotation of planet Earth produces the night-and-day cycle.

A young adult in grades 7–8:

- *Differentiates the layers of the geosphere, including the lithosphere, the hot convecting mantle, and the dense metallic core.* Distinguishes among layers of the geosphere by their composition, state, position relative to one another, and temperature. Explains how heat is transferred by convection from the core to the mantle and lithosphere. Demonstrates how changes in the major surface features of the geosphere can be documented over time.
- *Recognizes how the movement of Earth's lithospheric plates causes slow changes in Earth's surface (e.g. formation of mountains and ocean basins) and rapid ones (e.g. volcanic eruptions and earthquakes).* Models how heat flow and movement of material within the mantle result in the constant movement of lithospheric plates on the surface at rates of centimetres per year. Differentiates among types of plate boundaries and the kinds of slow and rapid changes that can occur at these boundaries. Distinguishes the characteristics and formation of sedimentary, metamorphic, and igneous rock in the process described as the 'rock cycle'. Explains how each type of rock can be transformed into the other under condition of time, pressure, and heat.
- *Applies concepts of rotation, revolution, and alignment to explain the predictable patterns of phasing, eclipses, and seasons.* Differentiates between rotation and revolution. Demonstrates and explains that the rotation of Earth produces the night-and-day cycle and that its revolution produces the year. Models how the Moon's phases can be explained by simulating the Moon's orbit around the Earth and its position relative to the Earth and Sun. Demonstrates the situations that will result in lunar and solar eclipses as seen from Earth. Relates seasons on Earth to variations in the amount of the Sun's energy that strike different latitudes on the surface of the Earth due to Earth's tilted axis of rotation.

Long-term assignment: Weather and its effect on ecosystems

Student Teachers could be assigned to study the effect of weather on an ecosystem of their choice. By doing their independent research, they should realize that data collection and analysis are essential for describing trends and making forecasts. In addition, they can document how the behaviours of organisms are related to their interactions with the living and nonliving components of their environment (including weather and seasonal change).

By comparing their findings to those of their peers (e.g. in a presentation at the end of the semester), the class could conclude that the changes in weather, the position of the Sun in the sky, and the length of day and night change in a cyclic pattern. In some places, this results in a dramatic change in the weather in terms of the type of precipitation; in other places, the amount of precipitation and wind speed may change, but the temperature remains fairly constant.

Additional resources

Misconceptions of the water cycle:

Henriques' article is a comprehensive review of the literature on children's (grades K–12) misconceptions about topics related to weather. It includes many of the concepts addressed in this unit, such as the water cycle, clouds and precipitation, atmosphere, and gases.

➢ http://beyondpenguins.ehe.osu.edu/issue/water-ice-and-snow/common-misconceptions-about-states-and-changes-of-matter-and-the-water-cycle.

Resource on clouds:

➢ http://www.universetoday.com/73198/what-are-clouds-made-of/.

UNIT 5

FORCE AND MOTION

Unit Overview

This unit builds a foundation for an appreciation for physics as its own scientific discipline. It provides an understanding of the processes by which physicists increase knowledge in their field. Student Teachers investigate physics through explorations of force and linear motion. In the first week, they apply forces and cause linear motion at constant speed and direction. Then they move on to accelerated motion in a straight line. In the second week, the study is expanded to motion that can change in magnitude and direction. Due to its simplicity, they have the opportunity to experience physical phenomena directly with their senses. This experience and learning will prepare them for the introduction of more abstract and complex concepts in Science II.

Student Teachers focus on the following topics:

- Motion
- The laws of motion
- Concepts of inertia and mass
- The relationship between action and reaction
- Force pairs
- Force and acceleration

You should make an effort to help Student Teachers develop an understanding of the distinction among speed, velocity, and acceleration.

The unit identifies a variety of forces considered in Science I (for instance, normal force, friction, gravity, net force). It does not include details on chemical, electrical, or magnetic forces, which will be introduced in units about energy in Science II.

The third week of this unit develops and deepens the prospective teacher's pedagogical content knowledge. They can then successfully introduce young children to appropriate concepts related to force and motion.

Learning outcomes for this unit

Student Teachers should be able to:

- articulate and demonstrate the principles of motion and forces and apply them to examples of interactions between objects
- investigate the relationships among force, mass, and motion of an object or system
- conduct investigations to determine the position and direction of a moving object (and represent its motion on a graph)
- draw free-body diagrams that list all the forces acting on an object and the resulting direction of motion
- analyse the motion of objects by the classical relationships known as the laws of motion
- begin to identify the unit's underlying core science concepts for children in elementary grades
- design inquiry-based activities and learning outcomes that are age appropriate.

Overall teaching suggestions: Essential core vocabulary

Because there are so many misconceptions about forces, it is important that Student Teachers develop a clear idea of what *force* means. *Force* is an action or agency that acts on a body and can cause a body to accelerate. They should observe and recognize forces before labelling them. Generally, they should be able to distinguish between two classes of forces:

1) **Contact**—types of forces in which the two interacting objects are physically in contact with each other
2) **Non-contact**—types of forces in which the two interacting objects are not in physical contact but are able to exert a push or pull despite the physical separation.

Other terms will be important to understand because they relate to the behaviour of all forces on objects. Two key terms are *dynamic equilibrium* and *net forces*. *Dynamic equilibrium* is a condition of flux but with all influences (forces) in balance. It is a term relevant to other areas of science as well, such as chemical reactions. *Net force* is the sum of the magnitude of all (force) vectors, including the sum of their directions (relative to axes). Vectors are added graphically. As Student Teachers attempt to display the magnitude and direction of forces acting on an object, they begin to refer to those representations as *free-body diagrams*.

A note on misconceptions

The most common misconception is the idea that a force can be given to an object. For example, a Student Teacher might think that when a force is applied by a hand, the force still acts on the object after the object leaves the hand. As a result, they may identify a force as causing a continuous motion.

Sometimes, Student Teachers might identify this 'force' as inertia. Once an object loses this 'inertia', it also stops. Thus, they believe that objects move because of some quantity they have been given. In addition, they think it is natural for this quantity to run out and the motion of the object to cease. Another misconception is that a force must act only through contact.

To deal with misconceptions about the measurement of a moving object, graphs and visual representations are highly recommended. Studies have shown that vector diagrams help Student Teachers gain a better understanding about force and motion concepts. A recommendation is for them to use force or free-body diagrams. A force or free-body diagram uses arrows to represent the forces acting on an object at a particular moment. The length of the arrow represents the relative magnitude of the force. The direction of the arrow represents the direction of the force acting on the object. It is also recommended that you consider the time during which forces act and during which speed changes. Failure to do so may be at the root of common misconceptions.

Unit 5/week 11: Force and motion

(Sessions 1–3)

We rarely experience all possible forces acting at one time. We may only 'see' the effects of some. Some forces' effects are not evident for Student Teachers in a given situation (for instance, normal forces). This unit gives them an opportunity to consider common situations and then to identify the diverse forces acting at one time.

Student Teachers first distinguish between moving objects that are under the influence of a force and moving objects that are not under the influence of an unbalanced force. When there are forces acting on an object so that it changes speed or direction, they think about the forces that are affecting the motion. They identify the kinds of forces and explain the relative strength of the forces. They consider how to measure the forces and how to diagram (vectors or free-body) the multiple forces acting on a single object.

More advanced Student Teachers can explore the relationship between mass and acceleration. They should construct an idea of the newton as a special force where a mass of 1 kilogram is accelerated to 1 metre-per-second squared. (As they begin to recognize consistencies in the relationship between force and motion, encourage them to hypothesize that the relationship exists at the microscopic level as well. They will revisit this idea later when they consider energy at the microscopic level.)

Student Teachers learn that the measure of each kind of force is expressed in units specific to that force, such as a 'spring constant' for compression or stretch of a spring. The three most important ideas about force that all Student Teachers should know include:

- A force has a measurable value
- Its unit is the newton
- It includes the values of acceleration and mass

Suggested activities for sessions 1–2

Investigating forces and linear motion with a model car

Student Teachers begin the unit with the challenge to design and build a toy car given available materials. They work in teams to design, build, and test their initial ideas.

Student Teachers begin a more in-depth exploration of the motion of their vehicles. Groups collect data about the distance their vehicle travels and the time it takes. After several trials, they calculate the speed and represent their results in graphical form. They realize and understand the relationship between the lines on the graph and the motion of the model vehicle across the floor. As a class, they examine and discuss each group's graph. They analyse and then identify the design features that contributed to the model vehicle's performance.

Begin the class by asking Student Teachers to list anything that can be in motion and what they think causes this motion. Continue to ask them to consider all the forces that might act on each object. This conversation is an entry point into the unit and also solicits their prior knowledge.

Possible questions could be:

- In what situations do you observe movement?
- Can everything move? Why do objects move? What causes them to move?
- How can you describe the motion of the object?
- For how long does an object move? Can it move forever? In the same direction?
- Is there a connection between forces and motion? How could you describe that relationship? Who can form a hypothesis?
- Are there any forces acting on an object that is not in motion? (For instance, a car standing still, a book lying on the table, etc.)

Accept all the answers without judgment. Encourage all Student Teachers to participate in this brainstorming and reasoning of what could cause motion. At the end of week 1, revisit these questions and answers. Allow them to revise their answers if they realize a mistake that they want to correct. By the end of week 2, all Student Teachers should be able to answer these questions correctly.

In the second part of this first lesson, invite Student Teachers to investigate a model car of their own design (if possible, let them build one using simple materials or modify an existing one). A car with a very simple chassis powered by a rubber band, an electric motor, or other propulsion system, such as the push of a hand or a ramp, is sufficient to teach this lesson.

Give Student Teachers the remainder of this first session to work in groups designing their car and building it (they can finish the car after school or at home if they want to invest more time). If building their own car is not an option, provide them with toy cars. Tell them that this week they will explore details of the forces that allow a car to move. While they design (and build) their cars, have them discuss the following two questions:

- What are the forces acting on the model car, and how can they explain its movement? (Consider the forces when it is stationary and when it is moving.)
- How can they measure and visually represent the motion of the car?

Allow Student Teachers time in the second session to explore the concept of forces and movement in more detail. Have them come up with ideas on how to measure the motion and how to visually represent it.

To facilitate the investigation, have Student Teachers consider their model car when it is stationary *and* when it is moving. To move the car, they can push it. If they are using a rubber band to propel the car, they need to wind up the rubber band. Then, as it unwinds, it acts to turn the axles of the model car, moving it forward. They might choose a ramp to launch their vehicle. In order to describe what is happening in these situations, they must consider a well-thought-out description of the forces involved. Make sure that they observe and reason carefully and record their responses and data.

Use the following background knowledge to guide your conversation with your Student Teachers as you facilitate their investigation. Do not hand out this information to them. Instead, support their learning and problem solving by asking good questions. Guide their observation and problem solving so that they can 'discover' these concepts themselves. You can give them the scientific terms, such as *gravity* or *friction*, when they have observed it and are trying to describe the forces but are lacking the words. They need to recognize that there must be a force that supports movement in one direction and another force that 'breaks' or 'redirects' that movement. This conceptual understanding needs to come from the Student Teachers. You should not have to tell them. You can follow up by telling them that for every force there is a counter-force. Forces come in pairs. In particular, they have a hard time with the concept of normal force. Give them time to realize that gravity and normal forces act on all objects on Earth at any point in time. They should then realize that any stationary object is not changing its motion (accelerating or changing direction) because the forces are balanced.

Background information

Several forces are involved when the model is at rest and when it is moving. The model has weight, and the wound-up rubber band exerts tension on the axle. The weight is described in terms of the gravitational force. The weight of the car has to be overcome to get it to move. Newton's first law states that an object will remain at rest unless an unbalanced force acts on it. Also, an object will continue to move unless an unbalanced force acts on it. Inertia is the resistance to motion, and friction causes a moving object to slow down or stop. A key idea here is the notion of unbalanced forces. In the model car example, several forces are involved. There is gravitational force, normal force, a tension force, a frictional force, and the force of air resistance, which in this case is negligible.

A force is a push or pull resulting from one object acting on another object. Forces have magnitude and direction. The gravitational force is gravity acting on the mass of the car. The Earth, which is one object, is attracting the model car, which is another object. The direction of this force is downward towards the centre of the Earth. At the same time, there is another force (normal force), which is the floor pushing upward on the wheels of the car. The tension force is the wound-up rubber band. It acts to turn the axle of the model car, causing the wheels to rotate and move the car forward. The magnitude and direction of this force overcome the downward force of gravity. When the model car is moving, the force of friction eventually causes the model car to come to rest. Friction acts in the opposite direction of the movement of the car.

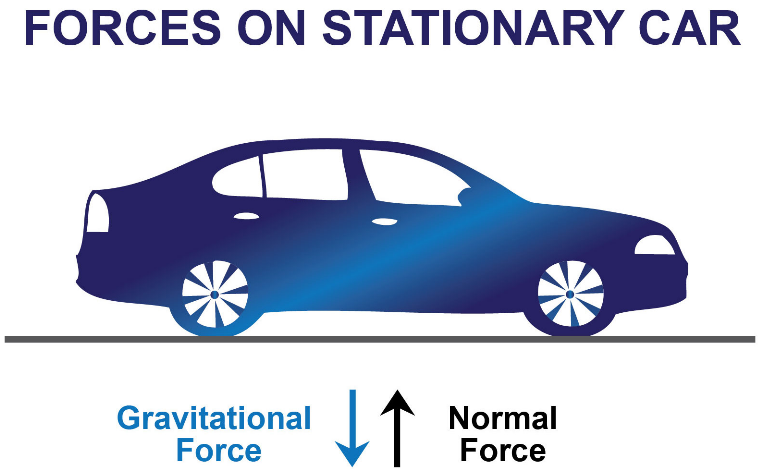
A tension force, or an applied force, (when the model car is pushed by hand or a magnet to illustrate that forces do not require physical contact) can overcome inertia. This results in unbalanced forces that cause the model car to move. As the model moves, it experiences friction. The better the design of the model, where friction is diminished between the axle of the wheels and the structure holding the axle, the farther the model will travel. Potentially, the model car could continue to move on and on in a frictionless world and never come to a stop. This is an essential point. Forces, such as friction, result in an unbalanced force that slow down the vehicle and eventually cause it to stop.

Suggested activity for session 3

Analysing and mapping forces and resulting motion

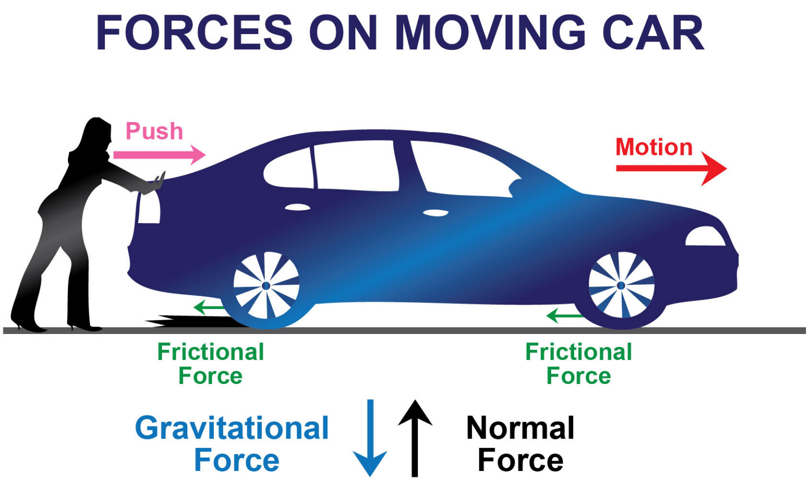
In the third session, introduce Student Teachers to free-body diagrams.[1] These will help them better understand how to visually represent the magnitude of a force and the resulting magnitude and direction of the motion. At this point, they should also understand the difference between a balanced and unbalanced force. They should be able to explain how unbalanced forces result in a change of motion. (For more advanced Student Teachers, add that a change of motion can either occur in the object's speed or in the direction that it is moving. You could demonstrate this by having the moving model car hit an object that deflects its movement.)

Begin again by discussing the forces that act on a stationary car: gravitational force and the normal force as the counter-force. (Both forces balance each other, so the car remains stationary.) While they discuss the forces, introduce them to the free-body diagram by adding the forces as they name them.



Sample Picture of Free Body Diagram of a stationary object (or an object travelling at a constant speed on a linear path).

Then draw the car with a force (a push or the rubber tension) that sets the car in motion. As counter-forces, there is friction from the surfaces on the wheels, between the axles and the wheels, and so on, and air resistance (negligible). These are unbalanced forces; the car is moving and eventually slows down.



Sample Picture of Free Body Diagrams of a positive acceleration (push) resulting in motion.

[1] Free-body diagrams are diagrams used to show the relative magnitude and direction of all forces acting upon an object in a given situation. A free-body diagram is a special example of vector diagrams. The size of the arrow in a free-body diagram reflects the magnitude of the force. The direction of the arrow shows the direction that the force is acting. Each force arrow in the diagram is labeled to indicate the exact type of force.

In addition, you can demonstrate that unbalanced forces can also cause a change in motion by changing the direction of movement. (For example, have the car roll down the ramp and then hit a brick at an angle at the bottom of the ramp. This causes the car to 'break off' the linear path it would have travelled without the brick.) Discuss and compare the forces and the result in motion in both scenarios (change of speed and change of motion).

Finally, ask Student Teachers: what would happen if there were no friction? They might have experienced an object moving over ice, where there is very little friction, and can predict what would happen if there were no friction at all (not even air resistance—these conditions are found in space).

It is important that Student Teachers begin to understand that motion, or acceleration, is the result of an unbalanced force acting on an object. The most common misconception is the idea that sustaining motion requires a continued force. If they voiced this misconception in the session 1 brainstorming, begin countering this false belief now in sessions 2 and 3. Draw their attention to the continuation of the movement of the car after the propulsion forces (rubber band, ramp, push with hand, etc.) are no longer applied. They then should explain the continual movement of the model and why the model car eventually stops. In addition, they need to be made aware of the different forces acting on an object and how these forces interact (using free-body diagrams or force diagrams). They should realize that if an object is in motion and no new force acts on it (for instance, any friction), that object would continue to move in that direction (Newton's first law). Only quoting Newton's laws of motion is not enough. Take every opportunity to discuss various scenarios. Have them account for all forces before they decide whether an object is changing its movement and how. This will help them begin to change their thinking about the motion of objects and the forces acting on them.

An object at rest tends to stay at rest. An object in motion tends to stay in motion with the same speed and in the same direction unless acted on by an unbalanced force.

You will continue this concept of motion in the next week.

Tell Student Teachers to hold on to their model cars because next week they will conduct more experiments to better understand force and motion.

Unit 5/week 12: Measuring and graphing motion
(Sessions 4–6)

Many Student Teachers might already know that when the model car is travelling, the expression for relating distance and time is: speed = distance/time. But a distinction needs to be made between the speed of an object and its velocity. Speed refers to a quantity; velocity refers to a quantity *and* direction. When specifying velocity, you also need to indicate the direction the object is moving.

This week, Student Teachers deepen their understanding of force and motion. They spend time measuring and graphing the speed of their model car at specific points in time. In addition to collecting data about the movement of their model car, they also practice graphing the data. As a visualization of data, a graph allows you to quickly determine if the car is:

- travelling at a steady rate
- moving at different speeds
- changing speeds over a given distance.

Suggested activity for session 4

Experimenting with speed and momentum

Tell Student Teachers that this week they will investigate motion. They will do so by obtaining quantitative data about the speed of their model car at various points in time. Hand out yardsticks (or measuring tape) and a stopwatch (or a watch that shows seconds) to each group. Tell them to work with the knowledge about forces from last week and design a scenario in which:

- their model car moves the longest distance
- their model car reaches the highest speed.

> NOTE: all Student Teachers should have the same experience and should focus more on the relatively difficult concept of gravity. To do so, have all groups work with their cars going down ramps instead of using other propulsion mechanisms that are harder to quantify (such as a push with a hand or the tension of rubber bands). They can build simple ramps using a piece of plywood and some bricks or books. For better incline comparison, bricks of the same height will work better than different books.

Use the entire session 4 for Student Teachers to design and experiment. Circulate among them while questioning them. Ask for their ideas on how to set the class record with their car. Then ask why they think that strategy would work best using their knowledge of balanced and unbalanced forces. Listen carefully for any misconceptions about motion. Instead of just correcting any wrong answers, ask probing questions. These questions will allow the them to grow in their thinking and find the correct answers in their group.

Once a group has a promising hypothesis and design, ask the group members to also think about how they will measure and record their data. While they conduct their experiment and record their data, encourage them to constantly refine their approach. They may even revise how they collect the data to make the most compelling case. Make sure that they discuss what might cause changes in the data and have them explain those changes. This is a good opportunity for Student Teachers to carry out an experiment on their own. They should test their hypothesis by changing a variable at a time to watch for the expected effect. Work with them on fine-tuning their ability to design and carry out controlled experiments. Again, guide them through questioning rather than correcting their responses.

Make sure that at the end of this session, each group has data for distance and speed. Have them explain all the forces acting on the car at the start, when it is in motion, and when it comes to a standstill.

To facilitate their investigation, you might ask the following questions:

- What makes the car move (down the ramp)?
- What keeps it from moving faster/farther?
- What are the effects of the different forces on the car (friction, gravity, etc.)?
- What does increasing or decreasing the angle of the ramp do to the motion of the car?

(Optional: determine if the model cars can run for several seconds and cover a longer distance. Then ask Student Teachers when they think the car reaches its highest speed and how they can prove it with their data. In order for them to answer this question, they need to measure the speed at various points so that they can compare the different intervals. This is valuable additional learning and skill building. It provides an opportunity for an additional discussion about maximum speed and average speed of the car.)

Suggested activity for session 5

Explaining and graphing

Discuss Student Teachers' findings and conclusions. Give each group 10 minutes to discuss its data in response to the task and the questions posed in sessions 4 and 5. You might want to add free-body diagrams to their task for additional practice.

Instead of having each group present its findings, you can save time by asking for volunteers. Then discuss that group's presentation with the rest of the class. For instance, after each group's presentation, you might ask questions such as: do you all agree with the findings and explanation of this group? Why or why not? Did you obtain similar or different data? Why do you think you have the same/different data?

At this point in the unit, make sure all Student Teachers understand that one major force in nature is gravity, which is an attractive force between matter. Earth creates a strong gravitational force that pulls everything towards it. When they place their car on top of the ramp, they lift it, giving it potential energy. When they let it go, the pull of gravity causes it to move faster and faster down the ramp, gaining more and more momentum. The higher the ramp, the more potential energy the car has, and the more momentum it will have when it reaches the bottom.

Also at this point of the exploration and discussion, introduce Student Teachers to the term *acceleration*. The steepness of the ramp influences how rapidly a car accelerates. (They might have experience from bicycling down steep hills.) The steeper the incline, the more rapidly a car accelerates. However, the explanation is not that simple. Listen carefully to how they explain the forces acting on a car that is standing still on top of the ramp. Then listen carefully when they explain what happens to the car when it moves down the ramp. Can they explain that the gravity acting on the car is always the same, but how the pull is distributed depends on the path? When the ramp is flat, gravity only pulls the car towards the ramp, and the ramp pushes back with an equal amount of force (normal force), so the car stands still. When the ramp is tilted only a small amount, the force of friction keeps gravity from moving the car. If the ramp is steep enough, the frictional forces cannot balance the downward pull of gravity. As a result, the forces are unbalanced, so the car rolls down the ramp. The steeper the ramp, the less gravity pulls the car towards the ramp, and the more gravity pulls the car down the ramp. Therefore, the car has a greater acceleration down the ramp and reaches the bottom with a greater speed.

As Student Teachers try to explain these concepts, help them understand by drawing the associated force or free-body diagrams for the different scenarios on the board.

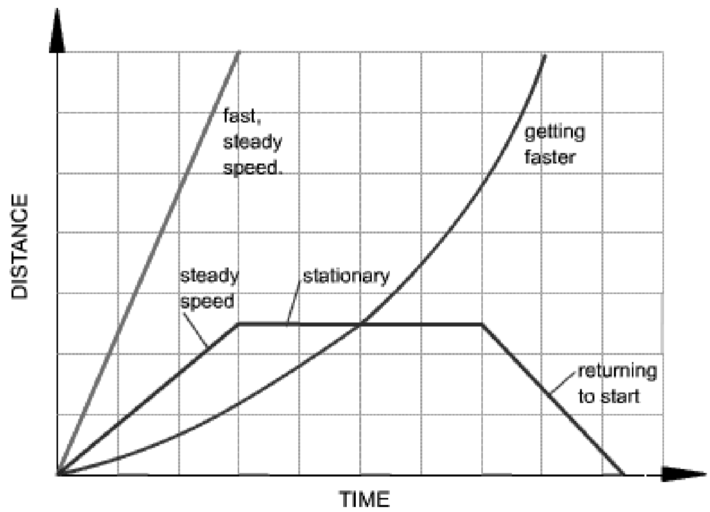
Also, let them know that acceleration is a change in speed of an object. (It can go faster or slower and is referred to as positive or negative acceleration, respectively.)

If you can, leave at least 20 minutes at the end of the session to show Student Teachers how to convert their data into a visual representation using a graph. Graphing data is a very useful skill in science, and this unit is an ideal context in which to work with data. Data from the classroom might not be sufficient to capture the car's speed at the beginning of the ramp, at the bottom of the ramp, and then in successive intervals. Therefore, you might want to take the class outside (if possible) for additional data collection. Using longer and higher ramps, the car will travel for a longer duration and distance, allowing for more data collection.

Make sure all Student Teachers understand how 'speed' is measured. For easier data collection, capture the speed by measuring how long it takes the car to cover a distance of 5-metre intervals.

Optional: Student Teachers with more prior knowledge in science, math, and graphing should be able to plot the data in a distance vs. time graph. (The y-axis is the distance in metres, and the x-axis is the time in seconds.) A distance vs. time graph shows how far an object has moved over time. The resulting graphs illustrate nicely the motion of the object:

- The steeper the graph, the faster the motion
- A linear graph means constant motion (balanced forces acting on an object, which is Newton's first law of motion)
- A non-linear graph means positive or negative acceleration (Newton's second law of motion)
- A horizontal line means the object is not changing its position. It is not moving; it is at rest



This graphing exercise is not easy and might not be possible with all Student Teachers. If they struggle with graphing, have them calculate the speed of the car (first have them convert their data into metres/second) and then plot the speed (y-axis) over time (x-axis). At a minimum, they should see that the car accelerates until it reaches the highest speed at the bottom of the ramp. Then it slows down again (negative acceleration) as the frictional forces make the car slow down until it comes to a standstill.

Suggested activity for session 6

Mass and acceleration

In session 6, investigate the relationship between mass and acceleration of an object. To begin this investigation, ask Student Teachers whether they think there is a difference between two trucks rolling down a hill. One is empty, and the other is fully loaded with heavy cargo. Let them speculate first (make sure they back up their hypothesis with science reasoning as much as possible, and accept different hypotheses). Then give them 15 minutes to experiment with their model trucks and different loads (for instance, use coins as a load). At the end of the investigation, each group should formulate its conclusion about what the relationship is among the mass of an object, how far it travels, and its acceleration.

Try this experiment yourself first. If you have difficulty timing the trucks to record their acceleration, consider switching the cars for balls on ramps or in tubes.

A heavy and a light truck/ball that have similar surfaces and are rolled down the same ramp will roll the same distance. How far they roll depends on the speed of the balls at the bottom of the ramp, not the weight! Although a heavier truck/ball has more momentum than a lighter one, the surface's push is greater on the heavy truck/ball. This surface push causes it to slow down at the same rate as the lighter ball.

It is difficult for Student Teachers to understand that objects fall at the same speed vertically. (Try dropping an empty and a full water bottle out a second-floor window at the same time. Both will hit the ground at the same time.) As with the bottles, the size or weight of the trucks (balls) does not affect how fast they reach the bottom of the ramps or how much farther they roll after they have left the ramp. However, the acceleration is different because acceleration depends on mass. Thus, heavier objects accelerate (positive and negative) slower than lighter objects.

These concepts are hard for Student Teachers to understand, and many hold misconceptions. You might need an additional session to make sure they have ample time to explore these concepts hands-on. They should see with their own eyes how a heavier truck or ball compares to a lighter one going down a ramp. You may also want to use longer ramps to see the phenomena more clearly. Use the time to develop a good conceptual understanding rather than introducing additional formulas, such as $F = ma$.

Unit 5/week 13: Teaching force and motion in elementary grades

(**Sessions 7–9**)

This week, you should prepare Student Teachers for their teaching of science in elementary school. It is essential to support them in making the transfer from their own study of science to becoming a teacher of science in the elementary grades. Many teaching strategies and pedagogies learned in this course are transferable to teaching at elementary grades. But the content, activities, and learning objectives must be adjusted to reflect the difference in age and prior knowledge.

Suggested activity for session 7

Identifying learning objectives for force and motion in elementary grades

Start this session by explaining to your Student Teachers that this week you will switch from eaching them content that enhances *their* science understanding to discussing how they can foster the science learning of young pupils in elementary school.

Ask your Student Teachers to reflect on the past two weeks and the content covered. Have them work in pairs and jot down ideas about how they could teach force and motion to children. What science topics would be relevant to teach in grades 1–8? Which principles and concepts do they need to establish as a foundation for learning science in high school and beyond regarding force and motion? What main ideas or concepts should be covered with these young children?

Possible answers are almost endless. This is not the time to approve or correct their ideas. Instead, have your Student Teachers discuss the ideas with each other. Have them explain their reasoning. Only interject if the discussion wanders too far off the topic. Record their ideas on the board or on a poster so that you can refer back to them in the next session.

Also, have your Student Teachers consult Pakistan's National Curriculum for General Science in grades 1–8. Have them analyse whether they have missed any relevant topics that they want to add now. You might want to form groups for different grade levels, for instance, grades 1–3, 4–6, and 7–8. Again, focus the discussion on only science concepts that relate to force and motion.

Suggested activities for sessions 8–9

Designing force and motion activities for elementary grade science

Pakistan's National Curriculum lists force and motion as a topic for grade 3 ('Student learning outcomes': 'Observe and describe how motion of vehicles can be changed by applying force'; 'Recognize that the greater the force, the greater the change in the motion of an object'.). Forces are included in sections of physical science in grades 4–8.

In addition, you need to teach the following process skills:

- Asking questions
- Problem solving
- Making an argument
- Defending an idea
- Making and recording observations
- Categorizing

These skills should be taught in meaningful context at all grade levels and can certainly be introduced in lower elementary grades.

Begin by using ideas generated by Student Teachers in session 7 that you recorded. Have them choose a specific topic and grade level that they will discuss in a small group and elaborate on. Their task is to identify age-appropriate activities that teach their concept of choice to children in elementary grades. Remind them to use hands-on inquiry activities if possible and to make them intriguing. Ask the following questions: what kind of question could children in elementary investigate? What kind of challenge could they solve, and what concept would they learn as a result? What kind of learning outcomes could be expected at that age level?

Motion can be observed in everyday life all the time (vehicles move around us, we walk, leaves are blown by the wind, raindrops fall from the sky, and rivers run downstream). The forces behind each motion and the exact nature of the motion are less intuitive. Therefore, the concepts of force and motion require age-appropriate teaching and learning over years. Prospective teaches should develop a range of ideas and activities suitable for children in the early elementary grades.

If Student Teachers struggle to come up with activities or lessons that they can teach in elementary grades, you might want to provide them with some of the following ideas to build upon.

Balls and ramps (force and motion)

You can provide children with ramps and tubes, allowing them to build roadways and explore the different behaviours of balls as they roll down inclines, up hills, and around bends. During these activities, they are continuously engaged in exploration, discovery, and problem solving. As they explore, they observe and share their experiences in groups using descriptive language. They make predictions and draw initial conclusions.

Children can investigate the effect of gravity (in their own words, it would be the 'pull' of the Earth) on objects falling to the ground or rolling down an incline. Children can observe how the steepness of a ramp influences a ball's acceleration due to gravity. They can compare different balls travelling down ramps and observe that the size and weight of the balls do not affect how fast they travel. When the balls reach the bottom of the ramp, children observe that lightweight balls and heavy ones travel the same distance. However, the heavier balls have more momentum (the tendency for an object to keep moving at a continuous speed). As a result, they are able to knock down heavier objects left at the bottom of the ramp.

In early elementary grades, children are too young to study formally the underlying concepts of physics. However, they will be able to build on those early experiences as they get older. Student Teachers could also draw on their own experiences with the activities presented in the past three weeks and modify them appropriately for grades 4–8.

Suggested learning progressions for 'force and motion'

In all the preceding activities, it is important that the Student Teachers understand the expectations for children in elementary. Science content can and should be taught to young learners, but it needs to happen in an age-appropriate, concrete, and hands-on inquiry way. Children can be expected to observe, for instance, the effects of a force on an object and develop a sense for the factors that affect motion. However, it is too early for them to understand or even explain their observations on an abstract level. Especially in grades 1–6, you need to design the learning experiences to help them establish a base on which to build future, more abstract learning.

A child in grades 1–3:

- *Recognizes that objects can move in a variety of ways.* Explains how the physical properties of an object may affect its motion (e.g. shape, size).
- *Demonstrates that pushes and pulls can change the motion of objects.* Describes how the motion of a variety of objects changes when pushed or pulled.
- *Builds an understanding that the motion of objects is affected by a 'pull' towards Earth.* Demonstrates that things fall towards the ground if they are not held up.

A child in grades 4–6:

- *Demonstrates a basic knowledge of the relationship between force and change of motion.* Compares the motion of various objects by examining the time it takes for the object to travel a certain distance. Describes the position of an object by locating it in relation to another object or to a background. Describes speed in qualitative ways (e.g. faster vs. slower). Identifies simple situations in which forces are balanced (e.g. designing mobiles, balance toys, and structures in which equal and opposite forces cause no change in motion).
- *Examines how magnets can cause some things to move without touching them.* Determines situations where magnets act at a distance to cause other magnets or objects to move towards them or away. Compares the magnetic attraction of different objects and materials to a magnet. Demonstrates that magnets can repel or attract each other.

A young adult in grades 7–8:

Investigates the relationships among force, mass, and motion of an object or system. Conducts investigations to determine the speed of moving objects. Cites evidence to explain that unbalanced forces cause changes in the speed and direction of an object's motion. Measures and describes the motion of an object in terms of its position, direction of motion, and speed.

A word about prior conceptions

Student Teachers and children alike are constantly forming beliefs and theories about the movement of objects from their everyday experiences. Both need many experiences that challenge their thinking about some common misconceptions. In particular, they need to realize that (1) if an object is at rest, no forces are acting on it, and (2) when an object 'runs out of force', it stops moving. To focus attention on the nuances necessary for understanding complex science concepts, ask Student Teachers and children:

- what they are observing
- why they think it is happening
- what evidence they have.

Children, in particular, do not need complex explanations; rather, they need the experiences and time for formulating (and reformulating) their own hypotheses.

Additional resources

The Physics Classroom. 'Newton's Second Law of Motion'.
➢ http://www.physicsclassroom.com/class/newtlaws/U2L3c.cfm.

University of Colorado Boulder: Interactive Simulations. 'Ramp: Forces and Motion'.
➢ http://phet.colorado.edu/en/simulation/ramp-forces-and-motion.

Regional Professional Development Program. 'Targeted Interventions for Proficiency in Science'.
➢ http://rpdp.net/sciencetips_v2/P12B1.htm.

Montana University. 'Common Student Difficulties with Forces'.
➢ http://www.physics.montana.edu/physed/misconceptions/forces/forces.html.

UNIT 6

PROPERTIES OF MATTER

Unit Overview

By the end of this unit, Student Teachers should recognize that the observable properties of matter result from atomic-level interactions. They start the unit by reviewing the distinctions between substances and mixtures. Most important, they focus on the concept that mixtures can be separated by physical means, but substances cannot. They learn that each substance has a characteristic set of chemical and physical properties, which leads to the idea that substances differ at the atomic level.

Student Teachers learn about the modern model of the atom, which can be taught in the context of historical models. They are then introduced to the periodic table and its organization. The primary focus is on understanding the organizational structure of the periodic table. They should also be able to apply the periodic table to identify trends in the properties of the atoms.

The model of the atom will be used as an example of working with models in science. Student Teachers will be introduced to the idea of using models in science classes to foster their understanding. In addition, they will realize the limitations of models and the potential for misconceptions.

This unit lays a foundation for Science II. In Science II, Student Teachers apply these concepts to predict chemical reactions (using the concept of orbitals, valence electrons, and the octet rule to support their understanding of the properties of the atom). They also explore in depth the different types of bonds that atoms form and how atoms and molecules interact in chemical reactions to form new compounds with new properties.

For Student Teachers to teach these concepts on matter successfully in the elementary grades, they must have a detailed discussion about state of matter, buoyancy, and density. Many misconceptions in this area stem from wrong ideas being developed in early science classes. They can be best prevented by carefully scaffolding the learning experience for elementary school children. The third week of this unit develops and deepens this kind of pedagogical content knowledge.

Learning outcomes for this unit

Student Teachers should be able to:

- differentiate between physical and chemical properties of matter
- classify chemicals as pure substances or mixtures (homogenous or heterogeneous) and classify pure substances as elements or compounds
- identify atoms and molecules as the building blocks of elements, compounds, and mixtures
- explain the atomic structure, addressing parts and properties of the atom
- analyse the relationship between the structure and the properties of matter, focusing on chemical properties of elements and their placement in the periodic table

- explain how substances change from one state to another by heating or cooling
- describe a model of the atom and what it depicts as well as its limitations
- begin explaining their misconceptions about properties and particle theory and what to do about them
- begin identifying the underlying core science concepts in this unit for children in elementary grades
- design inquiry-based activities and learning outcomes that are age appropriate
- begin developing learning progressions.

Essential core vocabulary

Substance, matter, particle, mixture, element, compound, molecules, atoms, physical and chemical property

In this unit, Student Teachers should develop a good grasp of the definition of these key words. Encourage them to use them correctly whenever they are communicating. Inaccurate, colloquial, or careless use of language in science instruction is often the foundation for misunderstandings. Misuse of terms can lead to misconceptions in conceptual understanding. Throughout your teaching, try to model accurate and precise use of scientific terms. Encourage your Student Teachers to do the same.

Be mindful of the common usage of certain words, such as *pure, substance,* and *compound*. They are not nearly as precise in everyday language as they are in the scientific usage.

Unit 6/week 14: What is matter?

(**Sessions 1–3**)

Begin with an activity that helps Student Teachers review the distinctions between substances and mixtures. Next, review the idea that each substance has a characteristic set of chemical and physical properties. Then review the concept that mixtures can be separated by physical means but substances cannot.

Introduce the model of the atom. Inform Student Teachers that it is composed of protons, neutrons, and electrons. You can do this in combination with introducing the periodic table. Describe how the periodic table evolved over time. Explain how the views of science constantly change based on new work, discoveries, and enhanced theory.

Suggested activities for session 1

A hands-on inquiry activity

Place Student Teachers in groups and give each group a mystery bowl (solids) and a mystery flask (liquids). Ask them to identify and sort the mystery substances into as many components as possible. Have them document their findings. Provide them with any ‘lab tools’ that you have available (for instance, funnel, sieve, different-size containers, magnifying glass, heat source, magnets, etc.). For the solid mystery, you can use organic and inorganic materials that you find around the house and school, such as:

- Branches
- Fruits
- Soil
- Stones
- Rusty nails
- Plastics
- Matches.

For the liquid mystery, you can use:

- Water
- Oil
- Vinegar or alcohol
- Sugar or salt dissolved in the solution.

The purpose of this activity is not for Student Teachers to identify each component that you added to the mixtures. Instead, they start using physical means to separate the mystery substances. They realize that mixtures can be separated and sorted into very small components. When they have made considerable progress, challenge them by asking whether they can find more components by looking at smaller items. For instance, the branches can be broken into smaller pieces, but how small can they get? What happens when you look at the rusty nail? What is it made up of? Encourage them to record their thinking, methods, and findings. Ask them to list the properties of each component that they isolated as best as they can. You might have to revisit the concept of physical properties and provide them with some examples.

In a final class discussion, guide Student Teachers in revisiting physical properties (and, if applicable, chemical properties). They do not need to physically separate all the mixtures. They should not conduct any chemical separation at this point. The goal is to construct a mental model that you can keep separating a substance using physical and chemical separation. They should also recognize that if you keep separating a substance, you can identify a compound or element that makes up the mixture.

During the final discussion, create an overview chart listing the identified physical and chemical properties of the identified substances. Student Teachers should be able to list physical properties. Have them explain and list how those properties can be used for physical separation. At this point, it is enough if they have a vague conceptual understanding of chemical properties and how they can be used for chemical separation. They do not have to be able to explain this yet on the atomic level.

If Student Teachers have more science background and better lab equipment, you could also try the following activities:

Extension/option 1

Conduct an electrolysis of water. Then have your Student Teachers test the products of the electrolysis (oxygen and hydrogen) for their properties and contrast them with the properties of water. Focus the discussion on how properties change dramatically when a substance undergoes a chemical reaction. Discuss how that differs from a substance undergoing a physical change. Without going too deep into molecular theory, begin to discuss why those properties changed.

Please note that in Science II, semester 3, Student Teachers explore chemical change and chemical reactions in more depth. For now, it is enough for them to understand that certain substances have unique properties. They should know that if substances undergo a chemical change, particles are rearranged on the atomic level; therefore, the properties of that substance also change.

Extension/option 2

The challenge: a mystery substance (for instance, white powder) was found in an envelope mailed to a celebrity. The substance was sent to a crime lab for identification. How can scientists identify what the powder is? How can they go about finding the answer?

Guide Student Teachers through their hypotheses and speculations. Encourage them to argue their points based on their scientific prior knowledge or common sense. Lead the discussions towards the point that substances can be separated, and then properties of the substances can be identified through a series of specific tests. Once the properties of the substance are established, the substance can be identified.

Suggested activities for session 2

Defining matter

Ask Student Teachers how they would describe matter. Have them describe what matter is and what it is not. It is appropriate for them to speculate and argue their point with their classmates. Have them think about the activity from session 1 where they separated substances into smaller and smaller parts. (They might mention elements, atoms, or even subatomic particles.) What might that tell them about matter? Capture their thinking (also 'wrong ideas') on the board for later discussion and revision.

The majority of the class should conclude that all matter is made up of mass and that mass is composed of particles. Then introduce the model of the atom. (It is OK if they do not use the right terminology yet, as long as they have reached that conceptual understanding.) For the model, you can use a physical model or a drawing. Introduce the atom and its subatomic particles (neutrons, protons, and electrons), including their respective electric charges. (Science II will explore this model in depth by adding electron orbits and energy levels to the model when chemical reactions are covered.)

Historic definition of matter

Provide Student Teachers with former hypotheses made by scientists over the centuries regarding matter and what matter is composed of.[2] You can begin, for instance, with the ancient Greek Empedocles. He argued that all matter was composed of four elements: fire, air, water, and earth. In addition, he claimed that the ratio of those elements determined the property of the matter. Have them reflect on that statement. Then have them discuss their understanding of the current model of the atom. You might want to establish a 'class model' using their ideas.

Use this exercise to model how the body of science knowledge is constantly changing. Inform Student Teachers again that science content is not static. Established theories and broadly accepted 'facts' can change over time; the quest of science is ongoing even today. Have them discuss other examples where the established understanding has changed dramatically over time. Use all science disciplines (a flat Earth, cause of disease, lightning, etc.).

[2] You might also want to use the reading 'Atoms from Democritus to Dalton'.

Suggested activities for session 3

Organization of matter

Ask Student Teachers to work in pairs and brainstorm a chart or some form of organization to capture and catalogue all matter on Earth. Have them compare their ideas and the thinking behind their chosen organization. Introduce Mendeleev and how he created the period table of the elements. Many consider this table the most important chemical document. The reason is that it allows you to quickly determine a significant amount of information about an element. This information includes its atomic mass, atomic structure, and whether it is a metal, non-metal, or metalloid.

Give Student Teachers simple examples on how to read the periodic table. Start with the elements in the main group. Describe how they are organized by their atomic number and what that means. Relate that information to the model of the atom. Have them draw atoms of different elements for practice. They should draw the correct number of neutrons, protons, and electrons. Electron shells and isotopes do not have to be discussed yet. Then introduce them to the atomic weight of each element as well as some of the properties (metallic vs. non-metallic, the noble gases, etc.). Demonstrate the patterns in the periodic table that capture those properties (for instance, the increase in atomic weight from top left to bottom right). Ask Student Teachers whether they can explain the patterns, such as the increase of the atomic weight. In Science I, they don't need to explain why certain elements are metals and others are non-metals, and so on. It is enough to just introduce them to the very basics.

Definition of an element

Ask Student Teachers what they think is an 'element'. As a prompt, remind them of the separating activity in the previous session. Ask how much further they could theoretically separate matter. They should realize that an element is the smallest form matter can be in. An element can't be decomposed into any smaller substances.[3] Elements are made up of atoms (of the same kind).

Ask them which elements they already know and where they appear in everyday life. Help them find each element they mention on the periodic table. Focus the remainder of the lesson on interpreting the additional information contained in the periodic table (see also suggestion 1).

Unit 6/week 15: States of matter

(Sessions 4–6)

In week 2, revisit the concept of state of matter with Student Teachers. The first part of the week (session 4 and parts of session 5) should focus on exploring states of matter and changes of states of matter in hands-on activities. The inquiry provides them with a shared experience to build a foundation for more detailed group and class discussions in sessions 5 and 6. In those sessions, you will introduce particle theory and discuss the models of states of matter.

3 At this point, it is not necessary to address radioactive elements that decay naturally into smaller particles

Suggested activities for sessions 4–5

Water

Have Student Teachers carefully observe what happens when an ice cube (if available) or tap water is slowly heated to 100 degrees Celsius. If possible, conduct these activities in small groups rather than as a class demonstration. Also, if available, have them use a thermometer to take measurements throughout the heating process. Then have them record their data points.

A note on guiding Student Teachers' activities/mini-experiments: some of them may not be comfortable conducting small experiments on their own. If this is the case, provide them with more detailed instructions on how to perform the experiment. Also, explain how to record the measurements. For instance, you can make it easier by:

- providing the materials and step-by-step instructions for the procedure
- assigning roles
- providing an empty data table to be filled in
- telling them how often to record the data (for instance, each time they see a change, every 10 seconds, randomly, etc.).

For more advanced Student Teachers, keep the instructions open. They then have the opportunity to apply their knowledge and conduct the experiment in an open-ended inquiry fashion. This might take longer than just conducting a demonstration. However, deeper learning takes place in open-ended inquiry to justify the time. Over the course of this semester, strive to give them fewer instructions on how to set up an experiment. They usually embrace the opportunity to work on their own. Also, the resulting discussion among them fosters learning and can reveal misconceptions you might have otherwise missed. In addition, richer and more natural discussions will occur when you discuss their findings. You can have them defend not only their results, but also how they recorded and presented their data. Even if their methodology is not exactly how a scientist might have conducted the experiment, do not judge or correct them at this point. Instead, encourage the class to take ownership and comment on, critique, and reflect on their peers' presentations. Big and obvious mistakes should be detected by the Student Teachers and corrected. Lack of knowledge on the particle level will be addressed in the next session; they will have a chance to revise and fine-tune their thinking then.

Once Student Teachers have conducted their experiments and recorded their observations and data, discuss their findings. Make sure you revisit the physical properties of last week. Solicit their observations on the physical properties of water.

Also, use Student Teachers recorded data points to mark the important point when ice melts and water begins to boil. Establish the terms melting point and boiling point. Ask them to speculate what is happening with the water at these points. Ask whether that is unique to water or whether those findings might be transferable to other substances. Encourage them to be as specific as they can be when describing what they see. But they should also hypothesize what might be happening on a much smaller level (the particle level), which is invisible to them.

The point of this discussion is twofold:

1) To apply the notion of physical properties revisited in week 1
2) To solicit Student Teachers' prior knowledge on states of matter

Encourage Student Teachers to brainstorm even if they are not sure about the correct answer. Make sure they always support their thinking with as much scientific reasoning as possible.

Move on and refocus their attention on the 'bubbles' in the boiling water. Ask them what they think they are. Not all Student Teachers might conclude that the bubbles are caused by water in a gas state; however, they might think that it is air or oxygen. Do not correct them at this point. Instead, ask the class to design an experiment for each hypothesis that would prove or disprove their points. If time allows, have them carry out these experiments. It is a good opportunity to discuss how to conduct an experiment, starting with a hypothesis to finalizing a shared conclusion.

Gases

Gases are more difficult to understand than solids or liquids. But you could also use gases to begin a discussion about states of matter. Remind Student Teachers of the solid and liquid mixtures used in the mystery activity during week 1. Ask them whether they can think of a mixture that consists of gases. Air would be an example they might mention. Push their thinking by not just accepting the right answer, but continue asking them what they think air is. What's in it? How do they know? Could air be in a liquid form? Could the mystery liquids (or solids) be turned into a gas mixture? What would it take to do so?

Ask Student Teachers to always provide their reasoning for their answer. Do not just accept simple yes/no answers. If they don't volunteer a more detailed answer or explanation, follow up by asking, for instance: why do you think that's the case? Ask the class whether they agree or disagree and why.

If Student Teachers struggle with the mental exercise and discussion, go back to the 'what's air' discussion. Establish a consensus that among many other gas molecules, water vapour is part of our air. (It's visible in the form of clouds or above a steaming cup of tea.) Using water vapour as an example, they should understand that water can exist in all three states. Have them name examples and explain how water changes from one state to the other in nature.

As an outcome of this session, Student Teachers should realize that all substances (and elements) can be found in three different states: solid, liquid, and gas (no need to mention plasma). They should also know that a substance can be in all three states depending on the temperature (pressure). Heating and cooling cause a substance to change from one state to the other. Discuss the meaning of melting point and boiling point. Talk about why they are physical, not chemical, properties. If they struggle with that concept, demonstrate how 10 millilitres of water can be changed from one state to another by adding or taking away energy. Discuss how the physical appearance changes. However, in the end, you have the same amount of water with the same properties as when you began. Therefore, a phase change is a physical change that is reversible, not a chemical change.

Make sure Student Teachers begin to develop a conceptual understanding of physical changes. They need to understand that the substance (for instance, water) only changes its state. But the water molecule (H2O) is present and unchanged in all three states. The composition and the atomic structure of the molecule remain unchanged at all times.

Suggested activities for sessions 5–6

States of matter and particle theory

Most Student Teachers have seen the models for states of matter in textbooks. As a result, they might be able to recall some of the basic descriptions.[4] However, most often they are only able to recite what they memorized. They lack a deeper conceptual understanding of particle theory. Therefore, it is it is essential to spend time developing this deeper understanding. Listen carefully to their ideas to prevent misconceptions.

Syringe with air

In this activity, establish the concept that gases are matter and that gases can be compressed. (Demonstrate, for instance, by compressing a closed syringe that contains nothing but air.) Ask Student Teachers what they observe and how they would explain what's happening inside the syringe. Push their thinking until they visualize the particles that are inside the syringe.

First, have them draw a picture that represents the syringe and the air inside. Discuss how they could represent the air in the syringe in their drawing. What kinds of particles are in air? Have them discuss a visual representation that reflects their understanding. How would they include the gas molecules in the drawing? Make sure they understand that air is a gaseous mixture of different molecules, such as nitrogen, oxygen, and so on. Continue the discussion by asking them to zoom in even closer and explain what's inside each molecule (revisit the atomic structure). What's in the space between the particles? Make sure that Student Teachers understand that there is nothing in that space. The concept of 'nothing' is very difficult to grasp because they can't experience it with their senses on Earth. (Often, 'nothing' is confused with air. In everyday language, we say that there is nothing in an empty container, but later we learn that air is in the container).

Second, continue the discussion about what happens if you compress the syringe. Draw a picture of that next to the uncompressed syringe. Student Teachers should realize that the only thing that changes is the space between the molecules. The number and type of molecules do not change; they are just contained in a smaller volume.

Third, relate the particle theory to the states of matter. Show the models of how the particles are arranged in the different states of matter. Make sure that Student Teachers understand that this is a theory. The drawing is a model representing any type of particles in those states. You might also want to discuss with the class what a theory is and what a model is.

Ice to water to steam

Remind Student Teachers of the activity in which they changed ice to water/vapour and that this change of state required energy. Ask them to brainstorm (in pairs) what

[4] An example of such a model can be found at the end of this unit guide.

happens to the water (and its molecules) when it changes from ice to water to steam. Ask them to visualize their ideas on a micro level. Have them draw what they think happens to the particles.

In this session, you may want to talk about the electrostatic forces that hold the particles together. Explain how, by adding energy to the substance, the particles gain more energy in the form of motion. Then the attractive forces between the particles weaken. As a result, the particles move more freely and go from a solid to a liquid to a gas state. (Note: if your Student Teachers are not ready for this deeper understanding, they will learn it in Science II.)

Continue the discussion as laid out in suggestion 1 about the space between particles.

Suggested activity for session 6

Checking understanding about states of matter

At the end of session 6, make sure that Student Teachers understood the main principles of the concepts covered. Confirm that they do not have any misconceptions. To do this, you might want to use the following questions to begin a conversation. Set aside ample time to repeat an explanation or even an experiment if several of them still struggle. Do not proceed unless they are ready.

Ask these and other open-ended questions to check for understanding:

- What is matter, and what is matter made of? Is there anything in the universe that isn't matter? What makes one kind of matter different from another kind of matter?
- Solids, liquids, and gases differ in the ability of particles to move around and away from each other. But all matter is mostly empty space. Where do you find that empty space? Do solids have as much empty space between particles as gases?
- All physical and chemical changes are due to changes in the arrangement and motion of particles. If you melt something, is it still the same substance? What if you grind it up? When you vaporize water, does any matter disappear? (If you pour acid on a substance, is it still the same? Note that this last question is for only those Student Teachers who have prior knowledge of chemical change. This unit guide only alludes to chemical change in contrast to physical change. It does not cover chemical reactions, which are covered in Science II. It is strongly suggested not to teach chemical reactions in this unit but to wait until Science II.)

Watch and listen for the following common misconceptions:

- Student Teachers might think that only inorganic matter is made up of particles/atoms. Make sure they understand that all matter is made of particle atoms. This doesn't just include chemicals or inorganic matter, but also includes everything that has mass (whether it is visible or not to the naked eye).
- Student Teachers might accept that living things are made of cells and biological molecules. However, they might persist in the idea that organic matter (especially cells) are not made of atoms. This misconception may be related to difficulty understanding the very small size of atoms and molecules.
- Because gases have a very low density and are very light, many Student Teachers believe that gases are 'weightless'. Because they have no mass, they think they can't be matter.

- The notion of 'nothing' or a 'void' is very difficult to understand. Student Teachers might infer from a visibly 'empty beaker' that contains just air that similarly, on the particle level, the empty space in between particles is filled with air. It is crucial for them to get a good grasp of scale when talking about matter, particles, and subatomic particles.

Unit 6/week 16: Teaching matter in elementary grades

(Sessions 7–9)

This week, you should prepare Student Teachers for their teaching of science in elementary school. It is essential to support them in making the transfer from their own study of science to becoming a teacher of science in the elementary grades. Many teaching strategies and pedagogies learned in this course are transferable to teaching at elementary grades. However, the content, activities, and learning objectives must be adjusted to reflect the difference in age and prior knowledge.

Suggested activity for session 7

Establishing content for elementary grade science

Start this session by explaining to your Student Teachers that this week you will switch from teaching them content that enhances *their* science understanding to discussing how they as teachers will foster the science learning of young pupils in elementary school.

Ask your Student Teachers to reflect on the past two weeks and the content covered. Have them work in pairs and jot down ideas about how they could teach the topic of matter to children. What kind of science topics would be relevant to teach in grades 1–8? Which principles and concepts do they need to establish as a foundation for learning science in high school and beyond regarding properties of matter, states of matter, and particle theory? What main ideas or concepts should be covered with these young children?

Possible answers are almost endless. This is not the time to approve or correct their ideas. Instead, have your Student Teachers discuss the ideas with each other. Have them explain their reasoning. Only interject if the discussion wanders too far off the topic of physical science and matter. Record their ideas on the board or on a poster so that you can refer back to them in the next session.

Also, have your Student Teachers consult Pakistan's National Curriculum for General Science in grades 1–8. Have them analyse whether they have missed any relevant topics that they want to add now. You might want to form groups for different grade levels, for instance, grades 1–3, 4–6, and 7–8. Again, focus the discussion on only science concepts that relate to matter.

Suggested activities for sessions 8–9

Designing activities for elementary grade science

Grades 1–3 do not explicitly specify 'matter' as learning content. However, it is somewhat contained in topics like water, resources, and weather. In addition, you need to teach the following process skills:

- Asking questions
- Problem solving
- Making an argument
- Defending an idea
- Making and recording observations
- Categorizing

These skills should be taught in meaningful context at all grade levels and can certainly be introduced in grades 1–3.

Regardless of the grade level, water is a theme that allows for inquiry teaching of various science concepts, such as state of matter, buoyancy, and density. Research has shown that the concept of matter is a difficult concept to understand. Even college Student Teachers still struggle with the conceptual understanding and have various misconceptions. Building a conceptual understanding of matter and particle theory requires a solid foundation that should be developed over the years. Carefully crafted learning progressions and activities will help lay such a foundation.

For all the following suggestions listed (water, matter, change of state), begin by using ideas generated by Student Teachers that you recorded in session 7. Have them choose a specific topic and grade level that they will discuss in a small group and elaborate on. Their task is to identify age-appropriate activities that teach their concept of choice to children in elementary grades. Remind them to use hands-on inquiry activities if possible and to make them intriguing. What kind of question could children in elementary grades investigate? What kind of challenge could they solve, and what concept would they learn as a result? What kind of learning outcomes could be expected at that age level?

If Student Teachers struggle to come up with activities or lessons that they can teach in elementary grades, you might want to provide them with some of the following ideas to build upon.

Water (buoyancy and density)

Water is easily obtainable and has many properties that you can use to teach various concepts, such as buoyancy and density, in the classroom.

Present some problems involving the sinking and floating of liquids in each other and solid objects in the same liquids. Have children take careful measurements and observe the relationship between the mass and volume of liquids and solids. These experiences lead to the concept of density, which is one of the properties used to identify a material.

Matter

If children struggle to come up with challenges or ideas for activities, supply some examples, such as the following:

- Is an empty glass really empty?
- What is air? Air is matter and matter has mass, but how can you verify that?

- How does a tree grow from a tiny plant? What does a plant need to grow? Why do you get taller/bigger?
- Some things you can't see with the naked eye. This is an introduction to the microscopic world and beyond.

Keep reminding them that a chosen activity needs to be a good example of investigating a specific science concept. It's not enough if the activity is just a fun experiment. Meaningful learning needs to be supported by it. In addition, the activity needs to be aligned with the children's prior knowledge and age.

Change of state

Water is a substance (molecule) that is found on Earth in all its states (solid, liquid, gas). Student Teachers could use the activities they conducted in the past two weeks and modify them appropriately for children in elementary grades. Use questions such as: if you melt something, is it still the same substance? What if you grind it up? Where do the water droplets come from that form outside the glass of an ice-cold drink? Why are states of matter important? Think about using the weather or the human body as challenges to build an activity on.

Suggested learning progressions for 'matter'

In all the preceding activities, it is important that the Student Teachers understand the expectations for the children in elementary grades. Science content can and should be taught to young learners. However, it needs to happen in an age-appropriate, concrete, and hands-on inquiry way. Children can be expected to observe, for instance, changes of state and develop a sense for the factors that affect the changes of state. But it is too early for them to understand their observations on a molecular level. Especially in grades 1–5, you need to design the learning experiences to help them establish a base on which to build future, more abstract learning.

A child in grades 1–3:

- Builds awareness that objects can be described by their physical properties
- Examines how properties of objects may differ from the properties of the materials by which they were made
- Investigates changes in the observable properties of materials due to heat, cold, and exposure to weather
- Demonstrates that water can be changed from one state to another and that these changes are reversible
- Concludes that materials can exist as solids, liquids, and gases that have describ able differences

A child in grades 4–6:

- Gains an understanding that mass is conserved even when materials are reshaped or broken into smaller pieces
- Recognizes that materials have properties that are independent of the shape or size of the sample
- Explains that water can change from one state to another by heating or cooling

- Explains that some materials may be composed of pieces too small to see without tools that magnify the material
- Investigates how some common materials interact to form new materials

A young adult in grades 7–8:

- Describes matter (e.g. chemical substances, common materials, living organisms) as being made of enormous numbers of minute particles called atoms (e.g. by referring to mixtures, pure substances, etc.)
- Demonstrates the relationship between the structure and the properties of matter, focusing on the physical properties of substances

A word about prior conceptions

As an adult, you try to make sense of your surroundings. When you encounter a phenomenon, you try to explain it using your prior experiences and knowledge. Children do the same, but their experiences and prior knowledge are more restricted. Some of their thinking might seem strange to you.

One major preconception about matter that young children might bring to the classroom is that anything invisible is not matter (for example, air or any gases). For them, air or gases are too light to be made up of matter, and they have no mass. On the other hand, some children might believe that a shadow is matter because it seems to be attached to objects and it can move. Such preconceptions are fine at a young age. With the help of carefully designed and scaffolded activities, young children will gradually observe outcomes that challenge their prior understanding. They will encounter situations and questions that will lead them to revise and fine-tune their conceptions as their conceptual understanding grows. This is a gradual process that might last throughout high school or even into college. It is the delicate task of the teacher to decide at which level the child or young adult is expected to have a certain level of conceptual understanding. Teachers should guide them accordingly in their quest for acquiring new understanding.

Course Resources

FACULTY RESOURCES

Faculty Resource: Unit 1, week 1, session 2

Three figures

(Original source: *Teaching the Nature of Science* by Wynne Harlen, Figures 5–7 (p. 47–50))

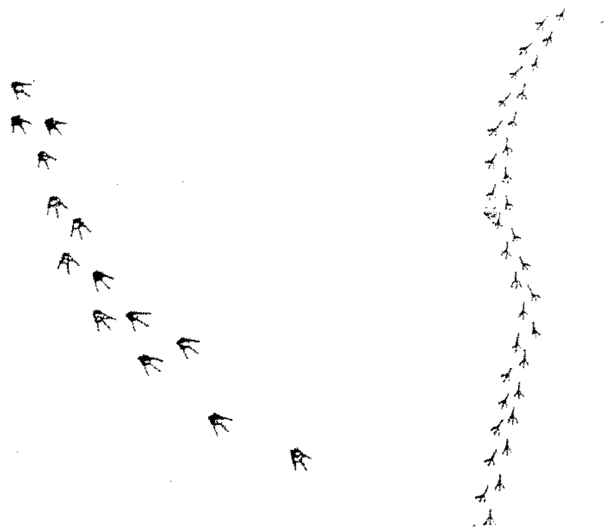


FIGURE 1

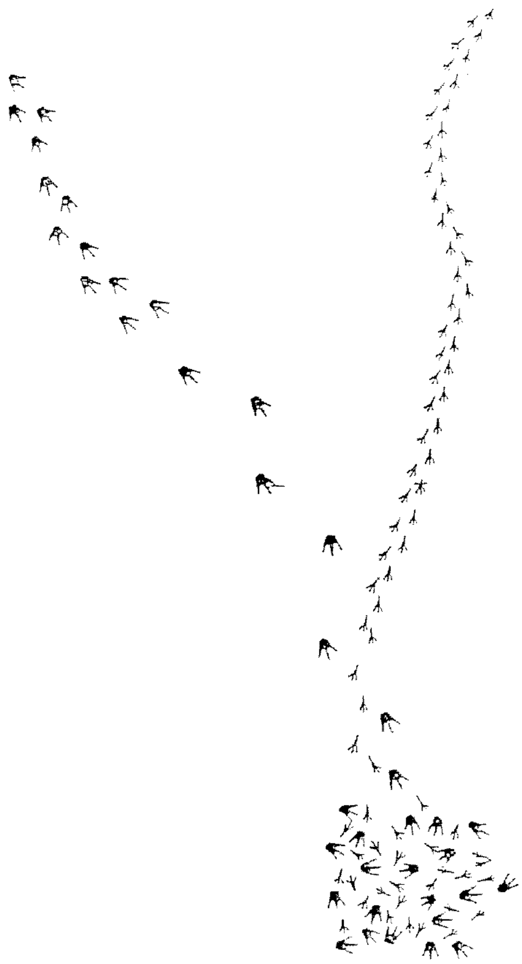


FIGURE 2

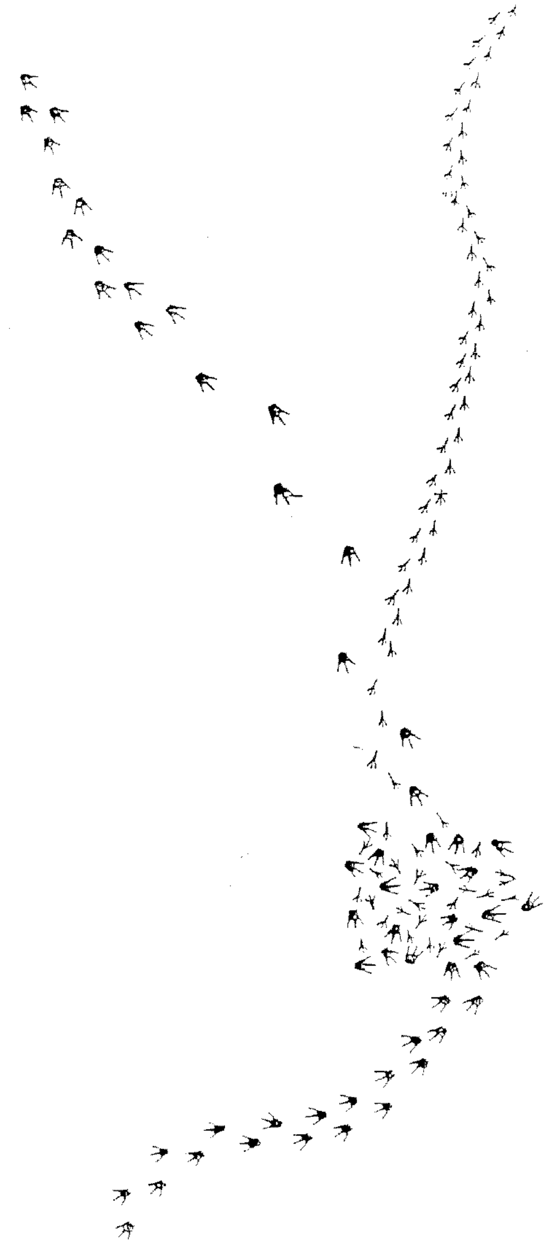
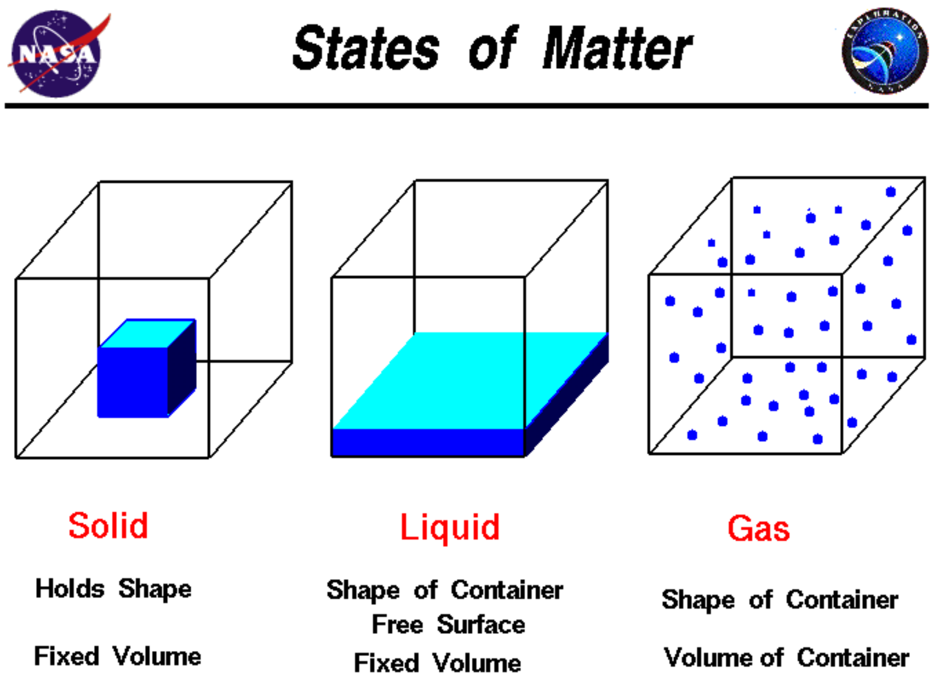


FIGURE 3

States of Matter



Source: NASA website

➢ (http://www.nasa.gov/offices/education/programs/national/dln/events/States-of-Matter-Final.html).

Main takeaway: in all three states, the same molecules of water (H2O) are present.

Additional resources

Chemistry: Matter and Change. The McGraw Hill Companies, Inc. (2005.)

- Chapter 3: Matter—Properties and Changes, p. 54.
- Chapter 6: The Periodic Table and Periodic Law, p. 150.
- Chapter 7: The Elements, p. 178.

Beyond Appearances, Chapters 4, 5 (Misconceptions).

➢ www.chemsoc.org/pdf/learnnet/rsc/miscon.pdf.

WebElements. 'The Periodic Table on the Web'.

➢ http://www.webelements.com.

Khan Academy. 'Periodic Table Trends and Bonding'.

➢ http://www.khanacademy.org/science/chemistry/periodic-table-trends-bonding.

Khan Academy. 'States of Matter'.

➢ http://www.khanacademy.org/science/chemistry/states-of-matter.

Appendix

Professional Standards for Teaching Science

In 2009, the Ministry of Education passed into policy a set of National Professional Standards for Teachers in Pakistan (NPSTP). The 10 standards describe what a teacher should know, be able to do and be like (with regard to knowledge, skills, and dispositions).

The following is a list of standards specific to the teaching of science. They were developed to be used in conjunction with the three science courses in the B.Ed. (Hons) Elementary / ADE. They provide a description of the knowledge, skills, and dispositions a teacher requires to teach science.

This set of standards for teaching science is linked to the NPSTP. The first standard in the NPSTP concerns Subject Matter Knowledge – the knowledge, skills, and dispositions a teacher requires to teach the content of the National Curriculum. In the NPSTP, knowledge, skills, and dispositions are described in general terms for all subjects. Here, they are described specifically for teaching science.

The standards for teaching science may be used by Instructors and Student Teachers in a variety of ways, including for assessment (including self-assessment) and planning instruction. The standards may also be used as part of instruction. Helping Student Teachers deconstruct and understand the standards (and what they 'look like' in the classroom) will help them learn about teaching science.

Subject Matter Knowledge (Teaching Science)

Knowledge and understanding

Teachers know and understand the following:

- the national curriculum framework for science
- the science domain; basic science concepts and theories; the history and nature of science; how to conduct experiments, collect, and analyse data; how to represent data visually; and the structure and process of acquiring additional knowledge and skills in science
- the evolving nature of science, its content, and the need for keeping abreast of new ideas in particular as they relate to teaching science
- the findings of latest science research and the latest trends at the national and international levels as they relate to teaching science
- in-depth knowledge of the subject matter and its relationship to other content areas
- the relationship between science and other disciplines and subjects, and science's usability and applications in everyday life.
- the relationship between reading, writing, and arithmetic principles and science

- that science is more than the accumulation of established scientific knowledge – it is an ongoing process
- that science content and science pedagogy cannot be separated and an effective lesson plan makes best use of both in a synergistic manner.

Dispositions

Teachers value and are committed to doing the following:

- facilitating learning in a variety of ways to help learners to construct knowl edge and understanding in science and to develop the skills required to do science
- providing meaningful learning experiences that lead to deep understanding of the topic, not just memorization of facts
- creating a challenging but non-threatening learning environment
- recognizing the diverse talents of all students and helping them to develop self-confidence and science literacy
- believing that *all* children and adolescents can learn science at high levels and achieve success
- identifying learner-relevant science content and teaching it in ways that connect to learners' daily lives
- teaching students how to think critically about information and how to make informed decisions that will affect their personal lives, careers, and society
- believing that the scope of science content is unlimited and can change
- believing in life-long science learning and in being part of a learning community.

Performance and skills

Teachers demonstrate their knowledge and understanding by doing the following:

- designing and teaching science lessons that take into account the learner's biological maturation, prior knowledge and experience, *and* present challenges and opportunities for new learning
- using tools and methodology of inquiry appropriate to the nature of science and the content being taught
- effectively explaining concepts and ideas in science from multiple perspectives and in multiple ways appropriate to the students being taught
- giving examples of how content can be applied in daily life
- encouraging 'scientific habits of mind' by asking relevant, open-ended questions and by creating opportunities for students to ask questions, analyse situations, and solve problems
- asking challenging, open-ended questions (rather than questions that depend on memorization of facts) to help students construct conceptual scientific understanding
- modelling skills and dispositions for scientific inquiry, including curiosity and openness to new ideas and data
- using teaching strategies that help learners to become aware of inconsistencies in their own or others' thinking and, thus, to construct new understanding
- facilitating laboratory work and hands-on activities to develop skills and techniques as well as to construct new scientific ideas

- arranging opportunities for discourse about scientific ideas to help learners develop evidence-based reasoning skills
- adapting available curricula, materials, and teaching strategies to fit the diverse needs of all learners
- promoting deep scientific understanding by applying the nature of science and inquiry in conjunction with core science concepts and ideas.

Adapted from National Professional Standards for Teachers in Pakistan. Policy and Planning Wing Ministry of Education Government of Pakistan. Islamabad, February 2009. Available from:

➢ http://unesco.org.pk/education/teachereducation/files/National%20Professional%20Standards%20for%20Teachers.pdf

References

National Research Council, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (Washington, DC: National Academy Press, 2011).

National Research Council, *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (Washington, DC: National Academy Press, 2000).

National Research Council, *National Science Education Standards* (Washington, DC: National Academy Press, 1996).

Higher Education Commission