DISSERTATION

A QUALITATIVE STUDY OF COLLEGE STUDENTS' CONCEPTIONS OF RIVERS

Submitted by

Julie Marie Sexton

School of Education

In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY JULIE M. SEXTON ENTITLED A QUALITATIVE STUDY OF COLLEGE STUDENTS' CONCEPTIONS OF RIVERS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

Committee on Graduate Work

James Banning

Ronald Narode

Eric Riggs

R. Brian Cobb, Adviser

Paul Kennedy, Co-Adviser

Timothy Davies, Interim Director

ABSTRACT OF DISSERTATION

A QUALITATIVE STUDY OF COLLEGE STUDENTS' CONCEPTIONS OF RIVERS

This study explored two research questions: 1) What are college students' conceptions of river topics and 2) What are the emergent patterns between students' conceptions and their gender and ethnicity? A basic interpretive qualitative research design was used. Purposeful sampling was used to recruit 24 college students from an introductory geology class. In-depth interviews were conducted and a demographic questionnaire administered. Interview responses were analyzed using a modified version of constant comparative analysis. Between-gender patterns and between-ethnic group patterns of the type of conceptions held were investigated by calculating relative likelihood statistics.

Four findings emerged. Finding 1: students held mostly scientific and incomplete scientific conceptions of the nine river topics covered in the study. Finding 2: students' conceptions were complex. In addition to scientific and alternative conceptions, students also held incomplete scientific, incomplete scientific-alternative, and scientific-alternative conceptions. Individual students held a range of conceptions across the river topics. For each topic, there was a range of conceptions held by students. Finding 3: students had more alternative conceptions for processes, causes, and difficult-to-observe features. Finding 4: patterns were observed between students' conceptions and their gender and ethnicity. Men held scientific, incomplete scientific, and scientific-alternative conceptions more frequently than did women. Women held incomplete scientific-alternative and alternative conceptions more frequently than did men. White students held scientific, incomplete scientific, and scientific-alternative conceptions more frequently than did Hispanic students. Hispanic students held incomplete scientific-alternative and alternative conceptions more frequently than did White students.

Julie Marie Sexton
School of Education
Colorado State University
Fort Collins, CO 80523
Fall 2008

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CHAPTER 1: INTRODUCTION

Research in science education and cognitive psychology over the last 35 years has shown that students bring their own ideas, or conceptions, of the natural world to the science classroom and use them to organize, interpret, and learn new science topics (Bransford, Brown, & Cocking, 2000; Driver, Squires, Rushworth, & Wood-Robinson, 1994; 1994). When students' conceptions agree with accepted scientific explanations (e.g., dinosaurs went extinct millions of years before humans appeared on Earth), they are called "scientific conceptions." When students' conceptions differ from accepted scientific explanations (e.g., humans and dinosaurs lived at the same time) they are called "alternative conceptions" (Hewson & Hewson, 1983).

Implications for Teaching and Learning

When students enter the classroom, they must find some way to make sense of scientific topics in light of their pre-existing conceptions (Bransford et al., 2000; Duit & Treagust, 2003). Students' alternative conceptions are often difficult to change and may hinder their learning of new science topics (Duit & Treagust, 2003; Wandersee et al., 1994). Rather than learning new science concepts, students may hold firmly onto their alternative conceptions (Wandersee et al., 1994).

The process students go through to change their alternative conceptions and adopt scientific conceptions can be complex and may require a long time (Driver, 1989; Scott, Asoko, & Leach, 2007; Vosniadou & Ioannides, 1998). There is considerable debate about the best way to modify students' alternative conceptions (Scott et al., 2007). However, there is general agreement that the first place to start in modifying students' alternative conceptions is to understand what the conceptions are prior to instruction (Driver & Oldham, 1986; Duit & Treagust, 2003; Dykstra, Boyle, & Monarch, 1992; Vosniadou, 1991; Vosniadou & Ioannides, 1998; Wandersee et al., 1994). This can be accomplished by reading the literature on common alternative conceptions (for an example of a review see Driver et al., 1994) and eliciting students' conceptions directly (for examples of methods see Abdullah & Scaife, 1997; Treagust, 1988; White & Gunstone, 1992).

After educators and researchers identify students' conceptions, they can design curricula and classroom instruction that will best modify alternative conceptions and strengthen scientific conceptions (Driver & Oldham, 1986; Vosniadou & Ioannides, 1998; Wandersee et al., 1994). Although there is debate about the best way to change students' alternative conceptions, there are best practices recommended by researchers and educators to modify conceptions (for example see Driver & Oldham, 1986; Scott et al., 2007).

Scope of Study

Most of the research on students' conceptions has been in the field of physics (Wandersee et al., 1994). There is now an extensive research base on students' physics conceptions. During the 1970s, 1980s, and early 1990s few studies investigated students' conceptions of geology topics (Libarkin & Kurdziel, 2001). In the last 15 years, the number of published studies to uncover students' conceptions of geology topics has been growing, but there is still a significant lack of understanding in this area (Dove, 1998b; Libarkin & Kurdziel, 2001). This study helps to fill this gap by exploring students' conceptions of a topic in geology.

Focus on River Conceptions

The specific geology topic explored in my study is rivers. Rivers are important surficial geologic processes that shape Earth's landscape. They are important to civilization because of their role in commerce, drinking water, agricultural irrigation, ecosystems, and so forth. College students taking introductory geology classes should understand river features and processes (Englebrecht, Mintzes, Brown, & Kelso, 2005; Kelso, Brown, Mintzes, & Englebrecht, 2000). Despite the importance of rivers, little research has focused on students' conceptions of rivers.

The studies that have been done have focused primarily on 9- to 12-year-old students. My study complements these studies and helps fill the gap in understanding of river conceptions by focusing on college students' conceptions. Research on students' conceptions of various geology and non-geology topics has shown that some conceptions are resistant to change and that students across grade levels hold similar alternative conceptions. My study identifies river conceptions held by students who have completed their K-12 education and compares these conceptions to those that have been identified in younger students. This has important implications for both K-12 and post-secondary pedagogy. It reveals which alternative conceptions are either not addressed or resist correction during K-12 education and provides college introductory geology instructors with information about their incoming students' alternative river conceptions, which can be used to design instructional strategies that promote adoption of scientific conceptions.

Factors that Influence the Development of Conceptions

Students' conceptual development may be influenced by multiple factors, including their personal experiences (e.g., direct observation of the natural world), social and cultural experiences, teachers' explanations, textbooks, information from the media, and so forth (Driver et al., 1994; Scott et al., 2007; Wandersee et al., 1994). Understanding the factors that influence students' conceptual development may help educators and researchers plan curricula and pedagogical strategies to improve student learning (particularly to change students' alternative conceptions) (Driver et al., 1994). For example, if educators and researchers discovered that students with good spatial abilities develop better understanding of geology topics, then they could develop curricula and classroom instruction that improve students' spatial ability in order to facilitate geology learning.

The specific factors influencing students' conceptual development are often difficult to determine because students generally cannot identify the factors that influence their own conceptual development (Schoon, 1995; Wandersee et al., 1994). To investigate the relationship between students' conceptions and possible factors, researchers typically identify conceptions, collect information about possible factors influencing conceptual development, and look for qualitative and quantitative relationships between the conceptions and the factors.

Research on students' conceptions in physics shows that students from different cultural, ethnic, gender, and age groups often hold similar conceptions of physics topics (Driver et al., 1994; Wandersee et al., 1994). There are too few studies on students' conceptions in geology to know if, as in physics, students from diverse groups hold similar conceptions. This study contributes to the conceptions field by investigating the relationship between students' conceptions of rivers and several possible factors that influence conception development.

Theoretical Framework

This study is a qualitative investigation of students' conceptions of rivers. Constructionism forms the epistemological foundation of most qualitative education research (Crotty, 1998; Merriam, 2002) and most empirical studies in science conceptions research (Driver & Erickson, 1983). Constructionism and interpretivism, a philosophical perspective situated within the constructionism epistemology, guided this study. Additionally, an emerging cognitive theory arising from the last 35 years of science conceptions research guided this study.

Constructionism maintains that individuals construct knowledge, rather than discover it as described by objectivism, and give meaning to that knowledge (Crotty, 1998). Interpretivism is a philosophical perspective that states that individuals' understandings of their experiences and world are historically and culturally situated.

Additionally, individuals construct knowledge through social interactions and by directly interacting with the natural world (Crotty, 1998).

Influenced by constructionism and interpretivism, many science conceptions researchers believe that students develop conceptions about the natural world through direct interactions with the natural world and through social interactions (Driver & Oldham, 1986; Wandersee et al., 1994). Situated in the interpretivism perspective, the purpose of conceptions research is to uncover and interpret the conceptions that individuals have of the world around them and to determine the factors that influence the development of those conceptions (Wandersee et al., 1994).

In addition to the epistemological and philosophical perspectives already mentioned, science conceptions research is guided by cognitive theories about how students learn (Driver, 1989; Duit & Treagust, 2003; Scott et al., 2007; Wandersee et al., 1994). The conceptions research field emerged in the 1970s with growing interest in how students learn science. The work in the 1970s built on Piaget's stage theory and Ausubel's meaningful learning theory (Driver, 1989; Wandersee et al., 1994). The cognition theories guiding conceptions research evolved over the last 35 years and moved beyond Piaget and Ausubel's work, although their work remains as a foundation. The cognitive theory now guiding conceptions research is a synthesis of constructivist learning theory (for a review of the theory see Driscoll, 2000), conceptual learning theories (e.g., conceptual change theory, social constructivism theory, and situated cognition) (for reviews of the theories see Duit & Treagust, 2003; Scott et al., 2007), and the work on learning by Piaget, Ausubel, Vygotsky, Driver, Posner, Strike, and others (Driver, 1989; Driver & Erickson, 1983; Driver et al., 1994; Gilbert & Watts, 1983; Scott et al., 2007; Wandersee et al., 1994). Although there is no official name for this new conceptions research theory, and it is not yet well defined, Wandersee et al. (1994) reviewed 20 years of conceptions research articles and summarized the general claims (Table 1).

Table 1

Claims that Make Up the Science Conceptions Theory

Claim 1:	learners come to formal science instruction with a diverse set of alternative conceptions about the natural world
Claim 2:	students from different age levels, ability levels, genders, and cultural boundaries hold similar alternative conceptions
Claim 3:	alternative conceptions are resistant to change by conventional teaching strategies
Claim 4:	alternative conceptions often parallel explanations of the natural world offered by previous generations of scientists and philosophers
Claim 5:	students' conceptual development is influenced by their personal experiences, culture, language, and instructional experiences related to claim six
Claim 6:	teachers often hold the same alternative conceptions as their students
Claim 7:	students' prior knowledge interacts with information presented in formal instruction, often resulting in unintended learning outcomes
Claim 8:	there are instructional strategies that facilitate conceptual change

Note. From Wandersee et al. (1994).

These claims form a framework around which the theory guiding conceptions research is structured. The claims are compatible with the epistemological and philosophical assumptions in my study. They acknowledge that students construct and give meaning to their conceptions through social interactions and through interactions between the individual and the natural world.

Researcher's Perspective

I approached this research from the perspective of a scientist and an educator. I have B.A. and M.S. degrees in geology and have worked as a geologist. This background places me in the culture of science. I value science as a fundamental discipline through which individuals can understand the natural world. I believe that scientific literacy is important to the individuals in our society who are confronted daily with issues that require knowledge of science to solve.

I am also in the culture of education. I have worked for the last nine years in the field of education, and my current Ph.D. program is in the School of Education. I believe in improving science education in the geology by learning how students learn and understanding students' conceptions. I believe that scientists, educators, and students construct knowledge through social interactions and through direct interactions with the natural world. I am aware that, during the interviews in this study, students were constructing knowledge. As such, I understand that my interaction in the interviews influenced and shaped the conceptions that the students expressed.

Research Questions

This study contributes to the conceptions literature by exploring students' conceptions of rivers. It uncovers students' conceptions of the river features and processes typically taught in college-level introductory geology courses. These conceptions were explored before the students received formal instruction on rivers in their geology class. The following are the specific research questions this study addresses:

1. What conceptions of river features and processes are held by college students enrolled in introductory geology classes? Which of these are scientific conceptions and which are alternative conceptions?
2. What are the emergent patterns between students' conceptions and their demographic and background characteristics?

Limitations

This study has limitations. Some conceptions about rivers may not have been uncovered. The study relied on volunteer participants, and students who did not volunteer may have had conceptions about rivers not held by the students who did volunteer. Additionally, some students had difficulty articulating their conceptions verbally or through drawings. This is a difficult challenge in the context of research. If a participant seemed to struggle expressing ideas, I used different questioning strategies that probed the participant in various ways to help the participant articulate his or her conceptions.

I interviewed each student once, which offers only a snapshot of the student's conceptions at the time of the interview. This study does not reveal the dynamic changes students' conceptions undergo. These dynamic changes are important to educators who want to know how curriculum and pedagogy affect student conceptual change, but conceptual change was not within the scope of this study.

Finally, I was the primary instrument of data collection; therefore, the data were interpreted by me, filtered through my lenses and perspectives. Another researcher with different lenses and perspectives may have developed a different interpretation of the data. This is an inherent and integral part of qualitative data analysis, which must be considered when the data are analyzed and presented.

Definitions

Alternative conceptions: conceptions at variance with scientifically acceptable conceptions (Hewson & Hewson, 1983).

Conceptions: students' personal ideas or hypotheses about the world (Gilbert & Watts, 1983). Students develop their conceptions through their personal experiences with the natural world and through social interactions (Wandersee et al., 1994).

Earth science: Study of the earth including the subdisciplines geology, astronomy, oceanography, and meteorology. The term is used interchangeably with the term geoscience.

Extrinsic factors: Those characteristics that are external to the student and are derived by people or objects external to the student or are created by the students' interaction with the external world. An instructional method is an example of an extrinsic factor.

Geology: The study of the Earth and its origin and evolution. It is also the study of the materials that make it up and the processes that occur within and on it (Chernicoff & Fox, 2000).

Geoscience: Study of the earth including the subdisciplines geology, astronomy, oceanography, and meteorology. The term is used interchangeably with the term earth science.

Intrinsic factors: Those characteristics that are inherent or internal to the student. Age is an example of an intrinsic factor.

Modified constant comparative analysis: A method used to analyze qualitative data. The typical method has three levels of coding: open, axial, and selective (Strauss & Corbin, 1998). The modified version used in this study only uses the open and axial levels of coding.

Scientific conceptions: Conceptions that are in agreement with the scientifically accepted ideas (Hewson & Hewson, 1983).

CHAPTER 2: LITERATURE REVIEW OF STUDENTS' CONCEPTIONS OF RIVERS

This literature review is separated into two chapters. Chapter 2 reviews students' conceptions of rivers. Chapter 3 reviews factors that influence students' conceptions of geology topics in general and of rivers in particular.

A systematic and thorough review was conducted to identify studies that investigated students' conceptions of rivers. The steps of the review and the number of articles resulting from each step can be found in Table 2. The first step was to establish inclusion criteria for studies (Appendix A). Only studies meeting the inclusion criteria were included in the review. During the second step, search terms were developed and research databases were searched (Appendix B shows the research databases that were searched and the search terms used).

The third step was to conduct a search of publications that were not found in the search of the research databases. Publications can be overlooked during the search of a research database because the search terms do not match the key words for a particular publication (Paterson, Thorne, Canam, & Jillings, 2001). Therefore, publication lists from geoscience conceptions researchers were acquired, and the reference lists included in geoscience conceptions studies were reviewed to find studies that were not found during the search of research databases.

During the fourth step, the abstracts of the articles identified in steps two and three were reviewed. Those publications meeting the inclusion criteria based on review of the abstracts were selected for the next step. It is not always possible to determine if a publication meets the criteria just by reviewing the abstract. Therefore, those publications identified in step four were acquired and reviewed in full for step five. Only those publications that, when reviewed in full, met the inclusion criteria were included in the literature review. Eleven studies completely met the inclusion criteria. The sixth and final step of the review was to analyze the publications. The primary goals of the analysis were to identify students' conceptions of rivers.

Table 2

Literature Review Steps to Identify River Conceptions Studies

	Steps	Resulting Number of Articles
Step 1.	Establish inclusion criteria.	NA
Step 2.	Develop search terms and search research databases.	2213
Step 3.	Conduct search for publications not found in the research databases.	20
Step 4.	Review abstracts of articles identified in steps two and three. Select and obtain publications meeting inclusion criteria based on review of abstracts.	20
Step 5.	Review in full those publications selected in step four. Select publications meeting inclusion criteria based on review of full publication.	11
Step 6.	Analyze the publications for review.	NA

Overview of Studies Investigating Conceptions of Rivers

An overview of the studies investigating students' conceptions of rivers is in Table 3. Most of the studies focused on the conceptions of elementary school students.

Two studies investigated college-level students' conceptions of rivers. Sample sizes ranged from 9 to 1,213. Three studies did not provide sample sizes. Almost all the studies were conducted in countries outside the United States.

The studies mainly used qualitative data collection techniques like interviews and drawings (Table 3). Quantitative content analysis was used by all but two studies (Table 3). A few studies did not explicitly describe their analysis methods (e.g., Englebrecht et al., 2005; May, 1996; Trend, 1998) but only provided a summary of the data without describing how data were analyzed. Based on the description of the data in the studies, analysis methods were inferred.

The studies investigated conceptions in two major categories: students' definition and characteristics of rivers and students' understanding of river processes. The findings in each category are discussed in the following sections.

Conceptions of the Definition and Characteristics of a River

Several studies investigated students' conceptions of the definition and characteristics of a river.

Definition of a River

An appropriate starting place in conceptions research and in the classroom is to identify students' definitions of scientific terms (Harwood & Jackson, 1993; Platten, 1995). A student's use of a scientific term does not indicate that the student holds the same meaning for the term as do educators and the scientific community (Mackintosh, 1999; Platten, 1995). Additionally, students can have incomplete or partial definitions of the term (Harwood & Jackson, 1993). Harwood and Jackson found that some students with limited definitions of physical geography terms (like beach, sea, and river) failed to identify examples of the physical geography terms. For example, when asked to identify a beach from a set of photographs, some students only identified a sandy beach and did not identify a pebble beach. To ensure that students and educators share the same meaning for a term, educators and researchers should determine students' definitions and identify how those definitions compare to the scientific definitions.

Table 3

List of Studies Reviewed that Investigated Students' Conceptions of Rivers

Study	Sample size	Data collection method[a]	Analysis method[b]	Grade level[c]	Country
Cin and Yazici (2002)	80	I	QN	E	Turkey
Dove, Everett, and Preece (1999)	306	D, I	QN	E	UK
Dove, Everett, and Preece (2000)	196	PR	QN	E	UK
Englebrecht et al. (2005)	18-24[d]	I, CM, D	QN	C	US
Harwood and Jackson (1993)	9	I, D, PR	QN	E	UK
Mackintosh (2005), May (1996)[e]	–[f]	CR, WA, D, I, PR	QN	E	UK
Piaget (1929)	–[f]	I	QL	E	Switzerland
Piaget (1930)	–[f]	I	QL	E	Switzerland
Schoon (1988, 1992)	1213	MC	QN	E, M, H, C	US
Trend (1998)	12	CR, PT	QN	E	UK
Wilson and Goodwin (1981)	66	D, CR, WA	QN	E, M	Australia

[a] Key to the data collection methods: I = interview, CR = constructed response questions, D = drawings, MC = multiple-choice questionnaire, WA = word association, CM = concept map, PT = performance tasks, PR = picture recognition. [b] Key to analysis methods: QN = quantitative analysis methods were used, QL = qualitative analysis methods were used. [c] Key to grade level: E = elementary school students, M = middle school students, H = high school students, C = college students. [d] Researchers did not state overall sample size but gave a range for the number of students who participated in the study. [e] These two articles report on the same study. [f] Researchers did not list sample size.

A river is a body of water with defined spatial boundaries, including a channel, that flows from high elevation to low elevation across the land surface under the influence of gravity (Huggett, 2003; Knighton, 1984). One study, described in two articles, explored students' definitions of rivers (see Mackintosh, 2005; May, 1996). May and Mackintosh asked 9- to 10-year-old British students in an urban school to write their definition of the term "river." Students offered a range of definitions (Table 4). May reported that, out of 31 responses, all students associated rivers with water, 10 mentioned that rivers have some sort of movement, 9 associated a shape with a river, 9 described a river as containing things (e.g., sediment or biota), and 9 described a river as flowing through a channel.

Table 4

Examples of Students' Definitions of a River

- "wet water running down"
- "a thing with water in a long ditch"
- "something that flows and has fish and water"
- "a long tube shaped full of water which is not man-made"
- "water that runs around a bank"
- "a long stream of water which has a long strong current which pulls everything along"

Note. Quoted from May, 1996, p. 12.

May (1996) and Mackintosh (2005) did not compare students' definitions to the scientific definition of a river or indicate if students held any alternative conceptions about the definition of a river. Based on the data she provided, it appears that 9- to 10-year-old students correctly associated rivers with water. However, the responses reported in the article are mostly incomplete. For example, one student defined a river as "wet water running down" (May, 1996, p. 12). This definition failed to associate a river with a defined boundary such as a channel. Another student who responded that a river was "a thing with water in a long ditch" (May, 1996, p. 12) correctly associated rivers with water and a channel-like structure—ditch—but failed to acknowledge that rivers flow.

Source of Water in a River

River water can come from several natural sources: groundwater, snowmelt, glacial melt, precipitation (generally rain), lakes, and tributaries (Ahnert, 1998). Humans often discharge water into rivers via such locations as wastewater treatment plants and industrial sites. However, humans are not actually sources of water but mechanisms by which water is transferred to a river; the ultimate source is natural. For example, a town could get its municipal water primarily from groundwater. After being cleaned, the groundwater is piped into homes and businesses for use. Used water is piped to treatment plants, cleaned, and often discharged into local rivers. For the discussion here, the term "artificial source" will be used when students state that humans or human objects (e.g., pipe, canal, fountain, etc.) are the source of water to a river. The term "natural source" will be used for non-human sources of water (e.g., rain) to a river.

Students hold a variety of conceptions about the natural and artificial sources of river water (Table 5). Piaget (1929) investigated 4- to 12-year-old students' conceptions of the source of water in rivers. He found that their conceptions changed with age. At younger ages (before age eight), students thought that humans were the source of water in rivers. The following is a transcript between the researcher and a six-year-old student about the source of river water:

> Researcher: Where does river water come from?
> Student: From a little tunnel.
> Researcher: Where does the water from the tunnel come from?
> Student: From a ditch.
> Researcher: And the water from the ditch?
> Student: Some man took the water from a fountain and put it in pipes.
> (Piaget, 1929, p. 327)

After about age eight, Piaget (1929) found that students generally attributed river water to natural sources. Here are two interviews with students who attributed river water to natural sources:

> Interview 1
> Researcher: And where does the water come from [in a river]?
> Student: From the rain.
> (Piaget, 1929, p. 329)

> Interview 2
> Researcher: And the water of the streams [where does it come from]?
> Student: From the mountains.
> (Piaget, 1929, p. 330)

Piaget (1929) did not probe the students about the meanings of their responses. For example, it is not clear what the student in Interview 2 meant by river water coming from the mountains.

May (1996), Mackintosh (2005), and Harwood and Jackson (1993) found that 9- to 11-year-old students also attributed the origin of river water to natural and artificial sources (Table 5). For example, students in the May and Mackintosh study thought that the following sources contributed to river water (the number of student responses for each source is given in parentheses): rain (13), sea (7), pipes (2), lake (2), ditch (2), and streams (1). Most students attributed the origin to rain, a natural source. Few students identified artificial sources (e.g., pipes and ditches).

Dove et al. (1999) found that 9- to 11-year-old students described several natural sources of water (Table 5). Students drew pictures and verbally described rivers receiving water from mountains, bogs, springs, glaciers, rain, lakes, and other rivers. Dove et al. did not report if students described any artificial sources for river water or analyze students' conceptions about the sources of river water.

Table 5

Students' Conceptions about the Sources of River Water

Source	Study
Natural Sources	
• Rain	Piaget (1929), May (1996), Mackintosh (2005), Dove et al. (1999), Harwood and Jackson (1993)
• Mountains	Piaget (1929), Dove et al. (1999)
• Lakes/ponds	Piaget (1929), May (1996), Mackintosh (2005), Dove et al. (1999)
• Sea	May (1996), Mackintosh (2005), Harwood and Jackson (1993)
• Tributaries	May (1996), Mackintosh (2005), Dove et al. (1999)
• Spring	Dove et al. (1999)
• Glacier	Dove et al. (1999)
• Bog	Dove et al. (1999)
Artificial Sources	
• Pipes	Piaget (1929), May (1996), Mackintosh (2005), Harwood and Jackson (1993)
• Fountains	Piaget (1929)
• Ditches	Piaget (1929), May (1996), Mackintosh (2005)
• Toilet water	Piaget (1929)
• Human saliva and sweat	Piaget (1929)

Artificial Sources

Students' descriptions of rivers receiving their water from various human sources may fit with the experiences that students have had in urban areas where rain water typically flows into gutters, which then discharge the water into nearby rivers through pipes, ditches, or canals. Additionally, natural rivers are often channelized and lined with cement or rocks in urban areas. These channelized rivers may not look like rivers to students, who may conceptualize rivers as flowing in pastoral, natural settings (Dove et al., 1999; Dove et al., 2000). Students may have seen pipes, ditches, and channelized rivers carrying water and assumed that they were the source of river water. The water that flows through the pipes and ditches ultimately came from some natural water source like rain or groundwater. Some students may be unaware of the natural sources. Some students in Piaget's (1929) study thought that human fluids (e.g., saliva and perspiration) were the sources of water in rivers. Piaget does not speculate on why students believed that human fluids are the source of river water.

Mountains and Sea

Students' responses that mountains and the sea are sources of river water require further explanation than that provided by the researchers to understand fully. Students in Piaget's (1929) and Dove et al.'s (1999) studies described river water as coming from mountains. Neither study expanded on what students meant by this response. Further research is required to determine if students believe that the mountains actually provide the water, if students believe that the river headwaters are located in the mountain and that the water has some other source like rain or glaciers, or if students hold some other meaning by saying that the water comes from the mountains.

Students thought that the sea was the source of river water; however, the researchers did not discuss the meaning or significance of this (Harwood & Jackson, 1993; Mackintosh, 2005; May, 1996). The students in the May (1996) and Mackintosh (2005) study lived near an estuary and had been on a field trip to visit the estuary prior to the study. Rivers that flow into the sea often experience the influence of tides, which can force ocean water to flow upstream into the river. By living near an estuary or visiting one during their field trip, students may have observed the sea flowing into the river under the influence of tides. This may have influenced their development of the conception that the sea is the source of river water.

Missing Sources

Students mentioned all but two of the possible natural river water sources: snowmelt and groundwater. None of the researchers hypothesized why the students failed to mention snowmelt and groundwater. Perhaps, in the case of snowmelt, students considered glaciers and snowmelt synonymous.

Suvedi, Drueger, Shrestha, and Bettinghouse (2000) conducted a study of 663 adult Michigan state residents' understanding of groundwater. They found that most participants (82%) understood that groundwater provides water to rivers. It is possible that the adults in the Suvedi et al. study understood that rivers are fed by groundwater because they had more formal and informal education and experience than did the elementary school age students in the Piaget (1929), May (1996), Mackintosh (2005), and Dove et al. (1999) studies.

Incomplete, Scientific, or Alternative Conceptions

None of the studies described which of students' conceptions about river sources were alternative, scientific, or incomplete. Additionally, it is not always clear from the data presented in the studies how a reader of the study should classify students' conceptions. For example, several students in the May (1996) and Mackintosh (2005) study stated that the sea was the source of river water. If these students thought the sea was the only source, then their conceptions could be labeled alternative. However, if the students believed that the sea was only a local source of water at the mouth of the river (caused by tides) and that the primary sources of water to the river originated upstream in the form of precipitation, groundwater, tributaries, etc., then the students' conceptions could be labeled scientific.

Harwood and Jackson (1993) reported that none of the students in their study gave correct multiple explanations for the sources of water. Seven of the nine students gave a single correct source (e.g., rain). None of the other researchers explained if an individual student understood all the possible sources of river water or if a student only thought that river water originated from one source (e.g., all river water came from rain). If a student offered only one or two possible sources, then their conceptual understanding was incomplete. If the student understood all possible sources, then their conception could be considered scientific. In none of the studies did the researchers provide enough information about students' full conceptions to judge whether the conceptions were alternative, scientific, or incomplete.

Origin of a River

Rivers originate in areas of higher elevation and flow to areas of lower elevation. The areas of high elevation can include hills, mountains, and plains. A river's specific beginning can include a lake, marsh, spring, the edge of a glacier or snowfield, and so on. May (1996), Mackintosh (2005), and Dove et al. (1999) investigated students' ideas about the origin of rivers (Table 6). The origins can be divided into two categories: water features and non-water features.

Some students stated that rivers originated on land (Mackintosh, 2005; May, 1996). Although technically true, more probing is needed to know if students understand that there are some places that are more likely than others to be locations where rivers originate. Some students thought that rivers started in hills and mountains (Dove et al., 1999; Mackintosh, 2005; May, 1996). These are possible locations, but rivers also start in the plains and in other areas with only moderate topographical variation; no students identified these types of areas as the origins of a river. Students listed three human structures—walls, sewers, and drains—as the origins of rivers (Mackintosh, 2005; May, 1996). The researchers do not explain what students meant by these locations.

All the water features mentioned, except for the sea and waterfalls, are possible origins of a river (Table 6). Rivers do not start at the sea or at waterfalls; these are alternative conceptions.

Table 6

Students' Conceptions about the Origin of a River

Beginning locations of a river	Study
Non-water feature	
Hills	May (1996) and Mackintosh (2005)
Land	May (1996) and Mackintosh (2005)
Wall	May (1996) and Mackintosh (2005)
Sewer	May (1996) and Mackintosh (2005)
Drain	May (1996) and Mackintosh (2005)
Mountains	Dove et al. (1999)
Water feature	
Sea	May (1996) and Mackintosh (2005)
Pond/lake	May (1996) and Mackintosh (2005)
Waterfall	May (1996) and Mackintosh (2005)
Bog	Dove et al. (1999)
Spring	Dove et al. (1999)
Glacier	Dove et al. (1999)

Destination of a River

Rivers flow to a variety of destinations downslope: into another river, lakes, and the ocean. River water can infiltrate the ground, flow to groundwater, and evaporate into the air (Brown & Bradley, 1995). Two studies investigated students' conceptions of river destinations (Table 7).

May (1996) and Mackintosh (2005) asked students during interviews to describe where rivers end. Most students said that rivers ended in the sea. The students in the study lived near an estuary and had visited an estuary prior to the study. Students' direct experience observing a river flow into the sea could have influenced their conception that rivers end in the sea. A small number of students also responded that rivers end on land, at a wall, or in the sand. Some students also said that they did not know where rivers ended. Here are two of the students' responses:

"I've never been to the end of a river." (May, 1996, p. 13)

"At the end of a river there'd be a wall across." (May, 1996, p. 13)

May (1996) and Mackintosh (2005) did not discuss the responses, so it is impossible to know what the two students meant. For example, it is unclear what was meant by the statement that rivers end at a wall. The student could be referring to a dam.

Dove et al. (1999) asked students to draw pictures showing where rivers ended. The researchers reported that more students knew where rivers ended than where they began. Most students in the study drew rivers ending in the sea. Some students (23%) did not depict rivers ending in the sea, but Dove et al. did not describe the other destinations that these students drew.

An important question to answer is if students thought that rivers had only one destination or if they understood that there are several possible destinations. For example, when Dove et al. (1999) asked students to draw where a river ends, most drew rivers ending in the sea, but it was not clear if students thought that the sea was the only destination. If they thought the sea was the only destination, their conception could be classified as incomplete. Several possible destinations were missing in students' responses, namely groundwater, lakes/ponds, and other rivers. Overall, the studies did not provide in-depth explanation of students' conceptions of the destinations of rivers.

Table 7

Students' Conceptions about the Destinations of Rivers

Destination	Study
• the sea	May (1996), Mackintosh (2005), Dove et al. (1999)
• on land	May (1996), Mackintosh (2005)
• at a wall	May (1996), Mackintosh (2005)
• in the sand	May (1996), Mackintosh (2005)
• do not know	May (1996), Mackintosh (2005)

Physical Nature of Rivers

Several studies include student descriptions of the physical nature of rivers. Wilson and Goodwin (1981) found that students perceived rivers as natural, deep, wide, cold, dirty, flowing, fresh, beautiful, and quiet (Table 8). Additionally, students associated water and currents with rivers. May (1996) and Mackintosh (2005) found that the most common words students used to describe the physical nature of a river were water, cold, and wet (Table 8).

May (1996), Mackintosh (2005), and Wilson and Goodwin (1981) listed the physical characteristics that students associate with rivers, but the researchers did not discuss the significance of these descriptions. All the student descriptions are possible characteristics of rivers, but the most common descriptions do not include the full range of characteristics. For example, some students described rivers as dirty, muddy, and deep; however, some rivers are shallow and clear. The students also described rivers as quiet, but some rivers are loud. The descriptions may not have included the full range of possible characteristics because the students may have been describing local rivers. The researchers did not comment on the relationship between students' descriptions and the characteristics of local rivers. Other researchers investigated how students' experiences with local rivers influenced their conceptions of rivers (see the discussion in the Direct Experience section in Chapter 3).

Table 8

Students' Ideas about the Physical Characteristics of Rivers

Beautiful	Muddy
Cold	Natural
Currents	Quiet
Deep	Water
Dirty	Wet
Flowing	Wide
Fresh	

Note. From Mackintosh (2005), May (1996), Wilson and Goodwin (1981).

River Environments

Several studies investigated how students conceptualize various aspects of the river environment, including the surrounding setting, the surrounding biotic features, and the role of humans in the river environment. Rivers have various shapes and sizes and exist in a variety of physiographic settings (Ahnert, 1998; Huggett, 2003). Rivers can be more than a mile wide, like the Mississippi River, and they can be narrow enough to jump over. They can be more than a hundred feet or a few inches deep. Rivers can be clear enough that the bed is visible or so muddy that visibility is less than an inch. River water can flow as fast as 15 mph and so slow as to be indiscernible to an observer. The biotic characteristics of a river environment are highly variable and related to the physiographic setting and ecosystem of which a river is part. Rivers flow in deserts and tropical regions, in mountains and plains, and in urban and rural areas.

Surrounding Environmental Setting

Four studies, which resulted in five publications, found that students conceptualize rivers as being natural (i.e., not constructed by humans) and located in pastoral settings (Dove et al., 1999; Dove et al., 2000; Mackintosh, 2005; May, 1996; Wilson & Goodwin, 1981). Dove et al. (1999), May (1996), Mackintosh (2005), and Wilson and Goodwin (1981) found that when asked to draw a picture of a river, 9- to 11-year-old students from Great Britain and Australia depicted rivers in natural, pastoral settings—with humans, vegetation, and animals commonly depicted in and around the rivers. The natural areas included mountains and flat and hilly rural areas. Few students depicted rivers in urban settings. Although the plants and animals were often described with generic terms (e.g., "fish"), students also used terms that described plants and animals found locally (e.g., "kookaburra" in Australia). Humans were usually depicted and described engaged in recreational activities like boating and fishing.

Two studies offer additional insights into students' conceptions of rivers as natural and located in pastoral settings. May (1996), Mackintosh (2005), and Dove et al. (2000) asked 9- to 11-year-old British students to sort photographs of rivers into two categories: those photographs depicting a water feature that was "most like a river" and those photographs depicting a water feature that was "least like a river." In both studies, the photographs students most commonly selected as "most like a river" showed rivers in natural, pastoral settings. The photographs that showed rivers in urban settings were typically selected as "least like a river."

The students' reasons for their selections are as informative about their conceptions of rivers as their actual selection of a photograph into a specific category

(Table 9). Students selected photographs for the “most like a river” because the water in the photographs showed pastoral settings, the water looked clean, the river contained rocks, and the banks were covered in vegetation (Dove et al., 2000; Mackintosh, 2005; May, 1996). The minority of students who selected urban rivers as “most like a river” did so because there were boats in the river, bridges across the river, or the river appeared large (Dove et al., 2000; Mackintosh, 2005; May, 1996).

Students categorized photographs as "least like a river" when the photographs showed rivers with signs of human intervention, like walls and garbage, or showed water bodies that the students thought did not have the appropriate dimensions or characteristics of a river (Dove et al., 2000; Mackintosh, 2005; May, 1996). For example, students selected a picture of a wide river as “least like a river” because they thought only lakes could be that wide (Dove et al., 2000). They selected another picture as “least like a river” because the water looked too still to be a river (Dove et al., 2000).

Dove et al. (2000) discovered that the students focused on some features in the photographs that the researchers had not anticipated would affect the students’ selections. For example, the researchers thought students would categorize a picture depicting a channelized river in an urban area as "least like a river." However, many students classified the photograph as "least like a river" because they thought that the water in the photograph looked still and was probably a lake because there was a reed growing next to the water and reeds only grow next to lakes.

Table 9

Students' Reasons for Sorting Photographs into Most and Least Like a River

Most like a river reasons	Least like a river reasons
• Located in the countryside • Water appeared clean • Water contained rocks • Banks were covered by vegetation • Meander bends were present • Bridges crossed the river • Boats were on the water • River appeared large or long	• Water feature is located in urban area or has signs of human intervention • Water appeared polluted • A reed was growing next to the water (students thought that reeds grew next to lakes not rivers) • Water features was too muddy, dull, shallow, small, still, or wide to be a river

Note. From Dove et al. (2000), Mackintosh (2005), May (1996).

Wilson and Goodwin (1981) found that students' conceptions of a river in general differed slightly from students' conceptions of a specific, local river. To probe students' conceptions of a river in general, Wilson and Goodwin asked students to list words they would use to describe a river and to complete a word association activity about rivers. To probe students' conceptions of a specific river, Wilson and Goodwin asked students to write a description about a local river.

When describing a river in general, students gave a more generic description of a river than when describing a local river. The general descriptions focused more on the physical nature of a river (e.g., water, flowing, wide) than on the biotic features in and around a river. When they described a local river, students described more biotic features and used more idiosyncratic terms than they did when describing a river in general. For example, when describing rivers in general, students were more likely to use the term "tree" or "fish" than the specific name of a fish or tree. When describing a local river, they more often used names of local animals (e.g., yellowbelly and codfish) and plants (e.g., gum trees) than they did when describing a river in general. Additionally, when describing a local river, students described recreational activities like swimming and fishing more frequently than they did when describing rivers in general.

The differences in students' conceptions between describing a river in general and a local river may indicate that fifth- and seventh-grade students synthesize their specific knowledge of several rivers to form one general conception. When describing a local example of a river, students may call on their direct experience with that river.

Surrounding Biotic Features

Three studies provided information on the biotic features students associated with rivers (see Dove et al., 1999; Mackintosh, 2005; May, 1996; Wilson & Goodwin, 1981). The most common biotic feature that students associated with rivers was fish (Dove et al., 1999; Mackintosh, 2005; May, 1996; Wilson & Goodwin, 1981). Wilson and Goodwin provided a detailed list of the biotic features that Australian fifth- and seventh-grade students associated with rivers (Table 10). Students associated local vegetation (e.g., gum and willow trees) and animals (e.g., cod, shrimp, and kookaburra) with a river environment. Students in the Dove et al. study associated ducks, fish, eels, otters, and herons with rivers. Students in the May study associated fish, crabs, rabbits, and snails with rivers.

Two observations can be made based on the list of biotic features students described. First, students conceptualized rivers as part of a system that included plants and animals as opposed to simply conceptualizing a river as a physical system. Second, students associated local biotic features with rivers. For example, students in the Wilson and Goodwin (1981) study associated kookaburras, koalas, and yellowbelly fish with river environments; whereas, students in the May (1996) and Mackintosh (2005) study associated eels and otters with rivers.

Table 10

Examples of the Biotic Features Students Associated with Rivers

Fish (yellowbelly, cod, carp, bream)	Mussels
Turtles	Shrimp
Birds (ducks, kingfishers, pelicans, kookaburra)	Koalas
Trees (willow, gum)	Grass
Reeds	

Relationship with Humans

Humans have a long history with rivers. Ancient and modern civilizations settled near rivers because rivers provide food, water, recreation, and transportation. Three studies identified students' conceptions of the relationship between humans and rivers through student drawings, interviews, and constructed responses. Students in the studies associated humans with rivers, particularly in the context of recreational activities like swimming, fishing, and boating (Dove et al., 1999; Mackintosh, 2005; May, 1996; Wilson & Goodwin, 1981). For example, almost all students in the Wilson and Goodwin study created drawings showing humans engaged in recreational activities near rivers. Students also associated human features with rivers. About 80% of the drawings in the Dove et al. (1999) study depicted human features like bridges, houses, roads, cars, and boats.

Age of Rivers

One study investigated students' conceptions of the age of rivers. In a study investigating students' conceptions of geologic time in general, Trend (1998) asked 10- to 11-year-old students about their conceptions of how long rivers have been on Earth. Students thought that rivers had been on Earth since the beginning of its existence. Trend provides three responses students gave (Table 11) but does not describe what students meant by their responses. More research is required to determine students' conceptions of when rivers first formed on earth.

Table 11

Students' Conceptions about How Long Rivers Have Existed on Earth

1. "forever"
2. "rivers leaked out of the earth's surface while it was being formed"
3. "since the earth was made"

Note. All responses are from Trend (1998, p. 981)

Cause of River Flow

Rivers flow from areas of higher elevation to areas of lower elevation due to the force of gravity (Huggett, 2003). May (1996) and Mackintosh (2005) found that some students did not know what caused rivers to flow. Other studies found that students offered artificial and natural causes for river flow (Table 12).

Artificial Causes

Piaget (1930) interviewed 5- to 11-year-old Swiss students and asked them to describe what causes a local river to flow. He found that 5- to 7-year-old students (the conceptions of the older students are discussed in the next section) attributed river flow to artificial causes, specifically human intervention (Table 12). For example, one student responded that boats in the water make the river flow. Students further explained that when there are fewer boats or people swimming in the water, then the water flows more slowly. When asked if the river flows when there are no boats or people in the water, some students responded that yes the river flows because there are other forces, like fish, causing the water to move.

Table 12

Students' Conceptions about the Causes of River Flow

Cause	Study
Artificial	
Boats moving in the river	Piaget (1930)
People swimming in the river	Piaget (1930)
Natural	
Wind	Piaget (1930), Mackintosh (2005), May (1996)
Stones/rocks	Piaget (1930), Mackintosh (2005), May (1996)
Fish	Piaget (1930)
Slope	Piaget (1930), Mackintosh (2005), May (1996)
Slope and gravity	Piaget (1930)

Piaget (1930) suggested there is a relationship between students' ages and their conceptions of the cause of river flow. In Piaget's study, the students up to about age seven thought that human activities caused rivers to flow. Besides level of biological maturation, Piaget does not suggest why students think that humans cause rivers to flow. No other study reported artificial causes for river flow; however, the other studies that investigated students' conceptions of the cause of river flow had older students.

Natural Causes

Several studies found that students attributed flow to natural causes (Table 12). Most of the natural causes described are alternative conceptions. For example, students thought that the movements of fish cause rivers to flow (Piaget, 1930). Students also thought that rivers spontaneously move when stones or rocks are in the river (Mackintosh, 2005; May, 1996; Piaget, 1930). Here is a transcript from Piaget's study:

> Researcher: How do stones make the water move along?
> Student: Because they make waves.
> Researcher: How do the stones make waves?
> Student: ... they hold the water back, and the water goes over and that makes waves.
> (Piaget, 1930, p. 95)

Several students thought that wind pushes water and causes rivers to flow (Mackintosh, 2005; May, 1996; Piaget, 1930). Interestingly, Piaget reported that two-thirds of the students in his study who attributed flow to wind also understood that wind blows in all directions and that a river flows in one direction (i.e., downhill). This contradiction did not deter students from attributing river flow to wind.

Students also offered alternative conceptions of river flow by attributing river flow to slope only (slope affects the nature of flow, like speed, but is not the cause) (Mackintosh, 2005; May, 1996; Piaget, 1930). Some students held a mix of scientific and alternative conceptions when they attributed flow to slope and gravity (gravity cause flow and slope affects the nature of it) (Piaget, 1930). In his study, Piaget found that only students older than age seven attributed flow to slope only or slope and gravity.

Flow Down Slope

Rivers flow from areas of high elevation to areas of low elevation (Huggett, 2003). A few studies reported students' conceptions about rivers flowing from high to low elevations.

Dove et al. (1999) asked students to draw a picture of a river that showed the river's beginning and end and the direction of river flow. Students' most common depiction was of a river flowing from the mountains to the sea. This may indicate that students associated river flow as starting at higher elevations and flowing to lower elevations. However, Dove et al. did not probe to find out if this was indeed the conception that students held.

Some students held the conception that rivers flow from the ocean onto land (i.e., upslope or from lower to higher elevation) (Dove et al., 1999; Englebrecht et al., 2005). If students have personal experiences with coastal rivers, they might describe river flow as moving from the ocean inland, which would mean that the water moves upslope. Some coastal rivers (e.g., the Hudson and Delaware Rivers in the Northeastern United States and the Columbia River in the Northwestern United States) experience tidal currents. Tidal currents flow into the river channel and push river water upslope some distance into the river. However, students might also think that rivers flow inland from the ocean for other reasons.

Conceptions of River Processes

The main processes of rivers are erosion, transportation, and deposition. These processes are controlled by several variables such as velocity, slope, discharge, and grain size. Rivers remove or pick up dissolved and solid sediment during erosion, transport the sediment downstream, and deposit it during deposition. During the formation of a river and floods all three processes generally occur.

Formation of Rivers

Rivers are generally formed when flowing water gradually erodes sediment and rock and transports it to form a channel that increases and decreases in depth and width depending on the levels of erosion and deposition occurring in the river (Bloom, 1998; Huggett, 2003). Three studies (see Cin & Yazici, 2002; Mackintosh, 2005; May, 1996; Piaget, 1929) investigated students' conceptions about the formation of rivers. Cin and Yazici reported that one-third of the students in their study did not know how rivers formed. However, the rest of the students in their study and the students in the other studies held conceptions about river formation that fall into two general categories: artificial origins (humans or God created the river) and natural origins (natural processes created the river) (Table 13).

Artificial Origins

Students offered three artificial origins for rivers. First, some students said that humans created rivers but did not give a specific method by which the humans did so. For example, when asked how a river channel formed, a student said that "some man made it" (Piaget, 1929, p. 327). Second, students thought that humans created the river by digging the channel (Mackintosh, 2005; May, 1996; Piaget, 1929). For example, one student said that the river was dug out using a "mechanical digger" (May, 1996, p. 13) (possibly a backhoe). The final artificial origin offered by students was that God created the river. This origin was only mentioned by Turkish students in the Cin and Yazici (2002) study.

Table 13

Students' Conceptions of the Formation of Rivers

Origin	Study
Artificial Origin	
Non-specific human activity made the river	Piaget (1929), May (1996), Mackintosh (2005), Cin and Yazici (2002)
Humans create rivers by digging using non-specific methods, using pickaxes, or using "mechanical diggers"	Piaget (1929), May (1996), Mackintosh (2005)
God formed the river	Cin and Yazici (2002)
Natural Origin	
"Stones rolling along hollow it [the river] out"	Piaget (1929, p. 331)
Water rubbed or broke away land	May (1996), Mackintosh (2005)
"The river is heavy so it sunk in"	May (1996, p. 13), Mackintosh (2005)
Non-specific natural processes created the river	Piaget (1929), Cin and Yazici (2002),

Piaget (1929) attributed students' conceptions of artificial origins to biological maturation. Another explanation is that students had observed construction work (e.g., dam construction or channelization work) in a river and therefore thought humans created the river. Cin and Yazici (2002) thought that formal and informal religious training for students in Turkey influenced students to attribute the origin of rivers to God.

Natural Origins

Students described several natural processes that they thought created rivers (Table 13). Piaget (1929) and Cin and Yazici (2002) reported that students attributed river formation to natural processes, and, with one exception (Piaget), they do not list the specific processes. Piaget found that, after age nine or ten, students thought that natural processes created rivers, and he gives one example. One student said that stones rolling along created the river. Piaget does not explain this comment, so it is unclear if the student thinks that sediment is eroded by river water, thus creating the river channel, or if there is some other meaning.

Students in the May (1996) and Mackintosh (2005) study attributed the formation of a river to water and the river (Table 13). Students thought that water "rubbed" the land to create the river. They also thought that because the river itself is heavy, it sunk into the earth and created a river. The researchers did not analyze what the students meant by these comments.

Summary

Students attributed the formation of rivers to artificial and natural processes. Students' conceptions about how rivers form are generally incomplete or alternative. For example, students' conceptions that water rubbed or broke away the land to create a river is an incomplete conception. Students' conceptions that God created a river or that a heavy river sinks into the land and creates a river are alternative conceptions.

Floods

Floods occur when a river's discharge exceeds the capacity of the channel, which causes the river water to overflow the banks (Bloom, 1998). Rainfall, snowmelt, human activities, landslides, dam failures, and so forth can cause floods. One study identified students' conceptions about floods.

Schoon (1988, 1992) administered a multiple-choice test to 1,213 elementary school, middle school, high school, and college students to investigate their conceptions of geoscience topics. One test question investigated students' conceptions of river floods (Table 14). Almost 40% of the students selected the scientific conception that floods can be caused by humans. A large percentage of students thought that floods occur only when snow melts in the spring. For many rivers, major floods are associated with snowmelt; however, snowmelt is not the only cause of floods. Almost 18% of the students selected the response that floods are worst during a full moon. There is no association between floods and the full moon. Schoon (1988, 1992) did not speculate on why such a high percentage of students selected this response.

A small percentage of students thought that floods only occur once every 100 years. It is common nomenclature in the scientific community and the general public to classify a river flood as a "hundred-year flood." The scientific meaning of this phrase is that, in any given year, there is a one in a hundred chance that a flood of a particular size will occur. Students in this study may have heard the term and incorrectly interpreted the term to mean that a large flood only occurs once every 100 years.

Table 14

Flood Question with Responses and Percentage of Students Selecting Each Response

Question and responses	Percent (n = 1,213)
The terrible floods that occur along a river:	
a. occur only once every 100 years	9.9
b. can be caused by man [a]	37.3
c. occur only when snow melts in the spring	33.6
d. are worst during a full moon	17.8
No answer or more than one answer marked	1.5

Note. From Schoon (1988, 1992). [a] Scientific conception according to Schoon.

Conclusion

This chapter reviewed students' conceptions of rivers. Most of the research focused on the conceptions of elementary school students. Previous research also primarily focused on students' definition of a river and students' conceptions of the characteristics of rivers. Little research was conducted on students' understanding of river processes. Future research should extend beyond elementary school students and investigate the conceptions of rivers held by students of other age levels. Future research should also investigate students' conceptions of the dynamics of river flow, the role of rivers in landscape evolution, and river processes. My study focuses on college students' conceptions of the definition of a river, river characteristics, and river processes.

CHAPTER 3: LITERATURE REVIEW OF THE FACTORS INFLUENCING STUDENTS' CONCEPTIONS

Current thinking in the fields of cognition and science conceptions points to several possible factors influencing students' conceptual development about science topics. Students' conceptions may develop as they mature and go through age-related cognitive developmental stages (i.e., Piagetian or neo-Piagetian stages of development) (Bransford et al., 2000; Dodick & Orion, 2003a; Liu & McKeough, 2005; Vosniadou & Ioannides, 1998). Students also develop their conceptions through direct observation and interaction with the natural world; because of their social and cultural roles (e.g., their ethnic, gender, religious, and socioeconomic associations); from teachers' explanations and textbooks; from information provided by the media; and so forth (Driver et al., 1994; Ogunniyi, 1987; Schoon, 1995; Thijs & Van Den Berg, 1995; Vosniadou & Ioannides, 1998; Wandersee et al., 1994). The specific factors influencing student conceptual development are often difficult to determine, and students generally cannot identify the factors influencing their own conceptual development (Schoon, 1995; Wandersee et al., 1994). Additionally, several factors may simultaneously influence students' conceptual development (e.g., students' conceptions might be influenced by their personal experience with the natural world, what they learned in the classroom, and by their religious beliefs) (Wandersee et al., 1994).

Much of the research investigating the factors that influence students' conceptual development in the sciences has been in the field of physics conceptions (for reviews of the literature, see Driver et al., 1994; Wandersee et al., 1994). Research across hundreds of studies investigating factors influencing students' conceptual development in physics shows that students from various social and cultural groups (i.e., ethnic, gender, religious, etc.), in Western and non-Western countries, and receiving different types of teaching methods in the classroom hold similar conceptions of physics topics (Driver, 1991; Driver et al., 1994; Duit, 2004; Thijs & Van Den Berg, 1995; Wandersee et al., 1994). Researchers conclude that students may develop similar conceptions of physics because there are a limited number of ways in which humans experience the natural world and that students from diverse populations and cultures share these common experiences (Driver, 1989; Mintzes, Wandersee, & Novak, 1999; Thijs & Van Den Berg, 1995).

There has been little research into the factors influencing students' conceptions of geology topics; therefore, it is unclear if, as in physics, students from diverse backgrounds and locations hold similar conceptions of geology topics. Studies that investigate the patterns between students' conceptions and factors that influence their conceptions are important. Knowing which factors influence conceptual development can help researchers and educators develop strategies to strengthen scientific conceptions and modify alternative conceptions (Wandersee et al., 1994).

A literature review was conducted for two purposes. The first purpose was to identify the factors that influence students' conceptions of geology topics and the relationship between those factors and students' conceptions of geology topics. The second purpose was to identify the factors that influence students' conceptions of rivers and the relationship between those factors and students' conceptions of rivers. The review is split into two sections. The first focuses on factors influencing the development of geology conceptions. The second focuses on factors influencing the development of river conceptions.

Factors Influencing Students' Conceptions of Geology Topics

A similar systematic and thorough review as that described in Chapter 2 to identify studies that investigated students' conceptions of rivers was conducted to identify studies that investigated factors influencing students' conceptions of geology topics. The steps of the review and the number of articles resulting from each step can be found in Table 15. The first step was to establish inclusion and exclusion criteria for studies (Appendix C). Only studies meeting the criteria were included in the review. During the second step, search terms were developed and research databases were searched (Appendix D shows the research databases that were searched and the search terms used). The total number of publications found in all of the research databases after searching is listed in Table 15. The number refers to the number of publications and not to the number of studies. Some studies were described in more than one publication, so the total number of studies is less than the total number of publications.

The third step was to conduct a search of publications that were not found in the search of the research databases. Publications are commonly missed during the search of a research database because the search terms do not match the key words for a particular publication (Paterson et al., 2001). Therefore, publication lists from geoscience conceptions researchers were acquired, and the reference lists included in geoscience conceptions studies were reviewed to find studies that were not found during the search of research databases.

During the fourth step, the abstracts of the articles identified in steps two and three were reviewed. Those publications meeting the inclusion criteria based on review of the abstracts were selected for the next step. It is not always possible to determine if a publication meets the criteria just by reviewing the abstract. Therefore, those publications identified in step four were acquired and reviewed in full for step five. Only those publications that, when reviewed in full, met the inclusion criteria were included in the literature review. Thirty-six publications (33 studies) completely met the inclusion criteria.

The sixth and final step of the review was to analyze the publications. The primary goals of the analysis were to identify factors that influence students' conceptions of geology topics and to determine the relationship between those factors and students' conceptions. Before discussing these findings, an overview of the general characteristics of the 33 studies is given.

Out of the 27-year period selected for this literature search, more than half of the studies were published between 2000 and 2006. Only 15% of the studies were published during the 1980s. This pattern emphasizes the recent nature of research investigating factors affecting students' conceptions of geology topics. Libarkin and Kurdziel (2001) found the same pattern.

About half the studies were conducted in the United States. Science conceptions research is a highly international endeavor, so it is not uncommon that half the studies were conducted outside of the United States.

Table 15

Literature Review Steps to Identify Studies that Investigated Factors

	Steps	Resulting Number of Articles
Step 1.	Establish inclusion and exclusion criteria.	NA
Step 2.	Develop search terms and search research databases.	1,840
Step 3.	Conduct search for publications not found in the research databases.	5
Step 4.	Review abstracts of articles identified in steps two and three. Select and obtain publications meeting inclusion criteria based on review of abstracts.	141
Step 5.	Review in full those publications selected in step four. Select publications meeting inclusion criteria based on review of full publication.	36[a]
Step 6.	Analyze the publications for review.	NA

[a] Although the total number of publications was 36, there were only 33 studies because some studies were described in more than one publication.

Although sample sizes ranged from two to more than one thousand, all but three studies had sample sizes of 30 and larger. About an equal number of studies investigated the conceptions of students from the four levels of education: elementary school, middle school, high school, and college. A range of qualitative and quantitative data collection and analyses methods were used (Table 16). The most common data collection method was the interview, which is also the most common data collection method in the broader field of science conceptions research (Wandersee et al., 1994). Drawing questions, constructed-response questions, and multiple-choice tests were also commonly used methods. The studies investigated a wide range of geology topics. Geologic time and history, general geology, rock and mineral identification, and the rock cycle were the most common topics investigated.

The studies were analyzed to identify which factors influenced students' conceptions of geology topics. The factors identified in the studies can be grouped into two categories: intrinsic factors and extrinsic factors (Table 17). Intrinsic factors are characteristics inherent or internal to the student, such as age. Extrinsic factors are characteristics external to the student, such as instructional method. The two categories of factors are discussed.

Intrinsic Factors

Several characteristics were classified as intrinsic factors (Table 17).

Age

Several studies investigated the relationship between students' conceptions of geology topics and their age or grade level. The studies explored a range of topics and ages (Table 16). Several patterns were identified between age and students' geology conceptions (Table 18). Patterns 1, 2, and 3 highlight contradictory findings. Each of the patterns is described in detail below.

Table 16

List of Articles Reviewed that Investigated Factors Influencing Students' Conceptual Development

Study	Sample size[a]	Data collection methods[b]	Grade level[c]	Geology topics investigated	Country
Assaraf and Orion (2005)	50	D, Q, WA, CM, I, O	M	water cycle	Israel
Ault (1982)	30	I	E	geologic time	US
Bezzi (1996)	2	RG, I	C	igneous petrology	Italy
Black (2003, 2005)	97	MC	C	geoscience (including topics in geology, astronomy, oceanography, and meteorology)	US
Blake (2001, 2004)	60	CM, I, PT	E	rock classification and rock cycle	UK
Blake (2005)	115	I, Q, PT	E	volcanoes, mountain building, weathering, erosion, diagenesis, rocks, minerals, Earth's interior	UK
Chang and Barufaldi (1999)	172	MC, CR	H	mountain building	Taiwan
Chiapetta and Russell (1982)	140	MC, CR	M	geoscience (including topics in geology)	US
Cin and Yazici (2002)	80	I	E	formation of water features (lake, sea, and river)	Turkey
Dodick and Orion (2003a)	172	CR	M, H	geologic time, relative age dating, correlation, faunal succession, depositional environments	Israel
Dodick and Orion (2003b)	343	CR	H	geologic time, relative age dating, correlation, faunal succession, depositional environments	Israel
Farnsworth and Mayer (1984)	95	MC	M	plate tectonics	US

Table 16 (continued)

Study	Sample size[a]	Data collection methods[b]	Grade level[c]	Geology topics investigated	Country
Feather (1998)	58	CM, MC, O, I	H	minerals, rocks, erosion, plate tectonics, earthquakes, volcanoes	US
Gobert and Clement (1999)	58	MC, CR, D	E	plate tectonics	US
Harwood and Jackson (1993)	9	I, D, PR	E	physical landscape features (e.g., river, beach)	UK
Hidalgo and Otero (2004)	256	CR	H, C	geologic time	Spain
Kali, Orion, and Eylon (2003)	40	CR	M	rock cycle	Israel
Libarkin, Anderson, Dahl, Beilfuss, and Boone (2005)	265	CR, I	C	earthquakes, Earth's interior, geologic time	US
Lillo (1994)	150	D	E, M	Earth's interior	Spain
Marques and Thompson (1997)	493	CR, I	E	geologic history	Portugal
Muthukrishna, Carnine, Grossen, and Miller (1993)	41	I	M	mountains, seasons	US
Oversby (1996)	181	CR	E, M	fossils, geologic time, definition of rock and mineral	UK
Philips (1992)	360	MC	M	geoscience (including topics in geology, astronomy, and meteorology)	US
Pulling (2001)	4	D, I, CR	E	evolution and geologic history	US
Reinfried (2006)	30	D, CR, I	C	groundwater	Germany
Rollins, Denton, and Janke (1983)	492	MC	H	geoscience (including topics in geology, astronomy, and meteorology)	US
Schoon (1988, 1992)	1,213	MC	E, M, H, C	geoscience (including topics in geology, astronomy, and meteorology)	US

Table 16 (continued)

Study	Sample size[a]	Data collection methods[b]	Grade level[c]	Geology topics investigated	Country
Schoon (1995)	122	MC	C	geoscience (including topics in geology, astronomy, and meteorology)	US
Shepardson, Harbor, and Wee (2005)	95	D, CR	E, M, H	watersheds	US
Sibley (2005)	492	D, I	C	plate tectonics	US
Steer, Knight, Owens, and McConnell (2005)	97	D	C	Earth's interior	US
Stofflett (1994)	111	CR	C	rock cycle	US
Trend, Everett, and Dove (2000)	444	D, I	E	mountains and Mountain landscapes	UK

[a] Sample size reflects overall study sample size. In some cases, the study had multiple parts so the text may describe a smaller study conducted in the overall study and may not exactly match with sample size. [b] Key to the data collection methods: I = interview, CR = constructed response questions, D = drawings, Q = questionnaire (qualitative and/or quantitative), MC = multiple-choice instrument, WA = word association, CM = concept map, O = observations, RG = repertory grid, PT = performance tasks, PR = picture recognition. [c] Key to grade level: E = elementary school students, M = middle school students, H = high school students, C = college students.

Table 17

Intrinsic and Extrinsic Factors Identified in the Studies

Intrinsic Factors
Age
Ethnicity
Gender
Cognitive ability
Extrinsic Factors
Major
Number and type of previous science classes
Religion
Direct experience
Instructional methods
Engagement level in lesson
Institutional characteristics

Table 18

Summary of Patterns between Students' Age and Conceptions

Pattern 1:	Higher percentage of students at higher grade levels held scientific conceptions than did the percentage of students at lower grade levels
Pattern 2:	No correlations exist between students' conceptions and their grade levels
Pattern 3:	Inconsistent relationship between students' conceptions and their age
Pattern 4:	Alternative conceptions are resistant to change and are held by students across grade levels

Pattern 1.

The first pattern, the most common pattern, was that in some studies a higher percentage of students at higher grade levels or ages held scientific conceptions than did the percentage of students at lower grade levels (for examples see Blake, 2005; Dodick & Orion, 2003a, 2003b; Hidalgo & Otero, 2004; Marques & Thompson, 1997; Oversby, 1996; Schoon, 1988, 1992; Schoon, 1995; Shepardson et al., 2005). For example, Blake (2005) investigated third-, fourth-, fifth-, and sixth-grade students' conceptions of weathering. He found that more students at each progressively higher grade level held scientific conceptions about weathering than did the percentage of students at lower grade levels.

Pattern 2.

The second pattern was that in some studies there was no difference in the conceptions held by students from different grade levels (Black, 2003, 2005; Blake, 2005; Trend et al., 2000). For example, Trend et al. (2000) found that the majority of third-, fourth-, fifth-, and sixth-grade students in his study held the same conception about the composition of mountains. Similarly, Blake (2005) found that the third-, fourth-, fifth-, and sixth-grade students in his study held similar conceptions about volcanoes. Black (2003, 2005) found no difference in the conceptions of geoscience topics held by college students between ages 18 to 49. It is possible that notable changes in students' conceptions for those topics investigated in the studies may occur at different ages than the ages investigated in the studies. For example, changes in students' conceptions of volcanoes might not occur until later ages.

Pattern 3.

The third pattern was an inconsistent relationship between age and students' conceptions (Blake, 2005; Oversby, 1996; Trend et al., 2000). For example, Trend et al. (2000) and Blake (2005) both investigated third-, fourth-, fifth-, and sixth-grade students' conceptions of the origins of mountains. Trend et al. found that most students from all grade levels (57% of third and fourth graders and 62% of fifth and sixth graders) did not know the origins of mountains. In contrast, the majority of students (60% of third graders, 80% of fourth graders, and 100% of fifth and sixth graders) in Blake's study were not only able to offer explanations about the origins of mountains but also gave scientific explanations for the origins. Blake also found that the proportion of students who held scientific conceptions for the origin of mountains increased with age. When comparing the Trend et al. and Blake studies, it seems there are inconsistent findings about students' conceptions of the origins of mountains from grades three to six.

Pattern 4.

The fourth pattern is that some alternative conceptions were resistant to change and were held by students across grade levels (Lillo, 1994; Schoon, 1988, 1992, 1995). For example, Lillo (1994) found that students in fifth, sixth, seventh, and eighth grades held the alternative conception that the lava that flows out of volcanoes originates in the Earth's core. Schoon (1988, 1992, 1995) found that 20% to 30% of fifth-grade, eighth-grade, eleventh-grade, and college students held the alternative conception that dinosaurs lived at the same time as humans. Lillo (1994) and Schoon (1988, 1992, 1995) suggested that some alternative conceptions are difficult to change and persist across grade levels.

Summary.

Contradictory and inconsistent patterns emerged for the relationship between age and students' conceptions. There may be several reasons for this. First, other factors besides age—like students' ability level, direct experience with the natural world, gender, and so on—may simultaneously influence students' conceptual development so that no single clear and consistent pattern emerged between students' age and their conceptions.

Second, cognitive level of the topic may influence the rate of conceptual change across grade levels. Some of the geology topics investigated in the studies may have been at a cognitive level that was too high or too low for the grade levels in the studies; therefore, little or significant conceptual development was seen across those grade levels. For example, a student's understanding of Earth materials (factual knowledge) may progress faster than his or her understanding of mountain building (a complex geologic process). Differing rates of conceptual development for the geology topics investigated in the studies may help explain the contradictory and inconsistent patterns between students' conceptions and age.

Third, some of the assessment methods in the studies may not have been effective at fully describing students' conceptions. For example, Black (2003, 2005) used a multiple-choice concept inventory to identify students' conceptions across ages. Students in Black's study may have experienced conceptual changes across ages that were not detected by the multiple-choice concept inventory. Using more than one type of assessment method may provide a more complete picture of students' conceptions (White & Gunstone, 1992) and aid in identifying differences and conceptions across ages.

None of the studies collected longitudinal data. All studies used groups of students who were at different contemporaneous grade levels. This provides only a snapshot of conceptions of different students across age levels. It would be a significant contribution to conduct longitudinal studies of students' conceptual development for key geology topics across a wide range of grade levels to determine at which grade levels researchers and educators can expect to see conceptual changes.

Ethnicity

Only one study found in the literature review explored the relationship between students' conceptions of geology topics and their ethnicity. Schoon (1988, 1992) administered a multiple-choice geoscience concept inventory to more than 1000 elementary, middle school, high school, and college students. The sample included 63% White, 16% Black, and 17.5% Hispanic students. Schoon analyzed the conceptions held by the three ethnic groups, finding that, although alternative conceptions were held across all three ethnic groups, the White students held significantly fewer alternative conceptions than did the Black and Hispanic students combined. Clearly, more research is needed to investigate the relationship between students' conceptions of geology topics and their ethnicity.

Gender

Four studies investigating the relationship between gender and students' conceptions of geology topics found inconsistent patterns. Two studies (Black, 2003, 2005; Steer et al., 2005) found no differences between the conceptions held by male and female students. Two studies (Philips, 1992; Schoon, 1988, 1992) found there were differences between the conceptions held by male and female students.

Black (2003, 2005) investigated 34 male and 63 female non-science-major college students' conceptions of geoscience topics by administering a multiple-choice geoscience concept test. Black found no correlation between gender and students' conceptions. Steer et al. (2005) investigated 51 male and 46 female college students' conceptions of Earth's interior by asking students to draw a diagram of Earth's interior. Steer et al. found no statistically significant differences between male and female students' drawings of Earth's interior.

Schoon (1988, 1992) investigated the conceptions of geoscience topics held by 617 male and 589 female elementary school, middle school, high school, and college students. Across all grade levels, Schoon found that male students held statistically significantly more scientific conceptions than did female students. Schoon also analyzed students' conceptions by gender and ethnicity (White, Black, and Hispanic) subgroups, finding that White and Hispanic female students held more alternative conceptions than did White and Hispanic male students. However, Black female students held fewer alternative conceptions than did Black male students.

Philips (1992) investigated the conceptions of geoscience topics held by 177 male and 183 female eighth-grade students by administering a 25-question multiple-choice test. Philips found that, overall, male students held statistically significantly more scientific conceptions than did female students on the entire test. Philips uncovered nuances when analyzing the test question by question. There were no gender differences on 15 of the 25 questions. On nine questions, male students selected the scientific conceptions significantly more often than did female students. On the remaining question, female students selected the scientific conceptions significantly more often than did male students.

Of the nine questions on which male students outperformed female students, seven incorporated spatial and temporal concepts (i.e., the question included a reference to time, size, or distance). For example, one question examined students' understanding of the diameter of the Earth, which included a reference to size and distance concepts. There were no spatial or temporal concepts in most of the 15 questions for which no gender differences occurred. Philips (1992) concluded that male students outperformed female students only on questions that involved spatial and temporal concepts. Female students performed as well as male students on questions that did not contain those concepts.

Cognitive Ability

Several studies investigated the relationship between students' conceptions of geoscience topics and the following cognitive abilities factors: logical thinking levels, cognitive tendencies, standardized math scores, ability levels, class grades, and spatial abilities. Those studies investigating spatial abilities are discussed separately in the next sub-section.

Chiapetta and Russell (1982) and Farnsworth and Mayer (1984) found a significant difference between students of varying cognitive ability levels and their conceptions of geoscience topics. Chiapetta and Russell examined the relationship between 287 eighth-grade students' logical thinking levels and their conceptions of geoscience topics. Chiapetta and Russell determined students' logical thinking levels by administering a test that evaluated students' levels of combinational thinking (ability to consider several different factors at the same time to solve a problem), hypotheticaldeductive thinking (ability to consider different hypotheses when solving a problem), proportional reasoning (ability to understand rate, ratio, and scale), and seriation (ability to understand how things fit into a series). The researchers administered a 10-question multiple-choice test to assess students' conceptions of geoscience topics. Chiapetta and Russell found that students with a higher level of logical thinking abilities scored higher on the multiple-choice test than did students with a lower level of logical thinking abilities.

Farnsworth and Mayer (1984) found a correlation between 95 eighth-grade students' cognitive tendencies and their conceptions of geology topics. The researchers administered a multiple-choice test to identify students' cognitive tendency. The researchers stated that cognitive tendencies are the same as the Piagetian levels of development. In their study, the researchers focused only on students at formal and concrete levels, with the formal level at a higher cognitive level than the concrete level. Students in the formal cognitive tendency group scored higher on a multiple-choice concept inventory instrument than did the students in the concrete cognitive tendency group.

Two studies found no relationship between students' cognitive abilities and their conceptions of geoscience topics. Muthukrishna et al. (1993) investigated 41 eighth-grade students' ability levels and their conceptions of mountain building and seasons. The researchers used students' math scores on a state standardized test to determine ability levels. The researchers selected students with high math scores (whom they classified as higher-ability students) and students with low math scores (whom they classified as lower-ability students) to participate in the study. Students were interviewed before and after an instructional intervention to determine their conceptions of mountain building and seasons. Prior to the intervention, the researchers found a significant difference between high-ability and low-ability students' conceptions of mountain building and seasons. After the intervention, they found no significant difference. The researchers concluded that the instructional intervention had more influence on students' conceptual development than did ability level.

Schoon (1988, 1992) investigated the relationship between students' class grades and their conceptions of geoscience topics. Schoon placed more than 1000 elementary school, middle school, high school, and college students into ability levels based on the grade they received in their last science course. He determined students' conceptions of geoscience topics by administering a multiple-choice test. He found no correlation between students' ability level (i.e., grade in science) and their conceptions of geoscience topics.

There is an unclear relationship between academic ability level, as defined by Harwood and Jackson (1993), and students' conceptions. Harwood and Jackson compared the relationship between nine 9- to 11-year-old students' conceptions of land features (e.g., hill, harbor, and cliff) and their academic ability level. The nine students were placed into two academic ability level groups: four in a special needs (lower academic ability) group and five in a non-special needs (higher academic ability) group. The researchers did not describe what method they used to categorize the students, although they did state that in the United Kingdom, where the study occurred, a wide variety of student behaviors and characteristics fall under the umbrella of "special needs." For example, one student was labeled special needs because she had problems spelling and another because she lacked motivation and confidence. To determine students' conceptions of land features, the researchers administered three assessments: an interview, drawing, and picture recognition. Harwood and Jackson concluded that there was no relationship between students' academic ability level and their conceptions of land features. However, the researchers did not state how they came to this conclusion nor provide evidence to support this claim. They presented the mean scores that students received on the three assessments, and it appears that the mean score for the special needs students across all assessment types and physical features was lower than the mean scores for the non-special needs group.

Spatial ability.

Three studies investigated the relationship between students' spatial abilities and their conceptions of geology topics. Black (2003, 2005) investigated 97 college students' conceptions of geoscience topics by administering a multiple-choice geoscience concept test. She administered three different multiple-choice tests to evaluate students' spatial abilities. Black found that students with better spatial abilities had more scientific and fewer alternative conceptions than did students with poorer spatial abilities.

Dodick and Orion (2003a) examined the relationship between 172 10^{th}- and 11^{th}-grade students' visual and spatial skills and their conceptions of geologic concepts. The researchers administered an open-ended constructed response test using geologic diagrams as prompts to understand students' conceptions of the geologic concepts superposition, original horizontality, uniformitarianism, and correlation. They administered a spatial visualization test to determine spatial and visual abilities. The researchers found a strong correlation between students' spatial and visual abilities and their understanding of geologic correlations. They found a weak correlation between students' spatial and visual abilities and their understanding of superposition, original horizontality, and uniformitarianism.

In some cases, students can have adequate spatial abilities to theoretically understand geology topics but lack other knowledge that allows them to apply their spatial abilities to solve geology problems. Ault (1982) investigated 30 elementary school students' ability to transfer their general cognitive temporal and spatial understanding to solve a temporal and spatial geologic problem. Ault found that elementary school students were able to sequence familiar events—the layering of garbage on a compost pile—in chronological order and correlate core samples from the compost pile. However, when the students were asked to place sedimentary rock layers in chronological order based on their relative age of formation and correlate the sedimentary rock layers of three different outcrops, they could not do so. Ault concluded that, although the elementary school students had the ability to place events in chronological order and correlate objects with which they were familiar, they were not able to transfer this ability to events or topics with which they were not familiar. Ault hypothesized that the students were not able to transfer their knowledge because they lacked discipline-specific knowledge of geologic processes (e.g., rock formation) that would have enabled them to apply their general temporal and spatial understanding to solving a geologic problem.

Summary.

Logical thinking skills, cognitive tendencies, and spatial ability were all found to have relationships with students' conceptions of geoscience topics. No relationship was found between students' conceptions of geoscience topics and their standardized math scores and grade in science. There an unclear relationship between academic ability level, as defined by Harwood and Jackson (1993), and students' conceptions.

Extrinsic Factors

The effects of several extrinsic factors on students' conceptions of geology topic were investigated in the reviewed studies (Table 17).

Major

Three studies investigated the relationship between students' majors and their conceptions of geology topics. Two studies found no relationship (Black, 2003, 2005; Sibley, 2005). One study found a relationship (Dodick & Orion, 2003b).

Black (2003, 2005) investigated college students' conceptions of geoscience topics by administering an geoscience concept inventory to 30 preservice elementary and middle school education majors and 67 other non-science majors. Black reported no significant difference in conceptions of geoscience topics between the two groups. Sibley (2005) compared the conceptual understanding of continent-continent convergent boundaries between 471 undergraduate non-geology majors and 21 upper-level undergraduate and beginning graduate geology majors. Sibley administered a drawing question in which students drew continent-continent convergent boundaries. Sibley reported that 43% of the undergraduate non-geology majors and 48% of the upper-level undergraduate and beginning graduate geology majors depicted the same alternative conceptions about the boundaries in their drawings. Sibley concluded that students' alternative conceptions of convergent-convergent boundaries seem difficult to change and persist even in upper-level undergraduate and graduate geology majors.

Dodick and Orion (2003b) investigated the conceptions of geologic time held by 58 high school geology majors and 285 high school non-geology majors (note that the students are Israeli high school students and not college students). The students completed a nine-question constructed response instrument. Four questions investigated geologic concepts related to geologic time. For all these questions, the geology major students performed significantly better than did the non-geology major students. Four questions investigated geologic and biologic concepts related to geologic time. For three of these four questions, there was no difference between geology major and non-geology major students' responses. For the fourth question that investigated geologic and biologic concepts related to geologic time, the non-geology major students outperformed the geology major students. The ninth question investigated students' concept of time, but it was structured to remove the need for geology-specific knowledge to solve it. For this question, there was no difference in how the two groups performed.

Dodick and Orion (2003b) hypothesized that the patterns between the two groups were related to the students' majors and the concepts investigated in the questions. A larger percentage of non-geology majors than geology majors was studying biology, which might have given the non-geology majors an advantage on the questions combining biologic and geologic concepts. For the four questions that relied on an understanding of geologic and biologic concepts of geologic time, there was no difference between the two groups or the non-geology majors outperformed the geology majors. For those questions that relied strictly on geologic knowledge, the geology majors outperformed the non-geology majors. For the question that tested a general understanding of time without reference to geology, there was no difference between the two groups. Dodick and Orion (2003b) concluded that students' major influenced their conceptions of geologic time.

Black (2003, 2005) and Sibley (2005) reported no difference between students' majors and their conceptions. Dodick and Orion (2003b) found that students' majors do influence their conceptions. These three studies are difficult to compare because they investigated different geoscience topics, different grade levels, and used different methods to assess conceptions. More studies are needed to investigate the relationship between students' majors and their conceptions of geoscience topics.

Number and Type of Previous Science Classes

Three studies investigated the relationship between students' conceptions of geology topics and the number and type of science classes the students had previously taken. The studies can be divided into two categories based on the grade levels of the students in the studies: high school and college.

High school students.

Rollins, Denton, and Janke (1983) and Schoon (1988, 1992) examined the relationship between high school students' conceptions and the number of science courses that the students had taken in high school. Rollins et al. measured 492 12th-grade students' conceptions of geoscience topics using a geoscience concept inventory test. They divided the 12th-grade students into two groups based on the number of science classes they had taken. The first group comprised students who had taken two years of science classes, the minimum required to graduate from high school in Texas. The second group comprised students who had taken more than the two years of science classes required for graduation. The researchers found that students completing more than two science courses performed statistically significantly better on the geoscience concept inventory than did those students who completed only two science courses.

These findings were noteworthy because the students taking more than two science classes generally did not take geoscience classes. The researchers hypothesized that students who took more than two science classes learned concepts in their non-geoscience classes that helped them understand the geoscience concepts included on the geoscience concept inventory (Rollins et al., 1983). Additionally, those students who opted to take more than the minimum two science classes may have had a higher ability level, interest in science, and motivation to learn science than did the students who only took the minimum required number of science courses. This greater ability, interest, and motivation may have given advantage to students taking more than two science classes when completing the geoscience concept test.

Schoon (1988, 1992) examined the relationship between 335 11th-grade high school students' conceptions of geoscience topics and the number of geoscience classes they took in high school by administering a general geoscience concept test. Schoon hypothesized that the more geoscience courses a student took, the better the understanding the student would have of geoscience topics. However, Schoon found no relationship between the number of geoscience courses taken in high school and high school students' geoscience conceptions.

Schoon (1988, 1992) hypothesized that students who took an geoscience course may have had less interest and less skill in science than students who did not take geoscience. In the schools the students attended, geoscience courses were recommended only for students perceived to be academically unable to succeed in more mathematically rigorous science courses like chemistry or physics (Schoon, 1988, 1992). This difference in interest and skill level may have resulted in Schoon's finding that students who took more geoscience classes did not have different conceptions from students who had taken fewer geoscience classes.

Two other explanations are possible for Schoon's findings. First, the concepts investigated on the geoscience concept inventory may not have been covered in the geoscience courses that the students took. Second, the concepts investigated in the geoscience concept inventory may have been difficult for students to learn so that, even after taking a geoscience course, the students still had not improved their understanding of the topics.

College students.

Two studies investigated the relationship between college students' conceptions of geology topics and the number of previous science and geoscience courses they took in high school and college. Schoon (1988, 1992) investigated the relationship between 224 college students' conceptions of geoscience topics and the number of geoscience courses the students took in high school, in college, and in high school and college combined. Schoon determined students' conceptions by administering a general geoscience concept test (the same test that he administered to the high school students as described above).

Schoon (1988, 1992) found no pattern between the number of geoscience courses college students took in high school, in college, and combined and their conceptions of geoscience topics. It is possible that the college students had been out of high school long enough so that the influence of their high school geoscience courses did not have a lasting influence on their conceptions in college. However, there is no relationship between college-level geoscience courses and college students' conceptions of geoscience topics. Schoon suggests that the concepts investigated on the geoscience concept inventory may not be the same concepts taught in the geoscience courses that the students took.

Black (2003, 2005) investigated the relationship between 97 college students' conceptions of geoscience topics and the number of geoscience courses the students took in high school and college as well as the number of other science courses they took in high school and college. Black administered a multiple-choice geoscience concept inventory test to assess students' conceptions of geoscience topics. Black only found a significant relationship between the number of geoscience courses the students took in college and the college students' conceptions. Students who had taken more geoscience courses in college scored higher on the concept inventory test than did students who had taken fewer geoscience courses in college. As suggested about Schoon's study (1988, 1992), it is possible that the students in Black's study did not retain geoscience knowledge from their high school science courses. Also, the concepts tested on the geoscience concept test may not have been the same concepts taught in the high school geoscience courses.

Summary.

There seem to be inconsistencies in the relationship between the number and type of science courses students took in high school and college and their conceptions of geoscience topics. More research is needed to explore the type and number of science classes that affect students' conceptions. Also, research is needed to determine what lasting effect science courses have on students' conceptions of geoscience topics (i.e., what conceptions should college students retain from their high school science courses).

Religion

Pulling (2001) investigated how religious beliefs affected four sixth-grade students' conceptions of geologic time and evolution. All four of the students said they were religious. To identify students' conceptions, the researcher administered drawing and constructed response questions in a classroom setting and conducted follow-up interviews. Pulling found that, on the questions answered in a classroom setting, the students generally expressed conceptions about geologic time and evolution that had little reference to religion. The students' conceptions contained scientific explanations and alternative explanations (although generally not religious ones). During the interview, however, when the researcher asked students to elaborate on their ideas, their explanations contained more integrated religious and scientific explanations than did their responses in the classroom setting. The researcher observed that, in the public arena of the classroom, students tended to exclude religious ideas from their explanations. In the private setting of an interview, the students' blended religious and scientific explanations. Pulling concluded that students' religious beliefs did not necessarily cause students to have difficulty or resist learning about geological time and evolution, but classroom responses may not mirror private beliefs.

Another study concluded that religion influenced students' conceptions of geology topics. Cin and Yazici (2002) investigated 80 eight-year-old students' conceptions about the formation of water features (lake, sea, and river). About 40% of the students thought that humans or God formed the water features. As discussed later in this review, students' responses that humans created water features was attributed to students' direct experience. However, Cin and Yazici concluded that students' religious environment influenced their responses that God created water features. For example, when one student was asked how the sea formed, he replied "God created it" (Cin & Yazici, 2002, p. 11). Students in the study, which occurred in Turkey, acquired religious knowledge from numerous sources. Religious education was required in primary schools in Turkey. Many students attended religious courses during the weekends and summers. Students also received information about religion through interactions with friends and family. The researchers believed that students' extensive exposure to religion influenced them to believe that God, not natural processes, created water features (Cin & Yazici, 2002).

Direct Experience

Two studies investigated how students' direct experience observing and interacting with the natural world affected their conceptions of geology topics. Harwood and Jackson (1993) assessed nine 9- to 11-year-old students' conceptions of nine landscape features (hill, mountain, beach, river, valley, harbor, ocean, sea, and cliff) by asking students to define the features during interviews, identify pictures of the features from photographs, and draw a picture of two of the features—river and mountain. To determine if students had direct experience with the features, the researchers asked the students if they had ever seen each of the features on vacation or some other occasion. If a student said that he or she had visited or seen a feature, then the researchers said the student had direct experience with the feature. Harwood and Jackson state that having seen or visited a feature implies a student has some understanding of its physical appearance.

The students' responses about if they had seen each of the landscape features were correlated with their cumulative levels of understanding across all assessment types for each feature. There was a high level of correlation between students' direct experience and their understanding of the concepts (Harwood & Jackson, 1993). The cumulative mean scores for each feature for students who claimed direct experience of the feature were almost double the cumulative mean scores for students without direct experience.

The researchers emphasize two nuances in the data. First, several students who claimed they had direct experience with a feature held little or limited understanding of the feature (Harwood & Jackson, 1993). For example, during interviews some students who said they had visited a beach and expressed a good understanding of the term "beach" did not correctly identify all the beach photographs. The students successfully identified a sand beach but failed to identify a pebble beach. The students' direct experience with a sand beach may have limited their definition of a beach to only a sand beach. The researchers recommend that students be exposed to many different types of the landscape features to gain fuller understanding of the features.

The second nuance highlighted by Harwood and Jackson (1993) was that 40% of the students said they had no direct experience with a feature and yet held a good understanding of the feature. The researchers suggest this is evidence that students gain understanding of features from factors (e.g., media) other than direct experience.

Cin and Yazici (2002) offered inconsistent interpretations of the influence of direct experience on students' conceptions of water features. They investigated 80 eight-year-old students' conceptions about the formation of lakes, seas, and rivers. They picked students from two geographic locations: along the Black Sea coast of Turkey near mountains dissected by rivers, and 40 kilometers inland next to a lake in a valley formed by a river. Students' conceptions of the formation of water features were assessed through structured interviews. The researchers selected water features located in the students' environments.

Almost 40% of the students thought that the water features were formed by humans or God (Cin & Yazici, 2002). As discussed earlier in this review, the researchers attributed students' responses about God's role in the formation of water features to their religious environment. The researchers were interested in the high number of students who thought humans formed the water features. For example, one student, when asked about formation of the sea, said, "the bulldozer opened a hole and put stones and rock around it, afterwards they [men] flowed water from a river" (Cin & Yazici, 2002, p. 12). Students offered similar responses about the formation of a lake. The researchers hypothesized that the students developed these ideas because of construction activities, including dam construction, in the students' local environment. In other words, students observed the construction activities and attributed the formation of the water features to those activities. However, in their conclusion section, Cin and Yazici state that direct experience did not influence students' conceptions of the formation of features. They state that because students thought humans or God formed the water features, instead of natural processes, that direct experience of the natural environment did not influence their understanding of the formation of the features. This contradicts their earlier claim that students' observations of construction activities influenced their ideas.

Summary.

Direct experience can increase students' understanding of landscape features, but it may also limit their definition of those features. Direct experience includes students' observations of and interactions with the natural world. However, direct experience can also include students' observations of humans interacting with and modifying the natural world. Students' conceptions of landscape features may be affected by their observations of humans modifying the landscape.

Instructional Methods

Many factors that potentially influence students' conceptions of geology topics are ones that educators have little to no control over (e.g., gender). One factor educators do have influence over are instructional methods used in the classroom. Eleven studies (Table 19) were examined to determine the relationship between teaching methods and students' conceptions of geology topics.

The types of intervention and comparison instructional methods varied across studies. Most of the studies examined the effectiveness (ability of the instructional method to improve students' understanding of a topic) of an instructional method by comparing students' conceptions on pretests and posttests. If the posttest scores were significantly higher than the pretest scores, then the researchers concluded that the instructional method was effective for bringing about conceptual change. The studies showed that many types of instructional methods were effective at improving students' conceptual understanding of geology topics (Table 20). The studies are grouped into two categories: studies with comparison group research designs and studies with one-group-only research designs.

Comparison group research designs.

Seven studies had comparison group research designs in which two or more instructional methods were compared to determine which method was more effective in changing students' conceptions (i.e., improving their understanding) (Table 19). Four of the seven studies found that some methods were more effective than others in changing students' conceptions. Blake (2001, 2004) found that use of analogy in instruction was more effective in changing students' conceptions than not using analogy. Problem-solving instruction was more effective than traditional teaching (Chiapetta & Russell, 1982). Mental modeling building strategy was more effective than traditional teaching

Table 19

List and Description of Studies that Investigated Instructional Methods

Study	Age of students[a]	Method to assess instruction effectiveness[b]	Intervention instructional method[c]	Comparison instructional method[c]	Intervention group understanding improved?	Comparison group understanding improved?	Intervention group had greater increase in understanding than control group
Comparison group research design studies							
Blake (2001, 2004)	E	PP	same instruction as intervention group, but with use of analogy	same instruction as intervention group, but without use of analogy	y	n	y
Chiapetta and Russell (1982)	M	PO	problem-solving strategy	conventional instruction	y	y	y
Feather (1998)	H	PP	Same as comparison, but with journals (journals, cooperative lessons, reviews, activities, creative writing)	Same as intervention, but with no journals (no journals, cooperative lessons, reviews, activities, creative writing)	y	y	mixed
Reinfried (2006)	C	PP	mental model building strategy	traditional lecture	y	y	y

Table 19 (continued)

Study	Age of students[a]	Method to assess instruction effectiveness[b]	Intervention instructional method[c]	Comparison instructional method[c]	Intervention group understanding improved?	Comparison group understanding improved?	Intervention group had greater increase in understanding than control group
Stofflett (1994)	C	PP	group 1: conceptual change strategy, group 2: micro teaching strategy, group 3 traditional didactic strategy	no instruction	y	n	y
Gobert and Clement (1999)	E	PO	summarized reading passage through drawings	summarized reading passages with writing	NA (no pretest)	NA (no pretest)	mixed
Chang and Barufaldi, 1999 (1999)	H	PP	problem solving instruction	traditional lecture	y	y	mixed
One-group-only research designs studies							
Bezzi (1996)	C	PP	social construction through collaborative analysis	NA	y	NA	NA
Steer et al. (2005)	C	PP	conceptual change model with peer discussion	NA	y	NA	NA

Table 19 (continued)

Study	Age of students[a]	Method to assess instruction effectiveness[b]	Intervention instructional method[c]	Comparison instructional method[c]	Intervention group understanding improved?	Comparison group understanding improved?	Intervention group had greater increase in understanding than control group
Muthukrishna et al. (1993)	M	PP	conceptually integrated instruction delivered via videodisc program	NA	y	NA	NA
Kali, Orion, and Eylon (2003)	M	PP	knowledge integration activity	NA	y	NA	NA

[a] Key to grade level: E = elementary school students, M = middle school students, H = high school students, C = college students. [b]Pretest and posttest (PP) or posttest only (PO). [c]Terms used are those used in the studies.

Table 20

Teaching Methods that Improved Students' Conceptual Understanding

• Analogy	• Knowledge integration activity
• Conceptual change model with peer discussion	• Mental model building strategy
• Conceptual change strategy	• Micro teaching strategy
• Conceptually integrated instruction delivered via videodisc program	• Problem-solving instruction
• Conventional instruction	• Problem-solving strategy
• Didactic lecture	• Social construction through collaborative analysis
• Instruction with and without writing tasks	• Traditional lecture

(Reinfried, 2006). Conceptual change instruction was more effective than micro teaching, traditional didactic teaching, and no instruction (Stofflett, 1994).

The other three studies that compared at least two teaching strategies found mixed results about the effectiveness of one strategy over the other (Chang & Barufaldi, 1999; Feather, 1998; Gobert & Clement, 1999) (Table 19). For example, Chang and Barufaldi (1999) compared problem-solving instruction with didactic lecture. They administered two-part pre- and posttests that evaluated students' knowledge of geology topics and their ability to solve geologic application problems. Students receiving both types of instruction significantly increased their conceptual understanding when comparing each group's overall pre- and posttest scores.

The researchers compared the posttest scores of the intervention and comparison groups on the knowledge questions only. There was no significant difference in posttest means for questions that assessed students' knowledge of geologic topics between students who received problem-solving instruction and those who received didactic lecture. The researchers also compared the posttest scores of the intervention and comparison groups on the application questions only. Students receiving problem-solving instruction scored significantly higher on posttest questions that assessed students' ability to solve geologic application problems than did students receiving didactic lecture.

One-group-only research designs.

Four studies had one-group-only research designs and investigated one teaching method to determine if it brought about conceptual change by comparing students' pre- and posttest scores (Table 19). Muthukrishna et al. (1993) investigated how conceptually integrated instruction delivered via a videodisc program affected students' conceptions of mountain building. They found that, prior to instruction, students held 78 different alternative conceptions of mountain building. Only seven of those alternative conceptions existed after instruction. The researchers concluded that their instructional method caused students to reject their previous alternative conceptions and adopt scientific conceptions of mountain building.

Bezzi (1996) conducted an in-depth study of how two undergraduate students constructed knowledge of igneous petrology through discourse and collaborative learning with each other. On pretests, Bezzi found the students held alternative conceptions about igneous petrology. After long-term collaborative learning and discourse, the students modified their conceptions so that on posttests they demonstrated better understanding of igneous petrology.

Kali et al. (2003) investigated the effectiveness of a knowledge integration activity on middle school students' understanding of the rock cycle. The researchers administered pre- and posttests to identify students' ideas. They found that 76% of the students in the study improved their understanding of the rock cycle after the knowledge integration activity.

Steer et al. (2005) tested peer discussion and model building (building physical models of the Earth) as methods to improve students' understanding of the physical layers of the earth. The researchers found that the two teaching strategies eliminated most of the alternative conceptions held by students.

In all of the one-group-only studies, students' posttest scores were higher than their pretest scores. The researchers in each study concluded that the teaching strategies used in their study effectively improved students' understanding of geology topics.

Summary.

The studies examined in this section investigated different teaching strategies and geologic topics and worked with students from different age groups. Some general patterns can be identified from these studies. First, all the intervention instructional methods tended to be student centered and not instructor centered. Second, almost all the intervention instructional methods improved students' understanding of geology topics. Third, there was little similarity among the comparison instructional methods across all the studies, with the exception of three studies that used traditional lecture as the comparison instructional strategy (Chang & Barufaldi, 1999; Chiapetta & Russell, 1982; Stofflett, 1994). Finally, instructional methods seem to influence students' conceptions of geology topics, and some methods can be more effective than others. It would be useful for future studies to identify common characteristics across all teaching methods that seemed to be effective in bringing about conceptual understanding.

Engagement Level in Lesson

One study investigated how students' personal level of engagement in a lesson affected their conceptions of geologic systems. Assaraf and Orion (2005) assessed 50 eighth-grade students' conceptions of geologic systems using several quantitative and qualitative data collection methods, including drawings, Likert scale questionnaires, word associations, concept maps, and interviews. The researchers conducted classroom observations to document students' level of engagement during a lesson on geologic systems.

Assaraf and Orion (2005) observed three levels of student engagement in the lesson: minimal, partial, and full engagement. All the students who improved their understanding of geologic systems over the course of the lesson engaged in partial or full engagement in the lesson. Those students who showed minimal engagement did not improve their understanding of geologic systems. Based on the findings, students' conceptions of geologic systems may partially be related to their level of engagement in a classroom lesson. The researchers state that future studies are required to determine the factors that influenced students to take active or passive roles in the learning process.

Institutional Characteristics

Institutional characteristics associated with the college or K-12 school that students attend may influence their conceptions of geology topics. Studies investigating the relationship between students' conceptions of geology topics and institutional characteristics found differences based on three institutional factors: size, urbanicity, and public versus private.

Size.

Rollins et al. (1983) investigated the conceptions of 492 12th-grade students at 100 high schools of various sizes in Texas (Table 21). They administered a geoscience concept inventory to determine students' conceptions of geoscience topics.

Table 21

High School Population Size Categories

≤ 129 students
130 to 249 students
250 to 579 students
580 to 1,259 students
≥ 1,260 students

Note. From Rollins et al. (1983).

Analysis showed that students attending moderately large high schools (580 to 1,259 students), in predominantly suburban areas, held statistically significantly more scientific conceptions than did students attending moderately small high schools (130 to 249 students), in small town or rural areas. Rollins et al. did not find statistically significant differences between high schools in other size categories. The researchers hypothesized that the moderately large high schools had higher quantity and better quality of science coursework and more instructional resources than did the moderately small high schools. They claim these institutional differences caused the differences in student scores on the geoscience concept inventory. However, the researchers did not actually investigate the curriculum and resource differences between the large and small high schools.

Schools within each size category were located in similar urban settings (i.e., schools with 580 to 1,259 students were located in suburban areas; smaller school were located in rural areas). It is not possible from this study to determine if the primary factor affecting students' scores was the size of the schools, the difference in resources of the schools, or the urbanicity of the schools.

Urbanicity.

One study examined the relationship between students' conceptions of geoscience topics and urbanicity. Urbanicity is the degree to which an area is urban (Martin, 2004). Schoon (1988, 1992) administered an geoscience concept test to 1,213 elementary, middle school, high school, and college students who attended schools in urban and suburban settings. Schoon found that students who attended schools in urban settings held more alternative conceptions than did students attending schools in suburban settings.

Schoon hypothesizes that the differences in conceptions between students attending urban and suburban schools were attributed to characteristics of the students and their school environments. For example, Schoon states that differences in students' socio-economic status and ethnicity between the urban and suburban settings could have caused the differences in conceptions held by the students. School factors (e.g., school funding and teacher quality) and the specific curricula adopted by the schools at the locations also could have influenced students' conceptual development (Schoon, 1988, 1992).

Private versus public institution.

Libarkin et al. (2005) investigated the relationship between students' conceptions of geologic time and the public or private nature of the institution of higher education they attended. Students attending Harvard University (n = 54), a small private university, University of Arizona (n = 62), a large state university, and Black Hills State University (n = 149), a small public liberal arts college, completed an open-ended questionnaire that probed their conceptions of geologic time. Libarkin et al. reported that 46% of the students from Harvard, 39% of the students from the University of Arizona, and 8% of the students from Black Hills State held the scientific conception that the earth is 4.5 billion years old.

Libarkin et al. (2005) did not investigate the characteristics of the three institutions that may have led to the differences in the students' conceptions of geologic time. Several characteristics (prestige of institution, entrance requirements, tuition rate, etc.) likely determine the types of students that attend the three institutions. Therefore, the background characteristics of the students before they get to the institution may influence their conceptions. Other institutional characteristics may have influenced students' conceptual development while the students were attending the institutions. For example, the institutions may have different curricula, subject offerings, instructional methods, and so forth that influenced students' conceptions.

Conclusion

An extensive literature review was conducted to find studies investigating factors that influence students' conceptions of geology topics. Researchers investigated the effects of several extrinsic and intrinsic factors on students' conceptions. For many factors, there were inconclusive findings about the relationship between the factors and students' conceptions. Several issues may have contributed to the inconclusive findings.

First, most factors were investigated by five or fewer studies. With so few studies, it may be difficult to identify consistent and conclusive patterns for the relationship between factors and students' conceptions. Second, a factor may affect students' conceptions of one topic differently than it affects their conceptions of another topic, and most studies investigating the relationship between a specific factor and students' conceptions investigated various geology topics. For example, several studies found that students' conceptions of various topics changed with age (Blake, 2005; Dodick & Orion, 2003a, 2003b; Hidalgo & Otero, 2004; Marques & Thompson, 1997; Oversby, 1996; Schoon, 1988, 1992, 1995; Shepardson et al., 2005). However, Blake (2005) found that students' conceptions of mountains did not change with age. Similarly, Dodick and Orion (2003a) found that spatial ability affected students' conceptions of some geology topics more than others. Care should be taken when generalizing about the relationship between a factor and students' conceptions of multiple geology topics because the factor may affect students' conceptions of various geology topics differently.

Third, researchers used various data collection methods (e.g., interviews, multiple choice tests, and drawings), and researchers who used the same methods used different versions (e.g., none of the researchers who used a multiple-choice instrument used the same one). Using a different method to identify students' conceptions may affect the findings of the study because different methods may uncover different conceptions. For example, Pulling (2001) found that, on constructed response questions answered in a classroom setting, students expressed conceptions about geologic time and evolution that had little reference to religion. However, during interviews, students' explanations contained more responses that integrated religious and scientific explanations than did those responses for the constructed response questions. Had Pulling only administered constructed response questions, she may have had different findings than she did from also conducting interviews.

Schoon (1988, 1992) and Black (2003, 2005) used the same data collection method (multiple-choice test) but used different tests to investigate the relationship between gender and students' conceptions. The two researchers got different results about the influence of gender on students' conceptions. It is valid to use different data collection methods; however, researchers should be cautious when comparing studies that used different methods because the results may be influenced by the method used to collect the data.

Fourth, multiple factors may simultaneously affect students' conceptions, making it difficult to isolate the effects of any one factor. For example, Philips (1992) concluded that students' responses on a multiple-choice concept test were affected by their gender and understanding of spatial and temporal concepts.

Two final recommendations can be made about the factors that influence students' conceptions of geology topics. First, the small number of studies investigating each factor highlights the need for more research to better identify the influence each factor has on students' conceptions. Second, future studies should attempt to replicate and expand the studies that have already been conducted to build on existing research. For example, Assaraf and Orion (2005) found that students' level of engagement in a lesson influences their conceptions. Similar studies should be contacted to verify or refute the findings.

Factors Influencing Students' Conceptions of Rivers

A systematic and thorough review was conducted to identify studies that investigated factors influencing students' conceptions of rivers. The review process was similar to that described in the Factors Influencing Students' Conceptions of Geology Topics section (see Table 15). The only significant difference was the date range. The date range was 1900 to 2006 for the river studies because a search over the range 1980 to 2006 found few studies. Although the extended date range only found two additional studies (see Piaget, 1929, 1930), these studies proved to be foundational in the investigation of students' conceptions of rivers.

A general overview of the studies is given before the findings for factors that influence conceptions of rivers are described (see Table 22). Seven studies investigated factors that influence students' conceptions of rivers. All occurred outside of the United States: four in the United Kingdom. All the studies investigated elementary school students' conceptions (one also included middle school students). One possible reason why several studies investigated elementary school students' conceptions of rivers in the United Kingdom is that the United Kingdom has a national science curriculum that requires elementary school students to learn about the water cycle and rivers (Dove et al., 1999; Harwood & Jackson, 1993). Two studies (Dove et al., 1999; Harwood & Jackson, 1993) specifically state they were investigating students' conceptions of rivers to learn how students' conceptions matched with the expectations of the national science curriculum.

All the studies collected qualitative data and analyzed the data using qualitative analysis or content analysis. Interviews were the most common method to identify students' conceptions of rivers. None of the studies used multiple-choice tests to identify students' conceptions of rivers.

The studies investigated only three factors that influenced students' conceptions of rivers: age, cognitive ability, and direct experience. Age and cognitive ability were categorized as intrinsic factors. Direct experience was categorized as an extrinsic factor.

Intrinsic Factors

The studies investigated two intrinsic factors: age and cognitive ability.

Age

Three studies investigated the relationship between students' age and their conceptions of rivers. Two (Piaget, 1929, 1930) found that students' conceptions of rivers changed with age. One (Wilson & Goodwin, 1981) found no relationship between age and students' conceptions of rivers.

Table 22

Studies that Investigated Factors Influencing Students' Conceptual Understanding of Rivers

Study	Sample size	Data collection method[a]	Grade level[b]	Country
Dove, Everett, and Preece (1999)	306	D, I	E	UK
Dove, Everett, and Preece (2000)	196	PR	E	UK
Harwood and Jackson (1993)	9	I, D, PR	E	UK
Mackintosh (2005), May (1996)	–[c]	CR, WA, D, I, PR	E	UK
Piaget (1929)	–[c]	I	E	Switzerland
Piaget (1930)	–[c]	I	E	Switzerland
Wilson and Goodwin (1981)	66	D, CR, WA	E, M	Australia

[a] Key to the data collection methods: I = interview, CR = constructed response questions, D = drawings, WA = word association, PR = picture recognition. [b] Key to grade level: E = elementary school students, M = middle school students. [c] Researchers did not list sample size.

In two separate studies, Piaget (1929, 1930) found a progression or evolution of students' conceptions of rivers that he attributed to biological age. In both studies, Piaget conducted interviews with 4- to 11-year-old students to explore the relationship between students' age and their conceptions of rivers. In the first study, Piaget (1929) studied students' conceptions of how rivers begin and the source of the water in rivers. He identified three stages of understanding through which students progressed at specific age ranges. During stage one, which ends at age seven or eight, students thought that the river channel and the water in the river were created by humans. For example, one student said that humans make river channels, and another student said that humans take water from fountains and put it into rivers. During stage two, which begins at age seven or eight and ends at age nine or ten, students thought that the river channel was still created by humans; however, they thought that river water had natural origins (i.e., rain or springs). In the third stage, which begins at age nine or ten, students no longer attributed the river channel or water source to humans. In this stage, students thought the river channel and the water had natural origins (e.g., water creates the river's channel and snowmelt is the source of water in the river).

In the second study, Piaget (1930) examined the relationship between students' ages and their conceptions of the cause of river flow. He found that students progressed through four stages of understanding linked to biological age. In stage one, students thought that humans created river flow and that the water, which they described as being alive or having a consciousness, obeyed the external force exerted by humans on the water. For example, students thought that when humans move boat oars in a river, the river obeyed the external force and moved. The average age for this stage was five years old. During stage two, which began about age seven, students thought that natural external forces (e.g., wind) initiated river flow and again the water obeyed the external force. The external forces (e.g., wind and rocks) that students described in stage two were all incorrect. During stage three, students' explanations were more scientific but were still incomplete. They thought that water flowed because of the river's slope but were not aware of the role of gravity. Students in this stage were on average nine years old. In the fourth stage, students offered scientific explanations for river flow and attributed flow to gravity and slope. The fourth stage started at age 10 or 11.

The stages identified by Piaget in both studies are similar. In the first stage, students held alternative conceptions and attributed the origins of rivers and cause of river flow to humans. In the intermediate stages, students still partially attributed the origins and causes to humans but also held incomplete scientific explanations. In the last stage, students offered scientific explanations for the origins of rivers and the cause of river flow.

Piaget acknowledged that several factors may influence the patterns he observed in students' conceptions of river origins and cause of flow (Piaget, 1929). He stated that formal and informal teaching, religion, direct observation, language, and socialization may have influenced students' conceptions (Piaget, 1929). However, Piaget stated that these were secondary factors in students' conceptual development and that the mental development of the brain related to maturation was the dominant cause for the patterns he identified in the two studies.

Wilson and Goodwin (1981) examined 66 10- and 12-year-old students' conceptions of river environments. To identify conceptions, the researchers administered an instrument that required students to write words they associated with a river, draw a picture of a river, write a story about a river about which they were familiar, and complete a pair-word activity. The students in both groups described and depicted similar river environments. Wilson and Goodwin concluded that students from the two age groups held similar conceptions of river environments.

There is not enough research to determine the patterns between students' age and their conceptions of rivers. Piaget (1929, 1930) and Wilson and Goodwin (1981) studied students of similar ages; however, they investigated different river subtopics and used different methods. More research should be conducted to determine how students' conceptions of rivers change with age.

Cognitive Ability

One study investigated the effect cognitive ability had on students' conceptions of rivers. Harwood and Jackson (1993) compared the relationship between nine 9- to 11-year old students' conceptions of landscape features (e.g., hill, harbor, cliff) and their academic ability level. River was one of the land features investigated in the study. The nine students were placed into two academic ability level groups: a special needs group (n = 4) and a non-special needs group (n = 5). The special needs group represented students with a lower academic ability level than the non-special needs group. The researchers did not describe what method was used to categorize the students into the groups, although they stated that in the United Kingdom, where the study occurred, a wide variety of student behaviors and characteristics fall under the umbrella of special needs. For example, one student was labeled special needs because she had problems spelling, and another was labeled special needs because she lacked motivation and confidence. To determine students' conceptions of rivers, the researchers administered three assessments: an interview, drawing, and picture recognition.

Harwood and Jackson (1993) concluded that there was no relationship between students' academic ability level and their conceptions of rivers. However, they did not state how they came to this conclusion or provide evidence to support this claim. They presented the mean scores that students received on the three assessments, and it appears that the mean scores for the special needs students across all assessment types for rivers was lower than the mean scores for the non-special needs group.

The results from this study are not conclusive about the relationship between student achievement level and conceptions of rivers. More studies should be conducted to explore possible relationships.

Extrinsic Factors

The studies investigated only one extrinsic factor: direct experience.

Direct Experience

Several studies investigated the influence of students' direct experience on their conceptions of rivers, with inconclusive results. Harwood and Jackson (1993) assessed nine 9- to 11-year-old students' conception of nine landscape features, including rivers. The researchers assessed students' conceptions of rivers by asking them to define a river during interviews, identify pictures of the features from photographs, and draw a picture of a river. Of interest are the drawings. Eight of the nine students drew pictures of nearby rivers. Harwood and Jackson suggested that the students' experience with local rivers influenced them to depict those rivers in their drawings. Although the drawings depicted local rivers, they also included features not found in local rivers. For example, one student drew a shark's fin and an octopus in her river. The drawings also included alternative conceptions. For example, one student drew a river flowing over the crests of hills instead of in the adjacent valleys. The researchers concluded that students' direct experience had some influence on how they conceptualized river environments. However, this direct experience may not have been the sole factor in students' conceptual development as evidenced by the students drawing features not found in local rivers.

May (1996) and Mackintosh (2005), reporting on the same study, stated that all the students in their study lived next to a river estuary and that prior to the study all students had been on a field trip to visit the estuary. The researchers assessed students' conceptions of various aspects of a river after the field trip by having them write definitions, complete a word association, draw a picture of a river, and participate in an interview. Out of 28 students, 20 students described rivers ending in the sea. Students may have developed this idea through their direct experience of living next to an estuary or from their experience on the field trip. However, eight students gave alternative responses. For example one student said, "at the end of the river there'd be a wall across" (May, 1996, p. 13). Two students stated they did not know where rivers ended. For example, a student said "I've never been to the end of the river" (May, 1996, p. 13).

The researchers did not hypothesize that students' direct experience visiting a river estuary influenced most of the students to describe rivers ending in the sea. Additionally, they did not explore why some of the students, who supposedly went on the field trip to the estuary, had alternative ideas about where rivers end. However, their data offer evidence that students' direct experience may have influenced their conceptions about where rivers end.

Unlike Harwood and Jackson (1993), May (1996), and Mackintosh (2005), Dove, Everett, and Preece (1999; 2000) concluded that students' conceptions of river environments are not based on their direct experience. Dove et al. (1999) investigated the conceptions of rivers held by 306 9- to 11-year-old students through interviews and drawings. The students attended schools located in rural locations. All school locations had rivers nearby. During the interview, almost all the students said that the rivers they had drawn were made up. Very few students included features characteristic of local rivers. The students generally depicted rivers in rural or pastoral settings. Students may have drawn rivers in rural settings because of their direct experience with rivers in the rural environments in which they lived. However, Dove et al. concluded that, through their drawings, students portrayed their idealized conceptions of rivers and that these idealized conceptions were not influenced by students' direct experience. Dove et al. do not provide evidence to support this claim.

To investigate this pattern further, Dove et al. (2000) studied 196 urban students' conceptions of rivers. Students were asked to sort photographs of rivers into categories of "most like a river" and "least like a river." Despite the fact that a large river flowed through the city where the students lived, most students selected rivers located in rural pastoral settings as most like a river (Dove et al., 2000). Dove et al. (2000) suggested that students get their conceptions from textbooks and children's literature, which generally depict rivers in rural rather than urban settings, instead of from direct experience with local rivers. Dove (1998a) examined rivers in popular children's literature and found that rivers were depicted in pastoral, rural settings. Dove et al. (1999; 2000) concluded that regardless of where students lived, in urban or rural settings, they developed idealized conceptions of rivers in pastoral rural settings, and their direct experience had little influence on their conceptions of river environments.

Wilson and Goodwin (1981) examined 66 10- and 12-year-old students' conceptions of river environments. To identify students' conceptions, the researchers administered a multiple-part, open-ended assessment instrument. The first question of the instrument asked students to write words they associated with rivers. Later in the instrument, students were asked to write a story about a river with which they were familiar. When comparing students' responses to the word association question with the responses to the story about a river question, the researchers made an interesting observation. They found the word association elicited more generic terms (i.e., not referring to a specific river) about rivers from the students than did the river story question. The river story question elicited more idiosyncratic terms than did the word association question. The idiosyncratic terms (e.g., vegetation, wildlife, and recreational activities) described a river environment near where the students lived. Wilson and Goodwin (1981) did not specify which words they thought were generic and which ones were idiosyncratic, which would have been valuable.

When asked to provide terms associated with the term "river," students provided generic terms, terms not based solely on their direct experiences with rivers and that may represent their idealized conception of a river. However, when asked to provide information about a specific river, students provided more specific descriptions of rivers related to their direct experience with the natural environment. Wilson and Goodwin's (1981) findings may support Dove et al.'s (1999; 2000) conclusions that when asked about rivers in general, students rely on an idealized perception of a river. However, this does not mean they are not influenced by their direct experiences because, when probed to describe a river with which they were familiar, Goodwin and Wilson (1981) found that students' descriptions of rivers changed, and they incorporated less generic and more idiosyncratic descriptions of river environments.

Summary.

There is evidence that students' conceptions are influenced by their direct experience with the natural world. However, students may also develop idealized conceptions of a river that are not specifically related to direct experiences with rivers. These idealized conceptions may be influenced by other factors (e.g., textbooks). Future research should determine if students develop idealized conceptions of rivers and how these idealized conceptions influence students' understanding of rivers.

Only one study investigated the type of direct experience students had with rivers. Harwood and Jackson (1993) asked students if they had ever visited or seen a river. None of the other studies gathered information about students' direct experience with rivers. The studies assumed that students had experience with their local environment but did not gather information from the students about the types of direct experiences they had with rivers. Future research should aim for a better understanding of how direct experience influences students' conceptions.

Conclusion

The literature review found inconclusive results about the effects of age, cognitive ability, and direct experience on students' conceptions of rivers. More studies are required to explore further the effects of the factors on students' conceptions of rivers.

Future research should also address gaps in the existing research. For example, the age range investigated by the studies was narrow, largely focusing on elementary school students. Future research should investigate how students' conceptions of rivers change through middle school, high school, and college. Only one study investigated the relationship between students' cognitive ability and their conceptions. More studies should be conducted to investigate the role of cognitive ability on students' conceptual development. Future studies investigating the role of direct experience in students' conceptions of rivers should define direct experience, describe how they will determine students' direct experience, and collect data that identifies students' direct experience. Finally, research should be conducted to determine how other factors (gender, ethnicity, instructional methods, etc.) affect students' conceptions of rivers.

Conclusion to Chapter

This chapter reviewed the factors that influence students' conceptions of geology topics and rivers. There is very little research in this area, and the results are largely inconclusive about the relationship between intrinsic and extrinsic factors and students' conceptions. My study helps fill the gap by exploring the relationship between college students' conceptions of rivers and their background and demographic characteristics.

CHAPTER 4: METHODOLOGY

A qualitative research design—basic interpretive qualitative research (BIQR)—was used to address the research questions in this study. The theoretical assumptions underlying BIQR are rooted in the interpretivism theoretical perspective that individuals construct meaning about their lives and the natural world through their interactions with other people and by directly observing and interpreting the natural world (Crotty, 1998; Merriam, 2002). The purpose of BIQR is to uncover and interpret the meanings that individuals construct (Merriam, 2002). I believe that students construct their own conceptions about rivers as they interact with the natural world and with other people. Therefore, BIQR was well-suited for investigating the research questions of this study.

The first research question was to uncover students' conceptions of rivers. This was accomplished through in-depth interviews with students. Data from the interviews were analyzed to interpret students' conceptions. The second research question was to identify patterns between students' conceptions and their demographic and background characteristics. I specifically focused on the patterns between students' conceptions and their gender and ethnicity. Students' gender and ethnicity information were collected from a demographic questionnaire. The relative likelihood of each conception category held by each gender and ethnic group was determined to identify patterns between the students' conceptions of rivers and their gender and ethnicity. Table 23 summarizes the research methodology steps.

Table 23

Summary of Research Methodology Steps

1. Develop interview protocol and demographic and background characteristics questionnaire.
2. Pilot interview questions and questionnaire.
3. Conduct interviews and administer questionnaire.
4. Analyze data.

BIQR was selected over other qualitative research designs. Some qualitative designs have additional purposes beyond that of uncovering and interpreting meaning. For example, the goal in a grounded theory design is to develop a theory about a phenomenon under study (Strauss & Corbin, 1998), and the goal of an ethnography design is to explore a culture (Merriam, 2002). Both these designs have goals that go beyond uncovering meaning. In addition, some qualitative designs have criteria that do not fit the scope of this study. For example, case study is a study of a unit, system, or phenomenon bounded in time, space, or component (e.g., a person, community, or program) (Merriam, 1998); this study does not have such boundaries.

A qualitative design also was selected over a quantitative design. In quantitative studies, researchers collect numerical data to test a theory or hypothesis (Gliner & Morgan, 2000). The goal of quantitative studies is to generalize the findings from a sample to a larger population (Gliner & Morgan, 2000). The goal of my study was to uncover deep understanding about students' conceptions, for which qualitative methods are better suited than quantitative methods. The numerical data collected in quantitative studies does not uncover the deep meanings that individuals construct about their world (Crotty, 1998; Wandersee et al., 1994). The in-depth data collection in qualitative designs (e.g., thick descriptions from in-depth interviews) was the best method for uncovering individuals' meanings (Crotty, 1998; Merriam, 2002). Assessing conceptions of science topics through qualitative methods provides a more comprehensive and in-depth picture of a student's understanding than do quantitative methods (Abdullah & Scaife, 1997; Brody, 1996).

Sample and Location

Purposeful sampling was used to recruit college students taking an introductory geology class at Colorado State University. Purposeful sampling is a sampling technique used in qualitative research to recruit participants who will provide an in-depth understanding of the research questions (Patton, 2002). In this study, men and women and Hispanic and White students enrolled in a college-level introductory geology class during the time of data collection were purposefully recruited to answer the research questions. To participate in the study, the students also had to be willing to be videotaped and audiotaped during their interview and to complete a demographic questionnaire. Students were recruited during class and were interviewed before they studied rivers in class. Participants were offered extra credit points in the class from which they were recruited. The professor of the class offered an alternative opportunity to earn extra credit in the class for those students who did not participate in the study.

Recruiting first occurred in Spring 2005. All college students in an introductory geology class were invited to participate in the interviews regardless of their gender, ethnicity, age, or other demographic or background characteristics (see recruiting statement in Appendix E). Twenty students volunteered and were interviewed. Two of the 20 students identified themselves as Hispanic students on the demographic survey. The remaining students identified themselves as White. I became interested in investigating the pattern between ethnicity and students' conceptions of rivers. I was particularly interested in comparing White and Hispanic students' responses and conducted another recruitment of students. This second recruitment occurred in Fall 2005 in the same introductory geology class, taught by the same professor, as that in which recruitment occurred in Spring 2005. Only Hispanic students were invited to participate (see recruiting statement in Appendix E). Four Hispanic students volunteered and were interviewed. The final sample size was 24. When reporting results, participants were described using numbers so their identities were protected. A summary of the general demographic characteristics of students is in Table 24 and the specific demographic characteristics of each student are in Table 25.

Data Collection

Interviews were conducted to gather data, including interview transcripts and students' drawings, about students' conceptions of rivers. A questionnaire was administered to gather data about students' demographic characteristics.

Table 24

General Demographic Characteristics of Participants

Characteristic	*n*
Gender	
Men	14
Women	10
Ethnicity	
White	18
Hispanic	6
Age	
18 – 22 years old	19
> 22 years old	5
College major	
Science	2
Non-science	18
Other	4

Table 25

Specific Demographic Characteristics of Participants

Participant	Gender	Ethnicity	Age	Major
R05-02	Female	White	22	Construction Management
R05-03	Male	White	23	Studio art
R05-04	Male	White	20	Music
R05-05	Female	White	25	German and Fine Arts with emphasis in Photography
R05-06	Female	White	21	Fine Arts
R05-07	Female	White	22	Apparel Merchandising
R05-08	Female	White	20	Art
R05-09	Female	White	57	Liberal Arts
R05-10	Female	White	20	Landscape Architecture
R05-11	Male	White	20	Construction management
R05-12	Female	White	21	Speech Communication and Construction Management
R05-13	Male	White	20	Construction Management
R05-14	Female	Hispanic	20	No Answer

Table 25 (continued)

Participant	Gender	Ethnicity	Age	Major
R05-15	Male	White	21	Journalism
R05-16	Male	Hispanic	24	Economics
R05-17	Male	White	29	Computer science
R05-18	Male	White	20	Undecided
R05-19	Female	White	21	English with emphasis in Secondary Education
R05-20	Male	White	20	Construction Management
R05-21	Male	White	20	Wildlife Biology
R05-22	Male	Hispanic	22	Economics
R05-23	Male	Hispanic	19	Business
R05-24	Male	Hispanic	19	Undecided
R05-25	Male	Hispanic	20	Undecided

Interviews

Interviews were conducted to explore students' conceptions of rivers. The interview is the most commonly used qualitative method to explore students' conceptions of science topics (Wandersee et al., 1994). The interviewing approach to uncover students' science conceptions was pioneered by Jean Piaget in the early 1900s (Posner & Gertzog, 1982). Conceptions researchers continue to use interviews to identify students' conceptions of science topics. Various researchers describe the interview process used by conceptions researchers (for a review see Abdullah & Scaife, 1997; Bell & Osborne, 1981; Berg, 1993; Osborne & Gilbert, 1980a, 1980b; Posner & Gertzog, 1982).

The interviews in this study were open-ended, semi-structured, and lasted 40 to 60 minutes. Before the interviews, participants were provided with information about informed consent and asked to sign a consent form to agree to participate in the study (Appendix F). During the interviews, participants were asked three to four lead-in questions from an interview protocol. Following methods described by conceptions researchers (for examples see Bell & Osborne, 1981; Brody, 1996), lead-in questions were followed by probe questions that explored students' responses to the lead-in questions. The questions asked participants to express their conceptions about rivers by responding verbally and by creating drawings of their ideas. At the end of the interview, participants completed a 10- to 15-minute questionnaire about their demographic and background characteristics. The interviews were audiotaped, videotaped, and transcribed.

Interview Protocol Development

An interview protocol was developed as a guide during the study. The protocol included scripted main questions and follow-up probe questions, which varied based on the particular responses of each participant. To create a conceptions interview protocol, Brody (1996) recommended that, first, a list of the important concepts related to the topic be developed. To do this, a list of topics related to rivers was created by reviewing introductory college-level geology textbooks (Table 26 has a list of concepts, Appendix G has a list of the textbooks reviewed). Textbooks generally define the content and organization of the curriculum about a particular topic (American Association for the Advancement of Science, 2000; Schmidt, McKnight, & Raizen, 1997). The list of topics developed from the textbook review formed the basis for the river concepts explored by the interview questions.

Interview questions were created that investigated participants' conceptions of at least one river topic (Appendix H has the final version of the interview protocol and which river topic each question addresses). Two types of interview questions were created: questions that require students to describe their conceptions verbally and questions that require students to express their conceptions through drawings. Combining verbal and drawing questions to investigate students' conceptions has been used by several science conceptions researchers (for examples see Blake, 2005; Dove et al., 1999; Harwood & Jackson, 1993; Lunnon, 1979; Mackintosh, 2005; May, 1996; Rennie & Jarvis, 1995; Strommen, 1995; Trend et al., 2000). When considered alone, students' drawings or verbal explanations may not express the breadth and depth of understanding that students have about a topic (Dove et al., 1999; Harwood & Jackson, 1993; Rennie & Jarvis, 1995). However, when used in conjunction, drawings and verbal explanations provide a richer picture of students' conceptions (Dove et al., 1999; Harwood & Jackson, 1993; Rennie & Jarvis, 1995).

Table 26

List of Major River Concepts from Geology Textbooks

1. Definition of a river
2. There are features associated with and created by rivers
3. River Processes
   a. Rivers modify the landscape through erosion and deposition
   b. Rivers move water and sediment from the land to the sea
   c. Rivers flood
4. Rivers are dynamic and change in time and space
5. Rivers are important to plants and animals
6. Rivers are part of earth systems (e.g., water cycle)

The interviews were planned so that the first two questions (Questions 1 and 2) asked all of the students to describe verbally and pictorially their general definition of a river and the features they associated with a river. These questions were asked first to establish participants' conceptions before they were influenced by pictures of rivers that were used later in the interview. In addition to verbally and pictorially defining and describing a river and river features, all students were asked subsequent questions (Questions 3-7) that explored their conceptions of river processes.

During the pilot study, it was found that students could respond to 3-4 main interview questions in a 45-minute period. Therefore, all students were initially assigned two questions to establish their basic understanding of rivers (Questions 1 and 2) and one to two questions to establish their understanding of River processes (Question 3, 4, 5, 6, or 7) (Appendix I, Table I1). The process questions were randomly assigned to students because there was no prior research basis to assign particular process questions to particular students. If there was time during the interview, additional process questions were asked. Appendix I, Table I2 lists the actual main questions that were asked during each of the interviews.

Technical terms were not used in the questions to avoid introducing concepts the participant did not know. If a participant used a technical term in a response, then I asked the participant to define the term and occasionally used the term in follow-up questions.

After the initial interview protocol was developed, five experts—a conceptions interview expert, a geology conceptions expert, and three geoscientists—evaluated the questions. The conceptions interview and geology conceptions experts evaluated the questions to verify they were appropriate clinical interview questions to elicit responses about students' conceptions. The geology conceptions expert and geoscientists evaluated the questions to ensure that the questions probed the river topic that I had hoped them to address. All five experts also evaluated the order that the questions would be asked. Minor changes were made to the questions based on the experts' input. For example, some terms in the initial questions were changed because they were too technical, e.g., the term "sediment" was changed to "dirt." After the expert review, the interview questions were piloted (see the pilot study section).

Questionnaire

A questionnaire was developed to collect information about participants' demographic characteristics (Appendix J). The questionnaire took 10 to 15 minutes to complete and was administered to the participants at the end of their interviews. The data from the questionnaire were used to provide background information about the students (see Table 25) to investigate the second research question: emerging patterns between students' demographics and their conceptions.

Initially, I intended to investigate emerging patterns between students' conceptions and several demographic characteristics including gender, ethnicity, age, and major. However, as the analysis of data evolved I became increasingly interested in focusing on gender and ethnicity. This interest surfaced when a special issue of the Journal of Geoscience Education (2007, volume 55, number 6) was released that focused on the low representation of minority groups (including Hispanic students) and women in the geosciences. The special issue emphasized a significant and growing interest by geoscientists to understand issues of diversity in the geosciences, particularly issues related to recruitment and retention of women and minorities (Holmes & O'Connell, 2004; Huntoon & Lane, 2007; Riggs & Alexander, 2007). After the release of the special issue of the Journal of Geoscience Education, I decided to focus my study on the investigation the emerging patterns between students' conceptions and their gender and ethnicity. Table 27 lists studies that have previously investigated the patterns between students' conceptions of geology topics and their gender and ethnicity.

Table 27

Studies that Investigated Patterns between Conceptions of Geology Topics and Gender and Ethnicity

Characteristic	Study
Gender	Black (2003, 2005), Philips (1992), Schoon (1988, 1992), Steer, Knight, Owens, and McConnell (2005)
Ethnicity	Schoon, (1988, 1992)

After the questionnaire was created, an expert in questionnaire design evaluated the order and wording. Based on recommendations, minor changes were made to the questionnaire. The questionnaire was then piloted (see the pilot study section). The final version of the questionnaire is in Appendix J.

Pilot Study

A pilot study was conducted to test the questions in the interview protocol and questionnaire and to test the audio and video equipment. The interview protocol and questionnaire were piloted with three students who had similar characteristics as those students in the main study. The protocol was modified based on the interviews. For example, during the pilot interviews, it was found that two of the original questions worked better when merged into one question. Therefore, those two questions were merged during the main study. The final interview protocol and questionnaire are in Appendices H and J.

Data Analysis

Qualitative data analysis is the process of finding patterns and structure in the data (Strauss & Corbin, 1998). In this study, the goal was to determine students' conceptions of rivers and to explore the patterns between students' conceptions and their demographic characteristics. To determine students' conceptions of rivers, the interview transcripts and drawings were analyzed using a modified version of constant comparative analysis. To explore the patterns between students' conceptions and their demographic characteristics relative frequency and relative likelihood calculations were made.

Analysis of Interview Transcripts

The interview transcripts were analyzed using a modified version of constant comparative analysis (Strauss & Corbin, 1998). In this technique, patterns and themes are developed from the data through inductive analysis. Constant comparison refers to the process in which data are placed into initial categories and are constantly compared with each other to develop broader categories (i.e., categories that include groups of related categories) (Strauss & Corbin, 1998). The constant comparison helps ensure that the resulting categories accurately reflect and include the data from which the categories were generated (Strauss & Corbin, 1998). Constant comparative analysis has three levels of coding: open, axial, and selective. The modified version of constant comparative analysis used in this study only uses the open and axial levels of coding. The third level, selective, develops a theory associated with the study; because theory development was not a goal of this study, only the first two levels of coding were used.

In the next sections, I will describe the analytical process as a series of steps to demonstrate the process of analysis (Table 28). However, the actual process of analysis is iterative and fluid. It is iterative because during the process of analysis I moved from open to axial coding continually as I developed codes, related codes to each other, merged and refined codes, and determined how codes ranged along their dimensions. The process of moving from open to axial coding is a fluid process in which there is generally no clear boundary between open coding and axial coding. Another characteristic of analysis is the constant movement between various levels of abstraction. The raw data represents the lowest level of abstraction. Open codes are one level of abstraction away from the raw data. Axial codes are another level of abstraction away from the data and the final interpretation of the data represents the highest level of abstraction.

Table 28

Steps in Analysis of Interviews and Drawings Using Constant Comparison Analysis

Step 1:	Conduct open coding
Step 2:	Conduct axial coding
Step 3:	Develop subtopics and dimensions (this step occurs during open and axial coding)
Step 4:	Classify responses into conception categories

Open Coding

In open coding, the data were coded into general categories, which are phrases, sentences, or paragraphs that express discrete conceptions (Strauss & Corbin, 1998). As additional data were analyzed with each new transcript, they were compared with existing categories. Categories were added or refined to accommodate the new data. The categories underwent modification to incorporate new information.

Table 29 has a simplified example of open coding using data collected in the study. The column on the left has interview transcripts from two students. In both transcripts, the students responded to the same line of questioning about how a canyon formed. The column on the right has the codes that were generated during open coding. In this example, four codes were created during open coding of R05-11's interview transcript. After R05-11's interview transcript was coded, then R05-19's interview transcript was coded. R05-19's responses were compared to the codes created during open coding of R05-11's interview transcript. The codes created during analysis of R05-11's interview transcript did not adequately capture the meaning of the data in R05-19's responses; therefore, new codes were created for R05-19's responses. Two codes were created during open coding of R05-19's interview transcript.

Axial Coding

In axial coding, the relationships between categories were explored. Through the process of axial coding, there was an ongoing comparison and revision of categories. When categories captured all the variations of participants' conceptions, and when the relationships among categories were delineated, a final list of categories was generated. In my study, the final categories are called river topics and the subcategories are called subtopics.

Table 29

Example of Open Coding

	Interview Transcripts	Open Codes
R05-11		
INT:	How was the canyon formed?	
R05-11:	**Through erosion. As the river goes constantly throughout the year, it picks up sediment and carries it along. Depending on how fast the river is flowing it carries sediment along with it and deposits it further down.** So in this picture, it takes millions of years to do this but **it cuts away at earth and keeps carrying it away to further distances and deposits it, deposits it and that's how a canyon is formed.**	• **Canyon created by river through erosion** • River erodes, picks up and carries sediments, cuts away at earth and carries it • Canyon formed over millions of years • River deposits sediment
R05-19		
INT:	OK. So how do you think the canyon formed?	
R05-19:	**Earthquake maybe, probably.**	• **Canyon created by earthquake**
INT:	How [did] the earthquake form a canyon?	
R05-19:	If the land splitting apart **by the earthquake,** I don't know how to explain it, it would just - **like the earthquake would happen** and then the earth would kind of like fall into it. Like the land that broke off and form a canyon. I don't know. (laughs)	• Land splits and falls in, land broke off

Note. For R05-11's interview, the bold formatted interview text generated the bold formatted open code, the dashed underlined interview text generated the dashed underlined open code, the single underlined text generated single underlined open code, and the double underline text generated the double underlined open code. For R05-19, the bold formatted interview text generated the bold formatted open code and the single underlined text generated the single underlined open code.

Table 30 shows a simplified example of axial coding. The column on the left contains the open codes created in the analysis example in Table 29. The column on the right shows the axial codes. During axial coding, the open codes were organized into categories and subcategories (or topics and subtopics) based on how they related to each other. In the example, three categories (canyon formation process, erosion, deposition) and several subcategories were created by relating and organizing the open codes.

Table 30

Example of Axial Coding

Open Codes	Axial Codes
R05-11 • **Canyon created by river through erosion** • **River erodes, picks up and carries sediments, cuts away at earth and carries it** • **Canyon formed over millions of years** • River deposits sediment R05-19 • **Canyon created by earthquake** • **Canyon created by earthquake** • **Land splits and falls in, land broke off**	1. Canyon Formation Process (cause, process, duration) **a. Cause and process** **i. Canyon created by river through erosion Over millions of years.** **ii. Canyon created by earthquake through land splitting and falling in. Duration not discussed in interview.** **b. Duration** **i. Over millions of years.** **ii. Duration not discussed in interview.** 2. Erosion (process) a. Picks up and carries b. Cuts away at earth and carries c. Through erosion, rivers modify the landscape 3. Deposition a. Deposits sediment

Note. The bold open codes in the column on the left were organized into the bold axial codes, the single underlined open codes were organized into the single underlined axial codes, and the dashed underlined open codes were organized into the dashed underlined axial codes.

Develop Subtopics and Dimensions

During open and axial coding the specific characteristics, or subtopics, of each river topic and the dimensions of the characteristics were determined. Subtopics are the properties or characteristics that define the topic and the dimensions describe the range of data along which the subtopics vary (Strauss & Corbin, 1998). For example, cause and process of canyon formation is a subtopic of canyon formation is. Table 31 shows the dimensions of cause and process.

Table 31

Example of Dimensions and Classification of Dimensions into Conception Categories

Topic	Subtopic	Dimensions	Conception Category
Canyon formation	Cause and process	1. River erosion caused formation 2. A catastrophic event, like an earthquake, caused formation	**Incomplete Scientific Conception** • Student described river erosion as the primary process that forms canyons. • Student did not describe the role of base level change in canyon formation. **Alternative Conception** • Student said that a catastrophic event (like earthquake) is the primary process in canyon formation • Student did not describe the role of base level change in canyon formation.

Note. Cause and process is the subtopic of canyon formation. The responses have two dimensions that are classified into two conception categories.

Classify Responses into Conception Categories

The final analysis step to answer the first research question of this study was to classify students' responses into conceptions categories (i.e., alternative and scientific conceptions). This was done by evaluating the range of responses making up the dimensions of the subtopics and developing criteria to place the range of responses into the conception categories. Responses that were the same as the scientific explanation for the phenomena were categorized as scientific conceptions. Responses that differed from the accepted scientific explanation were categorized as alternative conceptions.

During analysis, I found that the two conception categories alternative and scientific did not capture the full range of students' conceptions of river topics. Therefore, I developed three additional conception categories (Table 32). Responses that were scientific but incomplete were categorized as incomplete scientific conceptions. Responses that blended the scientific explanation and an alternative explanation were categorized as either incomplete scientific-alternative or scientific-alternative conceptions. Table 31 shows an example of how the range of responses making up the subtopic dimensions for canyon formation were placed into the conception categories.

Table 32

Conception Categories

Conception Category	Description of Category
Scientific Conception	Student provided the complete scientific explanation for a river topic.
Incomplete Scientific Conception	Student provided a scientific explanation for a river topic, however was missing components that would make the explanation scientific. The missing information could include a student explicitly stating that he/she did not know some of the information.
Scientific-Alternative Conception	Student blended a scientific explanation with an alternative, or non-scientific, explanation.
Incomplete Scientific-Alternative Conception	Student blended an incomplete scientific explanation with an alternative, or non-scientific, explanation. Note, there were missing components that would make the explanation a scientific alternative conception.
Alternative Conception	Student provided a non-scientific explanation (i.e., it differed from that accepted by the scientific community).

Analysis of Drawings

To get a richer and broader picture of the conceptions that the students held, the drawings were analyzed for their manifest content (i.e., the actual objects drawn) and their latent content (i.e., the meanings and conceptions expressed in the drawing) (Boyatzis, 1998) (Figure 1). Analysis of the drawings was conducted using the modified version of the constant comparative analysis described previously and occurred simultaneously with the analysis of the interview transcripts (Table 28). During open and axial coding, categories created through analysis of the manifest and latent content were compared with the categories created from analysis of the verbal responses. The categories developed from the manifest and latent content of drawings were merged with similar categories from the verbal responses or became additional categories if there were no similar categories from the verbal responses.

Questionnaire

The second research question was to investigate the emergent patterns between students' conceptions and their demographic characteristics, specifically gender and ethnicity. To investigate the patterns, relative frequency and relative likelihood calculations were made. Relative frequency is the percentage of occurrences of a particular gender or ethnic group holding each conception category. Relative likelihood is a measure of between gender-differences and between-ethnic group differences. Specifically, relative likelihood is the ratio of the gender-specific and ethnic-group specific relative frequencies for each conception category. Relative likelihood is easy to interpret. For example, a relative likelihood of 2 indicates that the percentage of students in one gender holding a particular conception category is two times larger than the percentage of students in the other gender holding the same conception category.

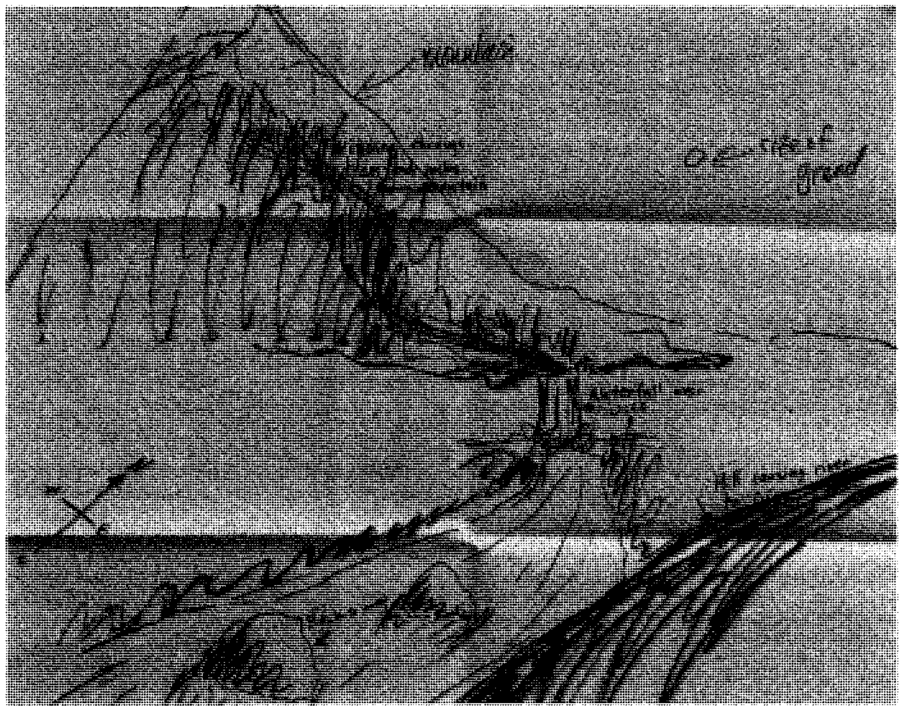

Figure 1. Example of manifest and latent content in a drawing. The manifest content is that a river is depicted in the drawing. The latent content is that the student conceptualizes the river as a linear feature on the landscape.

Relative frequency and relative likelihood calculations do not allow for probabilistic generalizations. However, the calculations are appropriate and useful statistics to investigate patterns in a qualitative study in which the purpose is to describe patterns in a unique data set. Relative frequency and relative likelihood calculations have been used for similar purposes by others (for example see Banning, Sexton, Most, & Maier, 2007).

To investigate the pattern between students' conceptions and their gender, first the total number of occurrences of female and male students holding each conception category was determined. Next, each gender's relative frequency holding each conception category was calculated. Finally, between-gender patterns were investigated by calculating relative likelihood statistics. All relative likelihood statistics were comparisons of women to men. Relative likelihoods greater than one indicate that a higher proportion of women held a particular conception. A relative likelihood less than one indicates a higher proportion of men held a particular conception.

To investigate the pattern between students' conceptions and their ethnicity, first the total number of occurrences of White and Hispanic students holding each conception category was determined. Next, each ethnic group's relative frequency holding each conception category was calculated. Finally, between-ethnic group patterns were investigated by calculating relative likelihood statistics. All relative likelihood statistics were comparisons of Hispanic students to White students. Relative likelihoods greater than one indicate that a higher proportion of Hispanic students held a particular conception. A relative likelihood less than one indicates a higher proportion of White students held a particular conception.

Trustworthiness

Several strategies were used in this study to ensure trustworthiness, i.e., the reliability and validity in a qualitative study (Creswell, 1998; Merriam, 2002). To confirm the emerging conceptions and patterns in this study, multiple sources of data (interview transcripts, drawings, and questionnaires) were collected. A review of the data collection and analysis processes and the findings were conducted by peers and experts.

A detailed description of the methods and analysis were maintained. In describing the findings, thick descriptions based on the data collected were used. Finally, my assumptions and theoretical orientations as the researcher were expressed.

CHAPTER 5: RESULTS AND DISCUSSION

The first research question was to identify students' conceptions of river processes and features and to classify the conceptions into scientific and alternative categories. Nine river features and processes (referred to as topics) were identified in the analysis (Table 33). Topics contained one or more subtopics. Additional conception categories were developed to accommodate the range of students' understanding of the river topics.

Overall, the students in the study mostly held scientific and incomplete scientific conceptions for the nine river topics (Table 34). Students held few alternative conceptions, scientific alternative conceptions, and incomplete scientific alternative conceptions (see the column on the far right in Table 34). Students' conceptions for the subtopics were analyzed and it was found that students held alternative conceptions only for subtopics that were processes/causes and difficult to observe features.

The second research question was to identify emergent patterns between students' conceptions and their gender and ethnicity. Men in this study held scientific, incomplete scientific, and scientific-alternative conceptions more frequently than did the women. Women held incomplete scientific-alternative and alternative conceptions more frequently than did men. White students in this study held scientific, incomplete scientific, and scientific-alternative conceptions more frequently than did the Hispanic students. Hispanic students held incomplete scientific-alternative and alternative conceptions more frequently than did White students.

A detailed description of the results for research question one followed by the results for research question two will be presented in the rest of the chapter.

Table 33

Nine River Topics Identified in Analysis

1. Cause of river flow
2. Definition and cause of river floods
3. Definition of a river
4. Destination of river water
5. Process of and factors affecting river erosion
6. Process of river channel formation
7. Role of rivers in canyon formation
8. Source of river water
9. Type and origin of sediment in the river

Research Question 1 Results: Conceptions of River Topics

For each river topic, students' conceptions of the subtopics were used to develop criteria to place students into one of the five conception categories. Although there were five possible conception categories, the specific conception categories held by students varied for each topic so that not all conceptions categories were held by students for all topics. For example, only incomplete scientific and incomplete scientific-alternative conceptions were held by students for source of water. The specific conceptions held by students for each topic and subtopics will be described. After students' conceptions for all nine topics are described, there will be a discussion of the general patterns of students' conceptions across topics and subtopics.

Table 34

Conception Category for each Student for each River Topic

Participant	River Topic[a]									# AC, SAC, & ISAC
	Definition of River	Cause of Flow	Source of Water	Destination of Water	Sediment Type and Origin	Floods	Channel Formation	Canyon Formation	Erosion	
R05-02	SC	SC	ISC	ISC	ISC	NA	ISC	NA	SC	0
R05-03	SC	SC	ISC	ISC	ISC	NA	SC	NA	SC	0
R05-04	SC	SAC	ISC	ISC	ISC	SC	SC	NA	SC	1
R05-05	SC	SC	ISC	ISC	ISC	SC	NA	ISC	SC	0
R05-06	SC	SAC	ISC	ISC	ISC	NA	NA	ISC	SAC	2
R05-07	ISC	AC	ISAC	ISC	ISC	SC	ISAC	AC	SAC	5
R05-08	SC	SC	ISC	ISC	ISC	NA	SC	ISC	SAC	1
R05-09	SC	SC	ISC	ISC	ISC	NA	NA	ISAC	SC	1
R05-10	SC	SC	ISC	ISC	ISC	NA	SC	ISC	SC	0
R05-11	SC	SC	ISC	ISC	ISC	SAC	NA	ISC	SC	1
R05-12	SC	AC	ISC	ISC	ISC	SC	NA	ISAC	SC	2
R05-13	SC	SC	ISC	ISC	ISC	SAC	ISAC	ISC	SC	2
R05-14	SC	SC	ISAC	ISAC	ISC	SC	ISAC	AC	AC	5
R05-15	SC	SC	ISC	ISC	ISC	SAC	SC	ISC	SC	1
R05-16	SC	SC	ISC	ISC	ISC	SC	ISAC	ISC	SC	1
R05-17	SC	SC	ISAC	ISC	ISC	SAC	ISAC	ISAC	SAC	5
R05-18	SC	SAC	SC	ISC	ISC	SC	ISC	ISC	SC	1

Table 34 (continued)

Participant	River Topic[a]									# AC, SAC, & ISAC
	Definition of River	Cause of Flow	Source of Water	Destination of Water	Sediment Type and Origin	Floods	Channel Formation	Canyon Formation	Erosion	
R05-19	SC	NA	ISAC	ISC	ISC	SAC	AC	AC	SAC	5
R05-20	SC	SC	ISC	ISC	ISC	SC	ISAC	ISC	SC	1
R05-21	SC	SAC	ISC	ISC	ISC	SC	ISC	ISC	SC	1
R05-22	SC	SC	ISC	ISC	ISC	NA	ISC	NA	SC	0
R05-23	SC	SAC	ISC	ISC	ISC	SC	SC	NA	SC	1
R05-24	SC	SAC	ISC	ISC	ISC	NA	ISAC	AC	SAC	4
R05-25	SC	SAC	ISC	ISC	ISC	ISC	SC	NA	SC	1

Note. The total number of alternative, scientific-alternative, and incomplete alternative-conceptions for each student is listed in the column on the far right. [a] AC = Alternative Conception, ISAC = Incomplete Scientific Alternative Conception, ISC = Incomplete Scientific Conception, NA = not applicable, topic not investigated, SAC = Scientific Alternative Conception, SC = Scientific Conception.

Definition of a River

A river is a body of water that flows in a channel from high elevation to low elevation. Students held two conception categories for the definition of a river (Table 35 and Table 36). Most students described (verbally and/or pictorially) rivers as being linear bodies of water (as opposed to rounded bodies like lakes), that flow, and that flow from uphill to downhill. Criteria to place students into conceptions categories were developed from students' understanding of these three subtopics of a definition of a river. If a student correctly described each of these three subtopics then he or she was coded as having a scientific conception of definition of a river. If a student was missing one or more of the subtopics then he or she was coded as having an incomplete scientific conception. Only one student held an incomplete scientific conception of a river (Table 36).

Table 35

Criteria to Place Students into Conception Categories for Definition of a River

Scientific Conception
1. Student described that a river is a linear body of water.
2. Student described that a river flows.
3. Student described that a river flows from high to low elevation.

Incomplete Scientific Conception
Student is missing one or more of the following criteria:
1. Student described that a river is a linear body of water.
2. Student described that a river flows.
3. Student described that a river flows from high to low elevation.

Table 36

Students' Conceptions for Definition of a River Subtopics and their Overall Conception Category

Participant	Subtopics[a]			Category[b]
	Linear body of water	Flows	Flows from high to low ground	
R05-02	Y	Y	Y	SC
R05-03	Y	Y	Y	SC
R05-04	Y	Y	Y	SC
R05-05	Y	Y	Y	SC
R05-06	Y	Y	Y	SC
R05-07	Y	Y		ISC
R05-08	Y	Y	Y	SC
R05-09	Y	Y	Y	SC
R05-10	Y	Y	Y	SC
R05-11	Y	Y	Y	SC
R05-12	Y	Y	Y	SC
R05-13	Y	Y	Y	SC
R05-14	Y	Y	Y	SC
R05-15	Y	Y	Y	SC
R05-16	Y	Y	Y	SC
R05-17	Y	Y	Y	SC
R05-18	Y	Y	Y	SC
R05-19	Y	Y	Y	SC
R05-20	Y	Y	Y	SC
R05-21	Y	Y	Y	SC
R05-22	Y	Y	Y	SC
R05-23	Y	Y	Y	SC
R05-24	Y	Y	Y	SC
R05-25	Y	Y	Y	SC

[a] Y = yes, student included and understood this concept in definition of a river; blank cells indicate that the student did not include this concept in definition of a river. [b] SC = Scientific Conception, ISC = Incomplete Scientific Conception.

Scientific Conceptions

Students held scientific conceptions if they described a river as a flowing linear body of water that flows from higher to lower elevations (Table 35 and Table 36). For example, R05-03 described a river as having a linear pattern (bold text) that flows (single underlined text) from higher to lower ground (double underlined text):

R05-03

Interviewer (INT):	OK, great. So the first question is, what is a river?
Respondent (RSP):	Umm. Water that flows down in a **sort of line pattern** uh from higher to lower ground. I would say.... Um like it follows a path, um like a sucking down - like a like down at the bottom of a valley or something like that, I guess.
INT:	Ok. Tell me more about - you said sucking down, what did you mean by that?
RSP:	Uh I guess just **flowing** from uphill to downhill um from gravity.

Many of the students did not verbally describe rivers as having linear patterns as R05-03 did. More typically, students described rivers as a body of water as demonstrated by R05-05's response (single underlined text):

R05-05

INT:	The first question is what is a river?
RSP:	A river is a body of water that often - it flows down and starts from like from mountains and it will flow down and it is just the transportation of water into the larger body of the sea - or the ocean.

Although most students did not verbally describe rivers as linear bodies of water, they all drew rivers as linear bodies of water. For example, R05-05 did not verbally describe a river as linear, but depicted a river as a linear water body (Figure 2).

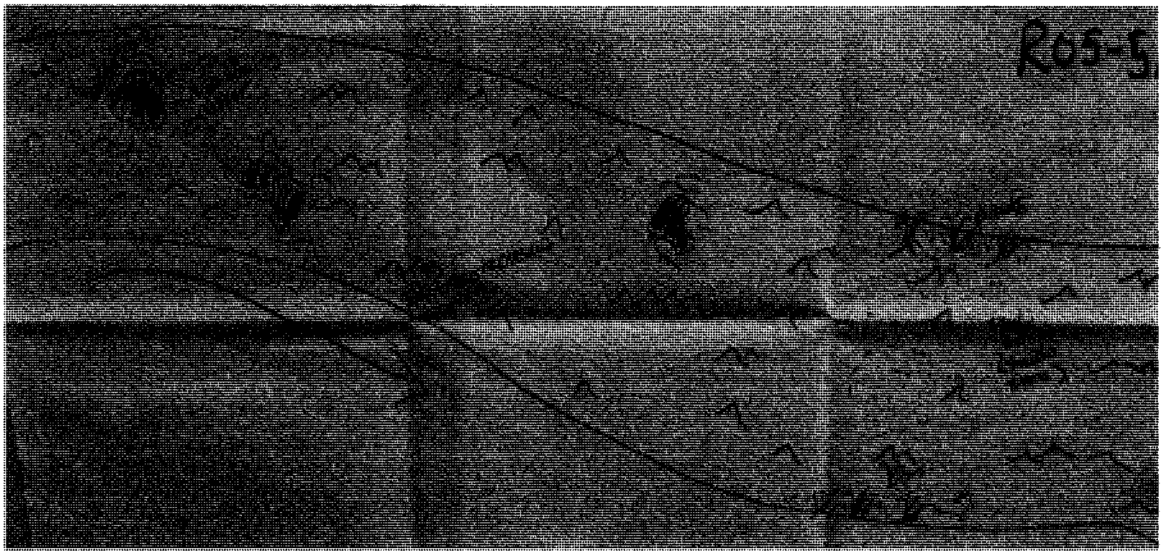

Figure 2. Drawn example of a river as a linear body of water. R05-05 drew a linear body of water, but did not verbally describe a river as a linear body of water.

Students' drawings were important in determining how they defined a river. For example, all students in the study drew linear bodies of water in their drawings. Additionally, many of students' drawings reinforced their verbal description. For example, as shown earlier, R05-03 verbally described all three of the components of a definition of a river and his drawing also depicted the three components (Figure 3).

Incomplete Scientific Conceptions

Only one student, R05-07, held an incomplete scientific conception of the definition of a river. R05-07 was missing one criterion from her definition: she did not describe rivers as flowing from higher elevation to lower elevation. She described a river as flowing water (bold text). She described the linear nature of a river by contrasting it with the ocean and then describing a river as having a stream pattern (indicated in underlined text).

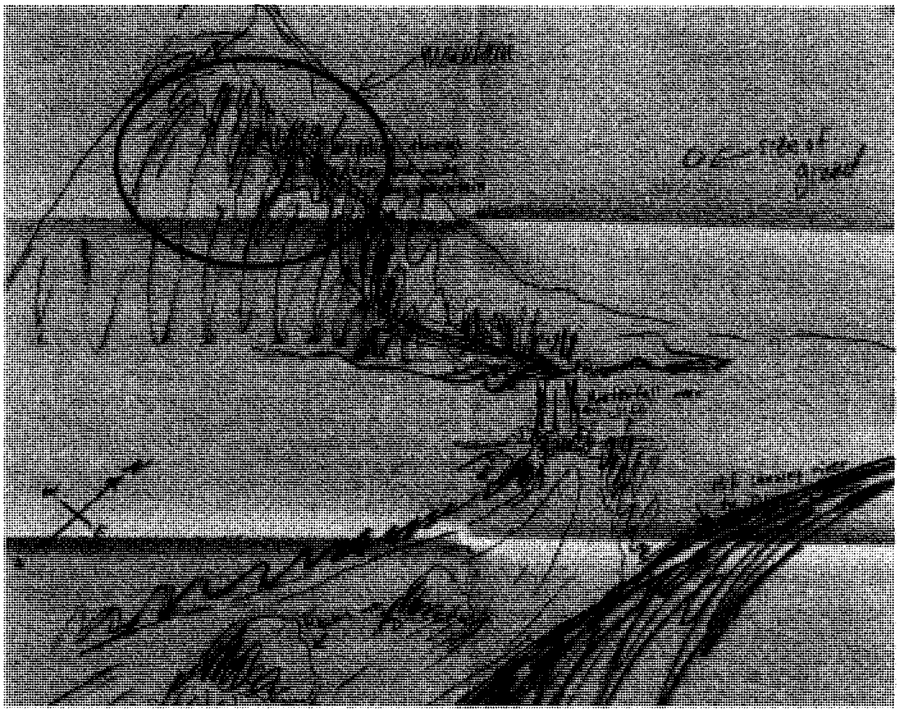

Figure 3. Drawing depicting all three components of the definition of a river. Here R05-03 drew a picture that depicts a river as a linear body of water flowing from higher to lower elevations. The thick black circle in the upper center of the drawing indicates an arrow and words from the student indicating that the river flows from higher to lower elevation.

> R05-07
> INT: The first question is 'what is a river'?
> RSP: I would just describe it as **water flowing**, <u>it's not like an ocean but more like a stream pattern</u>.

R05-07's drawing confirmed her verbal explanation (Figure 4). She drew a picture of a linear body of water that is flowing (indicated by an arrow that shows the direction the river is flowing and by inclusion of currents in the water). Like her verbal explanation, her drawing lacked depiction of elevation to illustrate that a river flows from higher to lower elevation.

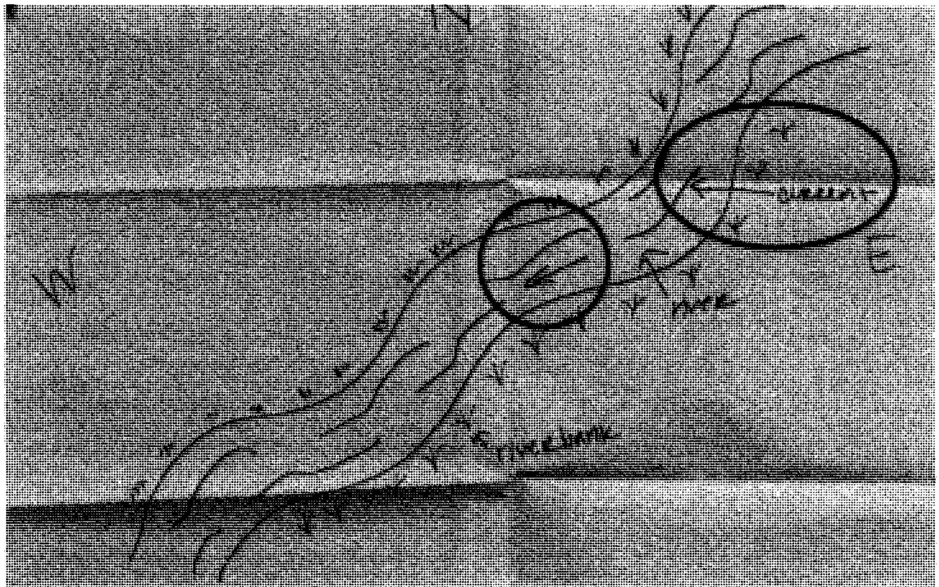

Figure 4. R05-07's drawing of a river. The overall shape of the river emphasizes the linear nature of rivers. The black circle in the center of the drawing highlights an arrow that indicates direction of flow. The black arrow in the upper right corner indicates the student's labeling of currents in the river.

Summary

All but one student in this study held a scientific conception of the definition of a river. One other study investigated students' definitions of rivers. The study was described in two articles: one by May (1996) and one by Mackintosh (2005). May and Mackintosh investigated elementary school students' definition of a river and found that younger students mostly held incomplete scientific conceptions of the definition of a river. For example, one student defined a river as "wet water running down" (May, 1996, p. 12). This definition failed to describe a river as a linear feature. Another student who responded that a river was "a thing with water in a long ditch" (May, 1996, p. 12) correctly associated rivers with water and a linear-like structure—ditch—but failed to acknowledge that rivers flow.

Cause of River Flow

The force of gravity causes rivers to flow. Students in this study were asked why they thought rivers flowed. Students' responses were not probed to uncover their understanding of gravity as a concept. Students were only probed to determine their understanding of what causes rivers to flow in general. If a student said that gravity was the cause of flow then the student was coded as having a scientific conception of river flow (Table 37). Students who described some other cause besides gravity were coded as holding alternative conceptions (Table 37). Students who said rivers flow because of gravity and some other cause were coded as holding scientific-alternative conceptions (Table 37). The cause of river flow was not investigated with one student so her interview was coded as not applicable. Most students held a scientific conception for the cause of river flow (Table 38).

Table 37

Criteria to Place Students into Conception Categories for Cause of River Flow

Scientific Conception Student understood that river flow is due to gravity.
Scientific – Alternative Conception Student believed that gravity and some other factor cause rivers to flow.
Alternative Conception Student thought that river flow is caused by some cause other than gravity (i.e., provided an alternative explanation for the cause of river flow).

Table 38

Students' Conceptions for Cause of River Flow Subtopic and Their Overall Conception Category

Participant	Cause of Flow	Category[a]
R05-02	Gravity	SC
R05-03	Gravity	SC
R05-04	Gravity, law of nature	SAC
R05-05	Gravity	SC
R05-06	Gravity, gradient	SAC
R05-07	Current	AC
R05-08	Gravity	SC
R05-09	Gravity	SC
R05-10	Gravity	SC
R05-11	Gravity	SC
R05-12	Elevation, force of movement	AC
R05-13	Gravity	SC
R05-14	Gravity	SC
R05-15	Gravity	SC
R05-16	Gravity	SC
R05-17	Gravity	SC
R05-18	Gravity, gradient, current	SAC
R05-19	NA	NA
R05-20	Gravity	SC
R05-21	Gravity, build of land, nothing to grab onto	SAC
R05-22	Gravity	SC
R05-23	Gravity, current, rush of molecules	SAC
R05-24	Gravity, a force, downward slope	SAC
R05-25	Gravity, level of grade	SAC

[a] AC = Alternative Conception, NA = Not Applicable, SAC = Scientific Alternative Conception, SC = Scientific Conception.

Scientific Conceptions

Students held scientific conceptions if they described a river as a flowing due to gravity. The two responses below are typical of students who held scientific conceptions:

R05-10
INT: OK, and why do you think they [rivers] move?
RSP: Gravity.

R05-13
INT: Why did it [the river] flow?
RSP: It's going downhill.
INT: Why does going downhill make it flow?
RSP: Gravity.

As described earlier, students were not probed to determine their understanding of the concept of gravity.

Scientific-Alternative Conceptions

Students with scientific-alternative conceptions thought that gravity and other factors were responsible for river flow. Table 39 lists the non-gravity alternative causes described by students.

R05-21 is an example of a student holding a scientific-alternative conception. R05-21 correctly identified gravity as a cause for flow (bold text), but he did not think it is the only cause. When initially asked why rivers move, he described rivers moving "because of the build of the land" (single underlined text). He also said a river flows because it is unable to grab onto anything (indicated by double underlined text). R05-21 did not differentiate between the force of gravity, which causes flow, and factors, like topography and friction, that affect the nature (e.g., velocity and direction) of flow.

R05-21
INT: OK, why does it move? Why does the water move?
RSP: It moves like down slope, across an area. I think like ultimately it's going to move to like a bigger river and into the ocean just because of the way they're situated, just because of the build of the land, I guess, I

don't know.

INT: And why do you think it flows downhill?

RSP: **Like gravity could be helping it**, and <u>there's nothing for it to grab onto, there's no soil or anything so it's going to have to go somewhere</u>.

Table 39

Explanations for Cause of River Flow Described by Students with Scientific-Alternative Conceptions

Cause	Example from interview
Geographic characteristics	
Gradient	"[The river flows] because of the gradient" (R05-18)
Build of the land	"[The river] moves like downslope...because of the build of the land" (R05-21)
Level of grade	"[The river flows because] the level of grade that it's coming down [which is] just like either on a mountainside or a hill or like in a valley or whatever." (R05-25)
Non-specific Causes	
A force	"Well, I guess I didn't mean gravity because that wouldn't make sense...It must have a force that makes it move downward." (R05-24). (Note the student stated specifically that the force was not gravity.)
Nothing for the river to grab on to	"There is nothing for it [the river] to grab on to, there's no soil or anything so it's going to have to go somewhere." (R05-21)
Law of nature	"[A river flows] because of the laws of nature, I guess." (R05-04)
Other Causes	
Rush of molecules	"Maybe it's like a rush of molecules from a waterfall or something is like pushing it [the river] out towards the other distances" (R05-23)
Current	"[The river flows] because of the current." (R05-23)

Alternative Conceptions

Students with alternative conceptions about the cause of river flow thought that factors other than gravity caused river flow (Table 40). Two students held alternative conceptions about the cause of river flow.

Table 40

Explanations for Causes of River Flow Described by Students with Alternative Conceptions

Alternative Cause	Student
Current	R05-07
Elevation	R05-12
Natural force	R05-12

R05-07 struggled with describing the cause of river flow and ultimately said that she did not really understand why rivers flow. R05-07 initially responded that rivers flow because of current (bold text). When asked for clarification, she said that a river is being "pulled" downstream (underlined text). She finally says that she knows that rivers flow down a certain way and that she thinks it is being pulled, but she says that she does not know what is pulling the river to flow in that way.

R05-07

INT: What do you mean 'water flowing' - tell me why it flows.

RSP: **Because of the current. I think.**

INT: And what do you mean by that?

RSP: Just, I guess, whichever way it's being pulled. I don't know if they all flow a certain way but I think they do - like downstream or whatever so.

Later in the interview.

INT: That's OK. So like why do you think they flow? Tell me more about that.

RSP: I honestly have no idea. Just the way I don't know if it's, just the way it's being pulled? But I don't know what causes that.

INT: OK, and how does it get pulled? What does that mean?

RSP: I mean I'm pretty sure that rivers flow down a certain way and I don't know what's pulling it but that's what it is. I mean you can just even see the patterns, like the ripples just going in one direction.

R05-12 described a non-specific force as the cause of river flow (bold text).

R05-12

INT: Why do you think the water moves?

RSP: I think that there is this melt and unless it comes to a lake or something, it's just **the natural force of movement**.

Summary

Most students held scientific conceptions about the cause of river flow. Students who held alternative conceptions and scientific-alternative conceptions about the cause of flow thought that various alternative factors cause river flow. Students' conceptions about gravity as a concept have been well documented (for a review see Driver et al., 1994). Palmer (2001) reported that previous studies show that students' conceptions of gravity may be related to the context or situation in which students are asked about gravity. However, only two studies investigated students' understanding of relationship between gravity and river flow (see Mackintosh, 2005; May, 1996; Piaget, 1930) (note, the study by May and Mackintosh was described in two articles). The findings in this study were both similar to and different from the findings in the previous two studies.

Similar to the findings of this study, Mackintosh, May, and Piaget found that some students correctly identified the cause of river flow whereas other students held alternative conceptions about the cause of river flow. Geographic characteristics were the only alternative explanations for cause of river flow that was shared by students in this study and by the students in the previous two studies. Some students in this study described geographical characteristics (e.g., elevation and gradient) as the cause of river flow. Mackintosh, May, and Piaget also found that some students attributed river flow to geographical characteristics, specifically slope. Students seemed to confuse the cause of river flow (gravity) with a factor that affects the nature of flow (e.g., gradient effects the velocity at which water flows).

Excepting geographic characteristics, the alternative ideas about river flow causes that were identified in this study differed from the causes identified in the other two previous studies. Piaget (1930), Mackintosh (2005), and May (1996) found that elementary school students attributed river flow to humans (Piaget), boat movement (Piaget), fish movement (Mackintosh, May, and Piaget), stones (Mackintosh, May, and Piaget), and wind (Mackintosh, May, and Piaget). None of these causes was described by students in this study.

Sources of River Water

River water can come from several sources. Not all sources necessarily feed into a given river. However when evaluating rivers of all types and in all locations, several sources of water exist. Students' conceptions about the sources of river water were coded into three conception categories (Table 41 and Table 42). Students who described all the types of sources for river water were coded as holding scientific conceptions. Students who described some of the types of sources for river water were coded as holding incomplete scientific conceptions. Students who described some of the types of sources for river water and who also described alternative sources were coded as holding incomplete scientific-alternative conceptions.

Table 41

Criteria to Place Students into Conception Categories for Sources of River Water

Scientific Conception
1. Student described all common sources for river water. This includes rain, snow/snow melt/glacier, lake/reservoir, groundwater/spring, tributaries.
Incomplete Scientific Conception
1. Student described some of the common types of sources for river water, but not all. This includes rain, snow/snow melt/glacier, lake/reservoir, groundwater/spring, tributaries.
Incomplete Scientific - Alternative Conception
1. Student described some of the common types of sources for river water, but not all. This includes rain, snow/snow melt/glacier, lake/reservoir, groundwater/spring, tributaries.
2. Students described alternative sources.

Scientific conception

To have a complete scientific conception of the sources of river water, students had to list all the possible sources of river water and not express any alternative ideas about the source or river water. Only one student, R05-18, held a scientific conception. In the excerpt, he described other rivers (i.e., tributaries), lakes, rain, and snowmelt as sources or river water (bold text).

<u>R05-18</u>
INT: What is a river?
RSP: [A river is] a body of water that flows from a point of source, **a river, a lake, a stream**...
INT: And where does the water come from [in a river]?
RSP: Sources such as **lakes**...mountain **run-off of snowmelt and rain**...

Table 42

Students' Conceptions for Sources of River Water Subtopic and their Overall Conception Category

Participant	Common scientific source[a]					Alternative source	Category[b]
	Snow / snow melt/ glacier	Rain	Lake / reservoir	Tributary	Ground -water		
R05-02	Y			Y			ISC
R05-03	Y		Y		Y		ISC
R05-04	Y	Y					ISC
R05-05	Y	Y					ISC
R05-06	Y	Y		Y			ISC
R05-07	Y	Y				human source	ISAC
R05-08	Y	Y	Y				ISC
R05-09	Y	Y			Y		ISC
R05-10	Y	Y	Y	Y			ISC
R05-11	Y	Y					ISC
R05-12	Y	Y					ISC
R05-13	Y	Y	Y	Y			ISC
R05-14	Y	Y			Y	human source, evaporation	ISAC
R05-15	Y	Y	Y				ISC
R05-16	Y	Y	Y	Y			ISC
R05-17	Y	Y		Y	Y	another planet	ISAC
R05-18	Y	Y	Y	Y	Y		SC
R05-19	Y	Y	Y			ocean	ISAC
R05-20	Y	Y					ISC
R05-21	Y	Y		Y			ISC
R05-22	Y	Y	Y				ISC
R05-23	Y	Y	Y	Y			ISC
R05-24	Y	Y					ISC
R05-25	Y	Y	Y	Y			ISC

[a] Y = yes, student correctly described this source river water; a blank cell indicates that the student did not include this source in his or her description of the source of river water. [b] ISAC = Incomplete Scientific-Alternative Conception, ISC = Incomplete Scientific Conception, SC = Scientific Conception.

Additionally, R05-18 described groundwater as a source of river water. He used the terms "spring" and "water table" to refer to groundwater. R05-18 said that a river would dry up unless it was connected to groundwater (bold text). When probed, R05-18 described a spring as water from groundwater (water table) that can feed a river (indicated by underlined text).

<u>R05-18</u>

RSP: But I would say if the water ran out then soon, pretty quickly, thousands of years, a thousand years maybe, a couple hundred years, maybe the sediment would build up and just form - cover up the river. **Unless there's like a natural spring area or something.**

INT: What's [a natural spring]?

RSP: <u>Natural spring. I don't know, [it] would cause a river somewhere maybe.</u>

INT: And what is that? Tell me about that.

RSP: <u>Natural spring - that's water in the water table maybe that bubbles up somewhere.... That's just water in the water table, I guess, that has a natural flow, and naturally flows in the area through...I guess that's what you'd call it, just a natural flow of the water that's in the water table. Natural source.</u>

Incomplete Scientific Conception

Most students held incomplete scientific conceptions about the sources of water because they described only some of the common sources of river water. Groundwater was the most common source that students did not describe as a source for river water. R05-05 provided a typical response about the sources of river water. She said that rivers get water from snow and rain (bold text).

R05-05

INT: OK, so where does the water come from then that gets into the river?

RSP: It would come from **melting snow** and other precipitation; **rain** would add to it, or anything like that.

Later in the interview, after student draws a picture of a river.

INT: OK, and then tell me again, about how the water got into the river [that you drew].

RSP: **Snow melted.**

Incomplete Scientific-Alternative Conception

Students with an incomplete scientific-alternative conception of the source of river water correctly described only some of the common sources of river water and described alternative sources of river water. Students described four alternative sources of river water (Table 42). The first alternative source was from another planet. R05-17 explained that a past rainstorm caused a large flood and the source of the water for the large storm was water from another planet (bold text).

R05-17

INT: And what would cause a large flood like that…? What would be a major cause for that?

RSP: I don't know exactly, but you know a large amount of rain all at once would definitely do it on a planetary scale. And what would cause that, who knows. **Maybe that's why there's an asteroid belt, maybe there was another planet there that had some sort of chasmiclitic [sic]- something that annihilated the planet and all the water went somewhere, and some of it came to earth and caused the large flood like was described.** But I don't know, I can't really tell you one way or another why things happen the way they did.

The second alternative source was water that originated from humans. R05-07 and R05-14 both described a human water source. For example, R05-07 explained that humans sometimes create river channels. When asked where the water comes from for those rivers, R05-07 explained that the water company provides the water (indicated by bold text).

R05-07
INT: What's a man made river, tell me about that?
RSP: When people - you know, if they want a river then they can dig out the area that they want to flow with water.
INT: And where do they get their water?
RSP: I don't know. **From the water company?**

R05-14 described water coming from "sewages" and it is possible that she meant from sewers. She listed "sewages" as a source (bold text) and later when probed she again mentioned "sewages" and clarified that water from the "sewages" would not need to be purified if it was a source of river water.

R05-14
INT: Where does the water come from in the river?
RSP: … **like sewages from us**
Later in the interview
RSP: **…And the sewages maybe sorta…… But somehow they have to purify the water [from sewages]. Well not for river water.**

The third alternative source was the ocean. R05-19 said that river water comes from the oceans (bold text). When probed to explain how oceans are the source for rivers she provided an unclear explanation. She initially explained that the water originated in the oceans. However, she then referred to the water cycle but she did not explain what she meant (underlined text).

R05-19
INT: And where does the water come from?
RSP: **From the oceans.**
INT: And how does it get into a river?
RSP: <u>Like the whole cycle, I think, like if there's a lake, and like it comes from the lake, or it could come from the ocean or the whole water cycle. I really don't know.</u>

The fourth alternative source was evaporation. R05-14 described several scientific and two alternative sources for river water (Table 42); however, she struggled with providing an explanation for the source of river water and referred to evaporated water from the ground as a source for river water. She initially explained that water comes from "underwater…from down below and rises" (bold text). Later she explained that water comes from underground (single underlined text). When probed about how water from underground gets into a river, she stated that water evaporated to the surface (presumably from underground) and somehow made its way into rivers (double underlined text). She later explained that rainwater evaporates into the ground and then evaporates from the ground to the surface to get into rivers (dashed underlined text). She then stated that she was confused about where river water originates. Later, she explained that snow evaporated and melted and then flowed into a river (bold italicized text). R05-14 struggled to understand where river water originated even though she listed several scientific sources. Additionally, she used the term evaporate in various ways that were not consistent with the scientific definition of the term. Her explanation of evaporated water making its way into rivers is an alternative conception. R05-14 could have confused evaporation with the processes of condensation, precipitation, and infiltration.

R05-14

INT: Where does the water come from in the river?

RSP: Usually from obviously rain….Besides like rain, like sewages from us, **from underwater, water does come from down below and rises.**

Later in the interview

RSP: [explaining again where rivers get water] So I guess that would be from underground, from the rain…

INT: Tell me more about how the water comes from underground to get to a river.

RSP: Well, I guess water evaporates to the surface of the ground maybe. I mean that's where we usually pull water up from like fire hydrants. Doesn't the water come from underground? And the sewages [sic] maybe sorta...... But somehow they have to purify the water. Well not for river water.

Later in the interview

INT: Tell me how the water in this river gets there.

RSP: Probably from rain.

INT: And tell me more about how the rain gets in there.

RSP: I guess it's like -- it has to rain a lot to get there because it's kind of a large area of water. So realistically speaking -- and then obviously the water from up above would eventually evaporate into the ground, so -- I'm not quite sure exactly. I mean, it would have to rain a lot for this much water. So then -- see, it doesn't make sense because I'm saying the water falls from the sky and evaporates into the ground, but then I'm also saying the water goes up from the ground. So, I'm a little bit confused about where this water's coming from.

Later in the interview

INT: Where do you think your river starts [referring to the picture of a river that the student has drawn]?

RSP: ...So it came from glaciers. From some snow, it came from some snow.

INT: OK. So tell me that again, tell me where the water in the river comes from then.

RSP: There is snow coming from the sky and then it fell onto rocks, and then ***it evaporated and melted and flowed into the river.***

Summary

Only one student held a scientific conception for the source of river water. Most students held incomplete scientific conceptions. Groundwater was the most common source that students did not describe as a source for river water. There were similarities and differences between students' alternative conceptions for source of river water from this study and students' alternative conceptions for source of river water from previous studies.

In this study, one student thought that the ocean was the source of river water. Similarly, May (1996), Mackintosh (2005), Harwood and Jackson (1993) found that younger students thought that the ocean was a source of river water. Two students in this study thought that humans were sources of river water. Piaget (1929), May (1996), Mackintosh (2005), Harwood and Jackson (1993) also found that students attributed the source of river water to humans.

Two sources of river water described in this study were not found in other studies. R05-17 thought that river water was brought to earth from another planet. R05-14 described snow "evaporating" as a way to get into a river and she described water "evaporating" from underground to the surface to get into a river. Other planets and evaporation as sources of river water were not found in other studies. One source of river water described in other studies was not found in this study. Younger students described river water coming from mountains (Dove et al., 1999; Piaget, 1929), but mountains was not identified as a source of river water by students in this study.

Destination of River Water

River water can flow downhill into another river, the ocean, or a lake (or reservoir). Some river water evaporates into the air and some infiltrates into the ground. Additionally, humans extract river water for use in irrigation and other purposes. Students held either incomplete scientific conceptions or incomplete scientific alternative conceptions of the destination of river water (Table 43 and Table 44).

Incomplete Scientific Conception

Students who held an incomplete scientific conception of the destination of river water described only some of the common specific destinations of river water and did not describe alternative destinations of river water. Some students who held incomplete

Table 43

Criteria to Place Students into Conception Categories for Destination of River Water

Incomplete Scientific Conception
1. Student listed some of the common specific destinations of river water, but not all. This includes lakes/reservoirs, other rivers, ocean, evaporation to the air, absorption into the ground, and human use (e.g., irrigation). Students may also list non-specific destinations like other water bodies or downstream.
Incomplete Scientific-Alternative Conception
1. Student listed some of the common specific destinations of river water, but not all. This includes lakes/reservoirs, other rivers, ocean, evaporation to the air, absorption into the ground, and human use (e.g., irrigation). Students may also list non-specific destinations like other water bodies or downstream.
2. Students described alternative destinations.

scientific conceptions also described non-specific destinations for river water like lower elevation and another body of water. All but one student held an incomplete scientific conception about the destination of river water. Students' verbal and drawn responses were important for determining their conception of river destinations. Many students depicted river destinations in their drawings.

R05-20 had a typical verbal and drawn response about the destination of rivers. He explained that river water flows into a lake, reservoir, ocean, or another river (bold text). Additionally, he said that river water evaporates into the air (single underlined text). He also explained that river water is used by humans as drinking water and other human uses (double underline text). Figure 5 shows R05-20's river drawing, in which he depicted a river flowing into a lake.

Table 44

Students' Conceptions for Destination of River Water Subtopics and Their Overall Conception Category

Participant	Common specific destination[a]						Non-specific destination[a]		Alternative destination[a]	Category[b]
	Lake / reservoir	Other rivers	Ocean	Evaporate into air	Infiltrate into ground	Human use	Lower elevation	Another water body		
R05-02		Y	Y							ISC
R05-03	Y		Y	Y	Y		Y			ISC
R05-04	Y		Y							ISC
R05-05			Y					Y		ISC
R05-06		Y	Y							ISC
R05-07	Y		Y							ISC
R05-08	Y		Y				Y	Y		ISC
R05-09	Y									ISC
R05-10		Y	Y				Y	Y		ISC
R05-11	Y	Y	Y							ISC
R05-12	Y	Y	Y							ISC
R05-13	Y	Y	Y					Y		ISC
R05-14								Y	Y	ISAC
R05-15	Y	Y	Y					Y		ISC
R05-16			Y		Y					ISC
R05-17	Y		Y							ISC
R05-18	Y	Y	Y					Y		ISC

Table 44 (continued)

Participant	Common specific destination[a]						Non-specific destination[a]		Alternative destination[a]	Category[b]
	Lake / reservoir	Other rivers	Ocean	Evaporate into air	Infiltrate into ground	Human use	Lower elevation	Another water body		
R05-19			Y					Y		ISC
R05-20	Y	Y	Y	Y						ISC
R05-21		Y	Y							ISC
R05-22			Y			Y	Y			ISC
R05-23	Y	Y	Y					Y		ISC
R05-24	Y		Y			Y				ISC
R05-25	Y		Y					Y		ISC

[a] Y = yes, student correctly described this destination; a blank cell indicates that the student did not include this destination in his or her description of the destination of rivers. [b] ISAC = Incomplete Scientific-Alternative Conception, ISC = Incomplete Scientific Conception.

R05-20

INT: Where does the water go?

RSP: **Lakes, ocean, reservoirs, usually ends up in the ocean** or back into the air. So it evaporates.

Later in the interview, the student drew a picture of a river. I asked the student about where the river in the drawing ended.

INT: And here you have it [pointing to the drawing the student made of a river] going into the lake, is that essentially where the river ends?

RSP: No, it can go from there on.

INT: On to...?

RSP: The **ocean, a lake, or into another river, then go to the ocean. A reservoir** or wherever, for water treatment or whatever it is needed for.

INT: Tell me about the water treatment.

RSP: The water treatment would be for drinking or for like household needs.

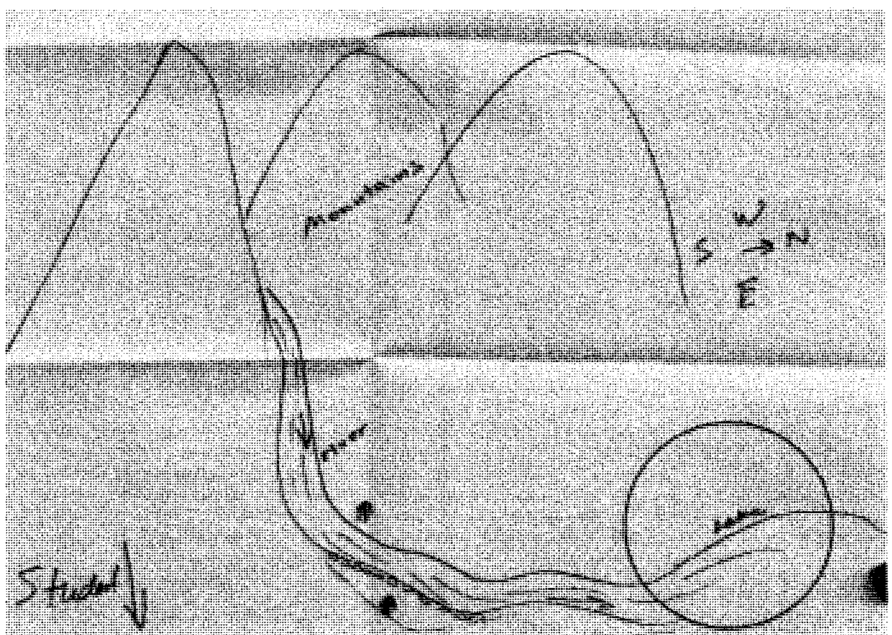

Figure 5. Drawing depicting river flowing into lake. In this figure, R05-20 drew a river flowing into the lake (indicated by black circle in lower right corner).

Incomplete Scientific-Alternative Conception

Students with an incomplete scientific-alternative conception of the destination of river water described only some of the common destinations of river water and described alternative destinations of river water. Only one student, R05-14, held an incomplete scientific-alternative conception. R05-14 drew a picture of a river that only depicted a segment of a river. Her picture did not show the beginning or end of the river; therefore, only her verbal explanation could be used to evaluate conception of the destination of rivers.

R05-14 described only one scientific destination: "larger pool of water" (bold text). No additional explanation was given for this destination and it was coded as "another water body." R05-14 described one alternative destination for rivers. Her explanation for this alternative destination is confusing, but it may be a reflection of her lack of understanding about river water destinations.

After explaining that river water goes to a larger pool of water (bold text), R05-14 indicated that it is uncommon to see the end or destination of a river (single underlined text). She then explained that river water would end in a "cut-off" where the water rises and gets wider (double underlined text). It is possible that she meant that the river ends in a lake or ocean. However, it is unclear if that was what R05-14 meant by her explanation. Further, she explained that the water would sink and "evaporate" into the ground (dashed underlined text). R05-14 used the word "evaporate" in inconsistent ways. Elsewhere in her interview she used the word evaporate to explain the process of how water gets into soil and the process of how water surfaces from the soil to get into rivers (see the Sources of River Water section in Chapter 5).

R05-14
INT: Where does the water go?
RSP: I guess it's going to maybe a **larger pool of water**. I guess rivers do have to end, so usually when you think of a river it's a really large

	stream but a lot of times <u>you never see the end of it.</u> But rivers do have to end somewhere. <u>If it were to end, it would just look like a cut-off.</u>
INT:	And what happens to the water at that cut-off?
RSP:	<u>It kind of just stays in the area. Maybe there's rocks that are built up here. I don't know. Eventually it just like rises so the river gets taller, maybe it widens too.</u>
INT:	Why does it do that?
RSP:	<u>Because it rains more and maybe more snow, it's obviously going to rise because there's more water.</u> <u>But then when it gets hot out, maybe it sinks down. It evaporates into the soil.</u>
INT:	And does it have to be hot for that to happen? Like what temperature?
RSP:	I'd say it'd have to be pretty dry weather, so it would be like in the 70's, maybe. I don't know, because actually heat does not make water melt so fast. Maybe slowly, but not like it goes down right away.

Although R05-14's explanation had parts that seem like she thought that a river ends at a lake or the ocean, she provided a confusing and unclear explanation. The explanation that river water ends at some type of cut-off where the water gets taller, wider, and evaporates into the ground is an alternative conception.

Summary

All but one student held incomplete scientific conceptions of the destination of rivers. The most common destinations that students described were lakes, other rivers, and the ocean. Few students described evaporation in the air, infiltration into the ground, and human uses as river destinations.

The river destinations in this study were different from those described by students in previous studies is several ways. First, all the destinations, with one exception, described by students in this study were different from the destinations described by students in previous studies (see the Destination of a River section in Chapter 2). The only destination that this study had in common with previous studies was the ocean. Second, the students in this study identified at least twice the number of river destinations as the students in previous studies did. Students in previous studies only indentified four river destinations: ocean, land, a wall, and sand (Dove et al., 1999; Mackintosh, 2005; May, 1996). Third, students in previous studies did not identify groundwater, lakes, tributaries, evaporation into the air, and absorption into the ground as possible destinations for rivers. Students in this study identified all of these destinations.

Sediment Type and Origin

Geoscientists generally classify river sediment into two categories: dissolved load (generally dissolved soluble minerals) and solid load (solid load includes rock, mineral, shell, and bone fragments transported along the bed of the river and carried in the main body of flow). Other materials in a river include other organic material (e.g., fish, leaves, insects, etc.) and human materials (e.g., trash). Sediments have several possible ways that they can get into a river. They can be transported by the river from upstream locations to downstream locations. They can be uncovered by the river as the river erodes into the bed and banks. They can be carried into the river by rain runoff or through mass movements (e.g., landslides or rock falls).

Students' responses were analyzed for their understanding of the types of sediment in a river and the origin of the solid inorganic materials. The students' conceptions fell into one conception category: incomplete scientific conception (Table 45 and Table 46). No student held an alternative conception for the type and origin of sediment.

Table 45

Criteria to Place Students into Conception Categories for Type and Origin of Sediment

Incomplete Scientific Conception
1. Student described some of the common types of river sediment, but not all. The common sediment types include solid sediment and dissolved sediment. Student also listed other types of materials in a river like organic materials (e.g., leaves, fish, and algae) and human materials (e.g., trash).
2. Student described some origins (e.g., mass movement, river transport, and being exposed by river) of the solid inorganic sediment, but not all.

Incomplete Scientific Conception

Students holding an incomplete scientific conception described some but not all of the common types of river sediment and the common origins of solid inorganic sediment.

Student conceptions of the type of sediment in a river were categorized based on the specific types of sediment they described (Table 46 and Table 47). All of the students described solid sediment; no student described dissolved sediment (one student explained that "pollutants from factories" can be found in rivers, but it was unclear if the student was referring to solid or dissolved pollutants) (Table 46 and Table 47). If a student described a fish in a river, that was categorized as a solid, organic material. Rocks were categorized as solid, inorganic materials. Trash and boats were categorized as human materials. If a student used a generic term like "sediment" then the context in which the student used the word was examined to determine what type of sediment the student meant. In all cases, students used the word sediment to refer to solid, inorganic material.

Table 46

Students' Conceptions of Sediment Subtopics and their Overall Conception Category

Participant	Solid inorganic sediment origin [a]				Sediment in rivers [a]			Category [b]
	Mass movement	River transport	Exposed by river	Other	Solid inorganic	Solid organic	Solid human	
R05-02	Y	Y	N		Y	Y	N	ISC
R05-03	N	Y	Y		Y	Y	N	ISC
R05-04	N	Y	Y		Y	Y	N	ISC
R05-05	Y	Y	Y		Y	Y	N	ISC
R05-06	Y	Y	N		Y	N	Y	ISC
R05-07	Y	Y	Y		Y	Y	N	ISC
R05-08	Y	Y	N		Y	N	N	ISC
R05-09	N	Y	N		Y	Y	Y	ISC
R05-10	Y	Y	Y		Y	Y	Y	ISC
R05-11	N	Y	Y		Y	Y	N	ISC
R05-12	N	Y	Y		Y	Y	N	ISC
R05-13	Y	Y	Y		Y	Y	N	ISC
R05-14	Y	N	Y		Y	Y	N	ISC
R05-15	N	Y	N		Y	Y	N	ISC
R05-16	Y	Y	N		Y	N	N	ISC
R05-17	Y	Y	Y		Y	Y	N	ISC
R05-18	N	Y	N		Y	Y	Y	ISC

Table 46 (continued)

Participant	Solid inorganic sediment origin [a]				Sediment in rivers [a]			Category [b]
	Mass movement	River transport	Exposed by river	Other	Solid inorganic	Solid organic	Solid human	
R05-19	Y	N	Y	Humans placed rocks in river	Y	Y	N	ISC
R05-20	N	Y	Y	Mining activity was origin of rocks, runoff carried rocks into river	Y	Y	N	ISC
R05-21	Y	Y	Y		Y	Y	N	ISC
R05-22	N	Y	N	Extinct glacier deposited rocks in the area where river now flows	Y	Y	N	ISC
R05-23	Y	Y	Y	runoff carried rocks into the river	Y	Y	N	ISC
R05-24	Y	Y	N		Y	Y	Y	ISC
R05-25	N	Y	Y		Y	N	N	ISC

[a] Y = yes, student included and understood this type or origin of sediment, N = no, student did not include this concept in their description of type or origin of sediment. [b] ISC = Incomplete Scientific Conception.

An example of a typical response about the type of sediment in a river was given by R05-02. R05-02 had just completed a drawing of a river and was asked to describe her drawing. She explained that solid, inorganic sediment (bold text) and various types of solid organic material (underlined text) are found in rivers.

R05-02

INT: OK, so I'd first like you to describe what you've drawn and then I'll ask you some questions about it.

RSP: ... there's **sediment and rocks** and all kinds of stuff coming down from the mountains and then it flows into the river, out in the meadow and the plains....

Later in the interview

INT: OK, so then the next question that I want to ask, besides the water that you've drawn, and the sediment, is there anything else that is in your rivers and streams?

RSP: There's <u>fish</u> in there...

Later in the interview

INT: OK, is there anything else in your streams and rivers (here I point to her drawing of a river)?

RSP: Well, there's <u>plant life.</u> I think the plant life that's in there has evolved over time to be able to survive under water; <u>slimy, gooey algae</u> grows on the rocks in the bottom of the river, cause it's slippery! But different things grow in there, <u>different organisms, different types of life</u>. I'm sure there's <u>other aquatic animals besides fish; turtles, frogs, snails, snakes.</u>

Students described some of the origins of inorganic sediment, but did not describe all the possible origins. The three main origins of sediment in a river were identified cumulatively across students, but no individual student described all three origins. The first origin, river transportation, was that the river transported sediment to its current location from further upstream (bold text in Interview R05-04). The second origin was that the sediment was already in the ground before a river flowed in an area. Once a river starting flowing in an area, the river water eroded some overlying sediments and exposed deeper sediments (single underlined text in Interviews R05-03 and R05-04). The third common origin described by students was that the sediment fell into the river in a rock slide or in a rock fall (double underlined text in Interview R05-05).

Table 47

Types of Inorganic Sediment and Organic Materials Described by Students

	Solid inorganic material	
Boulders	Limestone	Sand
Clay	Minerals	Sediments
Dirt	Mud	Silt
Gold	Pebbles	Stones
Gravel	Rocks	
	Solid organic materials	
Algae	Grass	Snails
Animals	Insects/ Bugs	Snakes
Bacteria	Leaves	Tadpoles
Beavers	Living Organisms	Trees
Dead Animal	Logs	Turtles
Diseases	Muskrats	Weeds
Ducks	Plants	
Fish	Pollen	
	Human Material	
Beer cans	Cigarette packs	Trash
Boats	Houses (during flood)	
Garbage	Pollutants from factories	

R05-04
INT: OK, so the first question I'm going to ask is, you said there were rocks in the river, how do you think the rocks got there?
RSP: Either from - they were already there, like underneath the ground before the river came and the river exposed them, or **they, through the years, got carried by the river itself...**

R05-03
INT: OK, how do you think the rocks got in the river and to the sides of the

river?

RSP: I would say that maybe they were just in the ground and the water sort of washed the more loose dirt and smaller things away leaving these bigger rocks which are, look all cleaned off and everything, that the water has just sort of taken away all the dirt and stuff and cleaned them off.

R05-05

INT: So how do you think the boulders got in the river?

RSP: They could have tumbled down from the mountain at some point in a rockslide kind of a thing.

Students also described a few other ways that sediment gets into a river (Table 46). For example, R05-19 explained that humans sometimes place sediment into a river and R05-22 described how now extinct glaciers could have deposited sediment in the area where a river now flows.

Summary

All students in the study held incomplete scientific conceptions for the type and origin of sediment in a river. No student described dissolved sediment and no student described all the various origins of river sediment. One previous study identified students' conceptions about the type of material in a river. Similar to findings in this study, Dove et al. (1999) found that elementary school students also described inorganic solids material, organic solid material, and human material in a river. None of the students in the Dove et al. study described dissolved sediment. No study was located that investigated students' conceptions of the origins of river sediment.

Floods

A river flood occurs when rainfall, snowmelt, human activities, landslides, dam failures, and so forth cause river discharge to exceed the capacity of the channel and the river water overflows the banks. Students' responses were analyzed for their understanding of the definition of a flood (temporary abundance of water that causes a river to overflow its banks) and the cause of a flood (overabundance of water produced by weather events, geological events, and human activities) (Table 48 and Table 49). Students held scientific conceptions, incomplete scientific conceptions, or scientific-alternative conceptions about flood (Table 48 and Table 49).

Scientific Conception

To hold a scientific conception of river floods, students had to define a flood as a temporary overabundance of water that causes a river to overflow its banks. Students also had to describe correctly at least one common cause of flooding. Some students also described uncommon causes of flooding (e.g., dam failure). R05-04 described the overabundance of water that occurs during floods (bold text), that the overabundance of water causes the river to overflow the banks or river channel (single underlined text), and that floods are temporary (double underlined text).

R05-04
INT: Can you tell me what a river flood is?
RSP: Yeah, from what I know it's just when a river **gains too much - or more water than it can handle like in a short amount of time** and it rises up over it's trench area and just floods out into the surrounding area.

Table 48

Criteria to Place Students into Conception Categories for Floods

Scientific Conception
Definition of Flood
1. Student described a river flood as a temporary overabundance or increase of water in a river.
2. Student understood that the temporary overabundance or increase of water causes a river to overflow its banks by getting wider and/or deeper.

Cause of a Flood
3. Student described at least one common weather cause for flooding. Possible responses included high levels of rain (could be from a hurricane), snow, or precipitation in general; and rapid melting of snow.
4. Student may have described uncommon causes of flooding. Uncommon causes include dam failure, flooding related to landslides or obstructions in a river, or flooding related to a river eroding its banks and breaking through its banks due to continual erosion.

Incomplete Scientific Conception
Definition of Flood
1. Student described a flood as a temporary overabundance or increase of water in a river.
2. Student understood that the temporary overabundance or increase of water causes a river to overflow its banks by getting wider and/or deeper.

Cause of a Flood
3. Student explicitly stated that he/she did not know what causes rivers to flood.

Scientific-Alternative Conception
Definition of Flood
1. Student described a flood as a temporary overabundance or increase of water in a river.
2. Student understood that the temporary overabundance or increase of water causes a river to overflow its banks by getting wider and/or deeper.

Cause of a Flood
3. Student described at least one common weather cause for flooding. Possible responses included high levels of rain (could be from a hurricane), snow, or precipitation in general; and rapid melting of snow.
4. Student may have described uncommon causes of flooding. Uncommon causes included dam failure, flooding related to landslides or obstructions in a river, or flooding related to a river eroding its banks and breaking through its banks due to continual erosion.
5. Student described alternative causes of floods.

Table 49

Students' Conceptions of Definition of Floods and their Overall Conception Category

Participant	Overabundance of water[a]	Overflows banks[a]	Category[b]
R05-02	NA	NA	NA
R05-03	NA	NA	NA
R05-04	Y	Y	SC
R05-05	Y	Y	SC
R05-06	NA	NA	NA
R05-07	Y	Y	SC
R05-08	NA	NA	NA
R05-09	NA	NA	NA
R05-10	NA	NA	NA
R05-11	Y	Y	SAC
R05-12	Y	Y	SC
R05-13	Y	Y	SAC
R05-14	Y	Y	SC
R05-15	Y	Y	SAC
R05-16	Y	Y	SC
R05-17	Y	Y	SAC
R05-18	Y	Y	SC
R05-19	Y	Y	SAC
R05-20	Y	Y	SC
R05-21	Y	Y	SC
R05-22	NA	NA	NA
R05-23	Y	Y	SC
R05-24	NA	NA	NA
R05-25	Y	Y	ISC

Note. The conception category was determined using students' combined understanding of the definition of a flood and the cause of a flood (Table 50). [a] Y = yes, student included and understood this component of a definition of a flood, NA = topic not discussed during interview. [b] SC = Scientific Conception, ISC = Incomplete Scientific Conception, SAC = Scientific Alternative Conception, NA = Not Applicable, Student was not interviewed for this topic.

Table 50

Students' Conceptions of Cause of Floods and their Overall Conception Category for Floods

Participant	Common[ab]					Uncommon[ab]			Other[ab]	Alternative[ab]					Category[c]
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	
R05-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
R05-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
R05-04	Y	Y			Y										SC
R05-05	Y														SC
R05-06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
R05-07	Y														SC
R05-08	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
R05-09	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
R05-10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
R05-11	Y	Y			Y	Y								IA	SAC
R05-12	Y	Y	Y												SC
R05-13	Y	Y	Y											IA	SAC
R05-14	Y														SC
R05-15	Y					Y	Y				IA				SAC
R05-16	Y		Y												SC
R05-17	Y				Y	Y				IA		IA	IA		SAC
R05-18	Y	Y													SC

Table 50 (continued)

Participant	Common[ab]					Uncommon[ab]			Other[ab]	Alternative[ab]					Category[c]
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	
R05-19	Y					Y	Y		Y						SAC
R05-20	Y	Y						Y							SC
R05-21	Y	Y					Y								SC
R05-22	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
R05-23				Y		Y									SC
R05-24	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
R05-25									Y						ISC

Note. A blank cell for a particular cause indicates that the student did not discuss that cause. The conception category was determined using students' combined understanding of the definition of a flood and the cause of a flood (Table 49). [a] Y = yes, student included and understood this component of cause of a flood, NA = topic not discussed during interview, IA = student included alternative cause in their explanation for cause of flood. [b]A = Rain, B = Snow, C = Rapid snow melt, D = Precipitation in general, E = Hurricane, F = Dam failure, G = Obstruction or landslide, H = Erode through bank and flood surrounding area, I = Student did not know cause of a river flood, J = Flood water came from extraterrestrial source such as an asteroid or another planet, K = God, L = Groundwater level filled up and caused a flood., M = Tsunami, N = Polar ice cap melted and caused a flood. [c] SC = Scientific Conception, ISC = Incomplete Scientific Conception, SAC = Scientific Alternative Conception.

INT: So let's say that this picture here (I point to a drawing of a river) - let's say that this river flooded, tell me how it would look different from now, like what the picture looks like now?

RSP: Well, it would probably be, like around these bend areas where the water's rushing the hardest or whatever, it, [river water,] would probably come up over those places first and just come up over the riverbanks here and just start to spread out from there, I guess.

Later in the interview

INT: OK, and what causes a flood to end?

RSP: When the excess water gets used up, or is absorbed or evaporates or isn't there anymore.

All students holding scientific conceptions of floods understood that weather events caused floods. For example, R05-12 and R05-16 explained that an unusual amount of rain and snow or the rapid melting of snow cause floods (bold text in both interviews). In addition to weather events, some students also described catastrophic and uncommon, although possible, events as the cause of floods. The uncommon events that they described were dam failures, obstructions, and channel erosion. For example, R05-20 explained that through erosion, a river could break through its banks and flood the surrounding area (dashed underlined text). R05-21 described how a man-made obstruction could be placed downstream of a river causing the river to back up, overflow its banks, and flood the surrounding area (underlined text). R05-23 explained that a dam could fail, releasing water that would flood a river (double underlined text).

R05-12

INT: And describe again what causes a flood.

RSP: If there is an **unusual amount of rain or snow or maybe the temperature increased drastically in the mountains or something and there was a lot more melt then.**

R05-16

INT: So what is a flood?

RSP: A flood is - the water - it would be either **rain fall or rapid melting or a combination of the two** would cause the river to overflow or a flood plain to overflow with water, above its normal level.

R05-20

INT: What causes a river to flood?

RSP: Excess water, or maybe it's just creating a new path from where it currently is.

INT: Describe again what causes a flood, I think you already mentioned it but I just want to make sure I understand what you said.

RSP: Excess water or it could be creating a new path but I don't know if that would really be considered a flood.

INT: And what do you mean by creating a path?

RSP: Like as the river is going down and hits something so it has to go back that way [the student uses his hands to show how river water would hit a bank and would flow in a different direction after hitting the bank] because so it's just causing a lot of force that way [by "that way" he means the bank that the river is hitting], but it [the bank] eventually breaks through from the constant erosion of that area. [Student points to his drawing and uses hand motions to indicate constant erosion on the banks of his river. Then when he says that the river breaks through, he uses hand gestures to indicate that the river would break through its banks and flow in a different path over area that had been previously dry].

R05-21

INT: So what causes a flood?

RSP: It can be like natural like things that cause a flood or like man-made things like obstructions that might restrict the flow of water and force it to flow [here student uses his hands to indicate that the river he had previously drawn would expand outward, out of its banks if it was obstructed] because the water is going to flow somewhere. If you were to put something here [student uses his hands to show that an obstruction was placed at the downstream end of his river] a bridge or something, it would stop the river or slow it down a lot to make the water start panning out [here the student uses his hands to show that as the water is stopped or slowed down by the downstream obstruction that the water flows out of its banks into the areas adjacent to the river].

R05-23

INT: Tell me what you – what would a flood look like?

RSP: Well, it's like more water like coming from – like obviously from a huge storm or something, or if a dam broke or something then this water level would rise over the bank which kind of keeps it from that. Like pretty much it would just flow over and like it depends on how big the flood was. If it was a huge one then it would just like run over like a lot of this land right here [he points to a drawing of a river to show where the water would flow]

Incomplete Scientific Conceptions

One student, R05-25, held an incomplete scientific conception of floods. R05-25 provided a correct definition of a flood similar to that given by students with scientific conceptions of rivers. However, he did not know what caused rivers to flood. R05-25 explained that he knew that rivers did flood, but that he did not know where the water comes from that causes the floods (bold text). R05-25's response of "I don't know" for cause of floods was not an alternative explanation for the cause of floods, but an indication that the student had an incomplete understanding of floods.

R05-25
INT: And what would make a river flood?
RSP: **That's a good question. I know that they do especially because of history and the Nile floods every year. I'm not really sure why and it didn't really make sense. I mean maybe it's because there's too much water flowing down but then I'm not really sure where that water comes from and how it sustains its shape all the way through this one point and then all of the sudden all this water ends up. I'm not really quite sure how that would happen.**

Scientific-Alternative Conception

Students holding Scientific-Alternative Conceptions of floods correctly defined a flood. All of the students also identified at least one correct weather-related cause for floods. For example, R05-15 described rain as a cause of floods (bold text). All but one of the students identified catastrophic and uncommon, although possible, events (e.g., dam failure) as causes for floods. For example, R05-11 explained how a dam failure could cause a flood (underlined text). However, these students also thought that alternative processes caused floods. Because of this blend of scientific and alternative understanding, these students held Scientific-Alternative Conceptions of floods.

R05-15

INT:	What would cause a flood?
RSP:	**A really big rain that takes the water level over its capacity or maybe if the water got backed up somehow**.

R05-11

INT:	So what are all the different ways - things that cause floods?
RSP:	If a dam gave away.
INT:	And how would that cause a flood?
RSP:	<u>Well, if Horsetooth dam gave away - Ft. Collins would be in some water I think. Because I mean it's like a big wall holding all the water, you know, and its usually a river, you know, they put a dam there and it will turn into a lake [here student uses his hands to draw a river in the air and indicate that a dam would be placed across the river]. But if that dam gave away all that water would be released at one time and it wouldn't be good. It would get a lot of houses and come down here. And we would be in a flood down here I think, if Fort Collins at least. That could definitely cause a flood.</u>

Students holding Scientific-Alternative Conceptions of floods described several causes for floods that are not those accepted by the scientific community. For example, students described tsunami as the cause for river floods. Tsunami can cause coastal flooding, but are not the cause of river floods. Students also described the melting of polar ice caps as a cause for river floods. The melting of the southern polar ice caps is considered a long-term global change that will affect sea levels; however, it is not considered a cause of river floods. R05-11 described tsunami and the melting of polar ice caps as causes for river floods (bold text).

R05-11

INT: What are all the different ways - things that cause floods?

RSP: So let me think, I said hurricanes, **tsunamis**, a lot of snow, a lot of moisture... I think that's all. **I mean like if the polar ice caps melted then I guess the water levels could raise.**

Three additional interesting alternative conceptions about the cause of floods emerged from the students' responses. The first was that God caused floods. For example, R05-15 explained that the floods can last a couple of days or as long as 40 days, in the case of Noah's ark (bold text). When asked to describe how Noah's flood occurred, the student said that God caused the flooding by "choosing it to rain" (underlined text).

R05-15

INT: How long does a flood last?

RSP: I guess only like a day or two until the water could flow all the way down and the levels could go down again. I've really never heard of a flood that - **except like Noah's ark that lasted 40 days or whatever.** I've never heard of a flood lasting for more than a day or two or a couple of days...

INT: You mentioned Noah's flood, what caused that flood?

RSP: <u>God choosing for it to rain and cover the earth. And 40 days and 40 nights later it stopped raining and</u> - it rained for that long and then I guess it just stopped and the water settled and went back to normal and re-vegetation occurred. That would be my guess, I don't know, I wasn't there.

The second cause was that water from a destroyed planet was delivered to Earth creating a large flood. R05-17 described a large biblical flood as the cause for a deep canyon (bold text). However, he did not say that God caused the flood. Instead, he said that the large amount of rain that caused the flood came from another planet that had been destroyed. He explained that after the other planet was destroyed somehow its water came to Earth (underlined text).

R05-17

INT: And how did the canyon form?

RSP: **...The other [theory] that I've heard is the one like where it's a giant flood, like in the Bible, and in many cultures they've described a giant flood.** And when you do have a lot of water it can carve out a massive chunk of land all at once. So if you have a massive amount of water coming through this area all at once then it can carry a lot of dirt and sediment away very rapidly. So I would tend to think of the large flood one being true because a lot of societies have described events of a big flood happening, and large chunks of - canyons being formed with that. And I just subscribe to that theory a little bit more.

INT: And what would cause a large flood like that, for this type of canyon? What would be a major cause for that?

RSP: I don't know exactly, but you know a large amount of rain all at once would definitely do it on a planetary scale. And what would cause that, who knows. Maybe that's why there's an asteroid belt, maybe there was another planet there that had some sort of chasmiclitic [sic] - something that annihilated the planet and all the water went somewhere, and some of it came to earth and caused the large flood like was described. But I don't know, I can't really tell you one way or another why things happen the way they did.

The third interesting alternative cause was that a river floods because the water table is filled up by rain; causing a flood. Earlier in the interview, R05-17 had described a relationship between rivers and water tables (bold text). He explained that the water table is water below ground and the rivers form in areas where land dips down below the level of the water table to expose the water in the water table to the surface (bold text). Later in the interview, R05-17 explained that the water table has a maximum level, the level of the ground, to which it can fill (single underlined text). He said that a flood would occur when the water table rises above its maximum level (single underlined text). R05-17 explained the sequence of events leading to a flood: rain fills up the water table, the water table rises to ground level, the river overflows its banks (double underlined text).

R05-17

RSP: **Underneath the entire dirt and stuff is a water table which is an amount of water and it's usually level unless somebody's dug a well or something like that. And at certain areas where the land actually goes below that water table, you actually see where the water level is.** That's what I meant by that.

INT: OK, and how does that [the water table] interact with the river?

RSP: It interacts with the river because it's exposed to the -- **it's [the water table] actually above ground so that makes it part of the river** and when it's exposed to air it has less resistance, it's not trapped in the earth Therefore, it flows…

INT: So you said it was above ground -- and I'm not sure I understand, like part of the ground water, or the water table is above....?

RSP: Yeah. Because the water table is flat everywhere. **The land actually has to curve down below the water table for it to - for the water to appear above the ground.**

Later in the interview

INT: So tell me what's a flood?

RSP: A flood is when a river overflows it's banks. <u>And I can put it another way, when the water table rises and like it's so much so that it's totally permeated the ground around it so that the ground cannot hold any more water so when the water actually goes up over the banks it has nowhere to go but up, so you get like a huge river, or a lake even if you have dam or something blocking flow.</u> So that's what I consider a flood to be.

INT: Tell me more about the water table and a river flood.

RSP: The water table and a river flood. Ok. <u>When you have a lot of rain like that, it fills up the water table to where it's basically at ground level. When it continues to rain it overflows - well, not overflows but it continues to fill the area and when the water has no place to go it just appears to flood everywhere. There's water just above the ground everywhere; standing water. And that's it. The water table will eventually - enough water will flow out that the waters will recede but it takes an amount of time.</u> The amount of time is directly proportional to the amount of water it releases at a certain rate.

INT: The amount of water that what releases?

RSP: <u>The water table as it moves out of the area.</u>

INT: So kind of tell me the sequence of events from like before a flood occurs to during the flood to after the flood, tell me how that sequence...?

RSP: <u>You'd have rain water flowing down that would start increasing the water table all around here and it would slowly rise up….and it will fill up the water table because - the water table will try to absorb as much as it can but it can't absorb that much water in a relatively short time span, so it causes the banks to actually overflow, almost the same</u>

principle. And then if it rains on top of that you'll get waters moving out from the banks everywhere along all points until you have a flood.

Summary

Students held scientific conceptions, incomplete scientific conceptions, or scientific-alternative conceptions of floods. All students, regardless of their conception category, correctly described the definition of a flood. The conception category to which students were assigned was determined based on their understanding of the causes of floods. All students, with one exception, understood at least one correct cause of river floods. The one exception was the student who did not know what causes floods.

Students described five alternative causes of river floods. Three of the alternative causes, tsunamis, ice cap melting, and God, are not surprising findings. Tsunamis and ice cap melting do cause flooding, coastal flooding. The students who described these causes may not have distinguished coastal flooding from river flooding. God as a cause of natural processes is also not surprising because other researchers have found similar results (for examples see Cin & Yazici, 2002; Pulling, 2001). Two alternative causes were unusual: floods created by water from an extraterrestrial body (a planet or asteroid) and floods that occur when the water table fills up. No previous study investigated college students' in-depth conceptions of river floods, so it is not possible to determine how the findings in this study compare with other findings about river floods.

River Formation

Rivers generally form when flowing water erodes sediment and rock to form a channel that increases in depth and width. Students were interviewed about their conceptions of river formation. Their responses were coded into four categories based on their understanding of two river formation processes: 1) water coalesces to form a river and 2) erosion occurs to form the river channel (Table 51 and Table 52).

Table 51

Criteria to Place Students into Conception Categories for River Formation

Scientific Conception
1. Student explained that a river starts when water gathers and forms a river.
2. Student clearly articulated the process that in the early stages of river formation, as water gathers, erosion occurs and creates the river channel.

Incomplete Scientific Conception
1. Student explained that a river starts when water gathers and forms a river.
2. Student understood that erosion occurs in the early stages of river formation, but was lacking an explanation of how the process of erosion creates the river channel.

Incomplete Scientific-Alternative Conception
1. Student explained that a river starts when water gathers and forms a river.
2. Student did not include erosion as a process in river formation.
3. Student expressed an alternative conception about how rivers start.

Alternative Conception
1. Student expressed an alternative conception about how rivers start.

Scientific Conception

Students holding scientific conceptions understood the two components of river formation (Table 52). First, they understood that rivers form when water coalesces. Second, they clearly articulated how the process of erosion created the river channel during river formation. R05-23 had a typical scientific conception response. He explained that runoff accumulates in a valley or "low point" and forms a river (bold text). He

Table 52

Students' Conceptions of River Formation Subtopics and their Overall Conception Category

Participant	Water coalesces[a]	Erosion forms channel[a]	Category[b]
R05-02	Y	I	ISC
R05-03	Y	Y	SC
R05-04	Y	Y	SC
R05-05	NA	NA	NA
R05-06	NA	NA	NA
R05-07	Y	N	ISAC
R05-08	Y	Y	SC
R05-09	NA	NA	NA
R05-10	Y	Y	SC
R05-11	NA	NA	NA
R05-12	NA	NA	NA
R05-13	Y	N	ISAC
R05-14	Y	N	ISAC
R05-15	Y	Y	SC
R05-16	Y	N	ISAC
R05-17	Y	N	ISAC
R05-18	Y	I	ISC
R05-19	N	N	AC
R05-20	Y	N	ISAC
R05-21	Y	I	ISC
R05-22	Y	I	ISC
R05-23	Y	Y	SC
R05-24	Y	N	ISAC
R05-25	Y	Y	SC

[a] Y = yes, student correctly described this river formation component, N = no, student did not understand this river formation component and held an alternative conception for the component, I = incomplete understanding held by student for this river formation component. [b] AC = Alternative Conception, SC = Scientific Conception, ISC = Incomplete Scientific Conception, ISAC = Incomplete Scientific-Alternative Conception, NA = Not Applicable, student was not interviewed for this topic.

showed his understanding of the erosion process by explaining that over time the river erodes or "carves" more rock, which creates a deeper path and an area in which the river can flow (underlined text).

R05-23
INT: What would make a river start?
RSP: Maybe just – **it's got to be probably at a low point between like in the valley or the basin or whatever where all this runoff starts accumulating. ...So all that water has like – some of it's going to soak into the ground but once all that water gets soaked up and all these areas are taken and this water has nowhere else to go but to flow with gravity down to the lowest point. And then as soon as that accumulates then I guess it could start like a small stream** and then maybe over time as that stream cuts through – it brings a deeper path, like easier for more water to flow. ...
INT: You said something about the river deepened, or has a deeper...?
RSP: Well, as the water's flowing, like over a long period of time, like I said the erosion is going to carve more rock out and stuff. And so it could like carve itself more area to flow.

Incomplete Scientific Conception

Students with an incomplete scientific conception understood that water coalesced to form a river. The students had some notion that erosion occurred during the formation of a river; however, they did not explicitly explain (as did the students with Scientific Conceptions) that the process of erosion creates the river channel. For example, R05-02 correctly explained that melt-off from snow forms a river (bold text). She explained that "glaciers and things" form a river channel (single underlined text), but she did not explain how that occurs. Then she said that melt-off and water erode during the formation of a river (double underlined text). Again, she did not explain how that erosion creates the river channel. Her comments about erosion imply that she understood that erosion occurs during river formation but she was unable to formalize her idea that water erodes and creates the river channel.

R05-02

INT: OK. And you said that it's there before the river starts, how does a river start - get started?

RSP: From like glaciers and things can cause and rocks and different things falling to form like beds for um. And then **the melt-off just starts flowing and sometimes melt off can start one itself** just by eroding different things away....

INT: ... So I'd like you to tell me maybe the history of your rivers and streams here (I point to her drawing of several rivers)? What it might have looked like before they (the rivers) were there and then how they would have formed here?

RSP: I think the land would have been real rough with kind of loose rocks and stuff already, where when the water started causing a force that it started to push things away and erode at things and eventually just kept eroding. But I think it would be a very rocky and loose sediment in order for the runoff to be able to push it away and start to form it.

Incomplete Scientific-Alternative Conception

Students with Incomplete scientific-alternative conceptions understood that water coalesced to form a river. However, none of the students included erosion as a process in river formation. Additionally, the students incorrectly thought that the river channel just exists (i.e., no formation process). For example, R05-16 explained that a river starts when snow melts and forms the river (bold text). In two different probes, I asked R05-16 what causes a river to start (single underlined text) to determine if he understood that erosion forms river channel. In response to the first probe, and he explained that a river starts when water accumulates (double underlined text), but he failed to describe the process of erosion. In response to the second probe, R05-16 again did not identify erosion as a process involved in the start or formation of a river. He explained that a river starts because of precipitation and water flowing in the "easiest path" (dashed underlined text). His response indicates an alternative conception about river formation. He said that the river "would just take the easiest path ... just follows whatever the easiest path that's there." This response was interpreted to mean that R05-16 thought the river channel already existed and that during river formation, water accumulates and follows a pre-existing path. All students having incomplete scientific-alternative conceptions had responses similar to that of R05-16.

R05-16

INT: And how do rivers start?

RSP: What do you mean? Like there's where the river is so, it starts where - yeah, I mean I guess like right in here, for example, **where the snow melts and that will form a natural river where the water is on the land and going downstream, so that would be where it starts...**

INT: So how would it start? Let's say that there was a time when there wasn't one here and then one started in the space that you have it, what would cause it to start there?

RSP: Precipitation from the water, most likely from the ocean. That's where it would originally start, like from the water that precipitates from the ocean, clouds that flow over that area and downpour on it. And that's what would really start it. But for like the physical river I'm thinking more of, like from this part. Like if you get a river .... through it, this is that river, that would start here but the whole process would start with the water that feeds the - the source of that river is water.

INT: Why would a river pick any particular path? Like why would it pick a path like this as opposed to one that was a little bit over... You mentioned going over in this direction...

RSP: I hadn't really considered that when I was drawing the river but it would just take the easiest path, as far as like however gravity is pulling it. It will take usually the steepest path and the easiest path, just follows whatever the easiest path that's there. So it just kind of takes it's own course.

Alternative Conception

One student, R05-19, held an alternative conception about the formation of a river (Table 52). At no time during her interview, did R05-19 explain that a river forms when water coalesces and erosion creates a channel. At one point she said that a river could form if water "shoved" its way through an area (underlined text), but it is not clear if she meant erosion or some other process. R05-19 described alternative processes for river formation.

R05-19 explained three times that earthquakes and tectonic plate motion formed rivers (bold text). Her explanation of how earthquakes and plate motion formed rivers was confusing. For example, she said that during an earthquake "the earth would split" and water would flow into "that area." It is unclear from her explanation what "that area" refers to and why a river would flow in that area. Equally confusing, is her explanation that rivers form when a lot of movement occurs when a continent splits (double underlined text). When asked why she thought that rivers form when a continent splits; she again explained that movement in the ground somehow facilitated river formation (double underlined text).

R05-19

INT:	And what would cause it [the river] to form?
RSP:	**It could be plates moving or earthquake maybe, like in any of that space.** <u>Or it could have just formed - like if the water needs to go by, it just shoved it's way through an area.</u>
INT:	How would an earthquake, tell me more about how an earthquake would cause a river to form?
RSP:	**Well, the earth would split in a certain area or the ground would move, the water would just go into that area naturally, it wouldn't go over the flat surfaces, if there's like an inverted surface on the ground.**
INT:	And do you think there's always been rivers on earth?

RSP: Always? No. I think there's always been - I don't know, I never thought about it.
INT: And how would they start, say there's a time when there wasn't a river?
RSP: I bet they were right there, right from the beginning because all the seasons were still there, so to me that's when they started forming first. Like all that earthquake .... - like if - on a test today we were talking about the super continent, **I guess the continent split, like obviously a lot of movement is going on, like plate tectonics and stuff, is when a lot of the rivers started to form.**
INT: And why would they form then do you think?
RSP: **There's enough movement in the ground and they have the most options of where to go at that time.**

Summary

Students fell into several conception categories for river formation. Students with scientific conceptions correctly described the river formation process. Students with incomplete scientific conceptions knew that water coalesces and erosion occurs during the formation of a river; however, they did not describe how erosion creates the river channel. Students with incomplete scientific-alternative conceptions correctly described that water coalesces when rivers form; however, they had an alternative conception about how a river channel formed. These students thought that the channel was a pre-existing feature that did not undergo a formation process. Finally, the student with an alternative conception thought that alternative processes (plate motion and earthquakes) form rivers.

Students in previous studies generally attributed the formation of rivers to artificial processes (humans or God created the River) or natural processes (a river forms when water sinks into the ground) (see the Formation of Rivers section Chapter 2 for a full review). In this study, no student attributed river formation to artificial processes. All of the students in this study described natural processes. The alternative formation processes found in this study (no formation process, earthquakes create rivers, plate motions create rivers) were not found by researchers in previous studies. Alternatively, previous studies found that when asked about how rivers form some students said that they did not know. All students in this study provided explanations for how rivers form.

Canyon Formation

Students were interviewed to determine their understanding of the role of rivers in the canyon formation process. River erosion is the primary process to form the solid rock canyons like the one in the picture shown to students during the interview. Weathering and mass wasting are also involved in the canyon formation process, but river erosion is the key process. A river generally forms a canyon where none had previously existed in response to base level changes caused by such things as tectonic activity or sea-level change.

Students were placed into conceptions categories based on their understanding of canyon formation processes in the context of the particular picture they were shown (Table 53 and Table 54). Students' conceptions about canyon formation fell into three conception categories: incomplete scientific conception, incomplete scientific-alternative conception, and alternative conception (Table 53 and Table 54).

Table 53

Criteria to Place Students into Conception Categories for Canyon Formation

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Incomplete Scientific Conception

- Student described river erosion as the primary process that forms canyons.
- Student did not describe the role of base level change in canyon formation.

Incomplete Scientific – Alternative Conception

- Student had one of the following ideas about the process of canyon formation:
  1. Student described a catastrophic event as initiating a canyon and gradual river erosion as a secondary process that occurs after the catastrophic event to further develop the canyon (this was the blended conception group), or
  2. Student described two simultaneously contradictory processes that create a canyon (this was the simultaneously contradictory group).
- Student did not describe the role of base level change in canyon formation.

Alternative Conception

- Student had one of the following ideas about the process of canyon formation:
  1. Student said that a catastrophic event is the primary process in canyon formation (catastrophic formation group), or
  2. Student said that there was no formation process (i.e., canyon had always existed) (No formation process group).
- Student did not describe the role of base level change in canyon formation.

Incomplete Scientific Conception

Students with incomplete scientific conceptions described river erosion as the primary canyon formation process. Students were not assigned to a scientific conception category because they did not describe the role of base level change as a key component to canyon formation. R05-08 and R05-11 had typical incomplete scientific conception responses. Both students described river erosion (bold text) as the primary canyon formation process.

Table 54

Students' Conceptions for Canyon Formation Subtopic and their Overall Conception Category

Participant	Formation process[a]	Category[b]
R05-02	NA	NA
R05-03	NA	NA
R05-04	NA	NA
R05-05	R	ISC
R05-06	R	ISC
R05-07	C	AC
R05-08	R	ISC
R05-09	CR	ISAC
R05-10	R	ISC
R05-11	R	ISC
R05-12	CR	ISAC
R05-13	R	ISC
R05-14	NF	AC
R05-15	R	ISC
R05-16	R	ISC
R05-17	CR	ISAC
R05-18	R	ISC
R05-19	C	AC
R05-20	R	ISC
R05-21	R	ISC
R05-22	NA	NA
R05-23	NA	NA
R05-24	C	AC
R05-25	NA	NA

[a] C = catastrophic event caused canyon formation; CR = catastrophic event and river erosion caused canyon formation; NA = non-applicable, topic not discussed in interview; NF = No formation process; R = river erosion caused canyon formation. [b] NA = non-applicable, topic not discussed in interview, AC = Alternative Conception, ISC = Incomplete Scientific Conception, ISAC = Incomplete Scientific-Alternative Conception.

R05-08

INT I'm going to show you a picture, this is picture D. So we'll start, if you can describe the picture? What's in the picture?

RSP A canyon with a river at the bottom. There's **layers that the river has cut away and - the river started at the top [pointing to the top of the canyon] and then over time just eroded down.**

INT And how long did that take to do that, to start at the top and erode down?

RSP Oh a long time! A couple of thousand years? Fifty, no, way longer than that. It could be a million, two million years? I don't know, I have no idea.

INT OK, and why do you suppose it eroded down like that?

RSP Well, it wouldn't go up. **Because it's carrying the material down the river.** I don't know, I'm just going to assume that it's coming this way [starting at top of page and flowing toward the bottom], I can't tell if it's going that way or this way. **But whatever direction the river is going down it's carrying the material with it, and so that's just going to keep breaking it down and carrying it down.**

R05-11

INT And I'm going to have you first describe the picture, what's in the picture?

RSP It's a large canyon **and it looks like it was created from a river.** I see a lot of different types of rocks. Some metamorphic rocks, some igneous rocks maybe. Yeah, it looks like just over millions of years **that this river has cut away at this land mass and it's gone down hundreds of feet.** Kinda like the Grand Canyon.

INT You said it was created by the river, so tell me about how the river created it?

RSP **Through erosion. As the river goes constantly throughout the year, it picks up sediment and carries it along. Depending on how fast the river is flowing it carries sediment along with it and deposits it further down. So in this picture, it takes millions of years to do this but it cuts away at earth and keeps carrying it away to further distances and deposits it, deposits it and that's how a canyon is formed.**

In both interviews, the students described river erosion as the primary process forming the canyon: "river has cut away and... then over time just eroded down" (R05-08) and "[the canyon was] created from a river... this river has cut away at this land mass" (R05-11). With further probing, the students added more detail of how they think the river formed the canyon. For example, R05-11 stated, "As the river goes constantly throughout the year, it picks up sediment and carries it along. Depending on how fast the river is flowing it carries sediment along with it and deposits it further down." Here the student explained that the river entrains sediment, carries it away, and deposits it downstream.

Incomplete Scientific-Alternative Conception

Students with incomplete scientific-alternative conceptions fell into two groups based on their understanding of the processes that form canyons. Students in the blended conception group thought that a catastrophic event followed by river erosion forms canyons. Students in the simultaneously contradictory group thought that two possible yet contradictory processes could form canyons. Like students with incomplete scientific conceptions, students with incomplete scientific-alternative conceptions did not describe base level change as a component to canyon formation.

Blended group.

Students in the blended group had incomplete scientific and alternative conceptions of canyon formation process. They described a catastrophic event (e.g., volcanic eruption or earthquake) as the process that initiates a canyon. This belief is similar to that expressed by students holding alternative conceptions (see next section). However, students in this category said that following the catastrophic event, gradual river erosion occurs to develop the canyon further. This idea is similar to that held by students with incomplete scientific conceptions. Students in the blended group also described other gradual processes, like weathering, that help form a canyon.

R05-12 had a typical blended group response. She believed that an earthquake or tectonic plate motion initiated the canyon formation process (bold text). The student also thought that after the catastrophic event a river played a role in forming the canyon (underlined text):

R05-12

INT: How do you think the canyon formed?

RSP: I think that maybe if **there was an earthquake or something happened, and the plates separated there.** But I think that eventually maybe this river wore down, part of some of the bottom and made it more steep. I guess.

INT: So let's start at the very beginning before -- tell me like the kind of sequence that would happen to form it.

RSP: To form the canyon? Well, I would think that these two [pointing at both canyon walls] would be together and then something happened, **the plate shifted, or something and they kind of got expanded apart a little bit**. And they probably move a little bit every year and then, I think, that the river started somewhere and eventually found like a nook in it and helped to wear it down a little bit but I think **most of it formed from where the plates were moving.**

Later in the interview

INT: Tell me more about the plates. Like what do you mean by the plates?

RSP: **Like the continental plates maybe underneath, how they shift, or if they collide and rub and hit against each other, just separating, over time they're just pulling further apart - maybe in this picture (pointing to the picture) and that's how it [the canyon] got made...**

Simultaneously contradictory group.

One student, R05-17, was in the simultaneously contradictory group. R05-17 held two simultaneously contradictory ideas about canyon formation. He had the incomplete scientific conception that canyons are gradually created by river erosion (bold text).

However, he said that he did not believe the incomplete scientific conception of canyon formation. Instead, he said that he believed that canyons are created by a catastrophic biblical flood (single underlined text), which is an alternative conception. He also believed that after the large flood created the canyon, gradual weathering and erosion would further develop the canyon (double underlined text).

R05-17

INT: And how did the canyon form?

RSP: There's a lot of - I know of two theories. **The first one is the widely accepted geological theory, that over a long period of time this river has carved out this piece of land, and that through millions of years it's carried the sediment away from its current place as it's dug itself deeper into the mountain.** The other one that I've heard is the one like where it's a giant flood, like in the Bible, and in many cultures they've described a giant flood. And when you do have a lot of water it can carve out a massive chunk of land all at once. So if you have a massive amount of water coming through this area all at once then it can carry a lot of dirt and sediment away very rapidly. So I would tend to think of the large flood one being true because a lot of societies have described events of a big flood happening, and large chunks of - canyons being formed with that. And I just subscribe to that theory a little bit more.

INT: And how long would that process take? You know, like a large flood.

RSP: Probably just a couple months, very rapidly. And then I think what really weathers and opens this up to, is since then you have a lot of rain and stuff that will continually wear away the sides of these [pointing to the sides of the canyon] and then that sediment would go down into the river, obviously, and be carried away. So it would look like that you had a long time for something to be worn away, but it's continually being worn away, so...

R05-17 simultaneously held an incomplete scientific conception and an alternative conception. Although he said that he only believed the alternative conception, he accurately described the incomplete scientific conception of canyon formation. The two conceptions are contradictory because the incomplete scientific conception requires long-term gradual geologic processes to form a canyon and the alternative conception requires short-term supernatural forces to form a canyon.

Alternative Conception

Two groups of students held alternative conceptions about the canyon formation process. The first group of students described catastrophic geologic processes as the cause for canyon formation. The second group of students thought that a canyon had always existed (i.e., did not undergo a formation process).

Catastrophic formation group.

There were three students, R05-07, R05-19, and R05-24, in the catastrophic formation group. These students believed that earthquakes or volcanic eruptions formed canyons. For example, R05-19 explained that a single earthquake (bold text) created a canyon. In response to a follow-up question about the relationship between the river the canyon formation process, she did not think that the river was involved in that process. She thought that the river could have existed before or after the canyon was formed by the earthquake and that the river would flow at the bottom of the canyon because that is the lowest elevation. R05-19 did not attribute any part of the canyon formation to process to river erosion (underlined text).

R05-19
INT OK. So how do you think the canyon formed?
RSP **Earthquake maybe, probably**.
INT And tell me how that occurred?
RSP How the earthquake occurred?
INT How the earthquake would form a canyon?

RSP If the land splitting apart by the earthquake, I don't know how to explain it, it would just - **like the earthquake would happen and then the earth would kind of like fall into it. Like the land that broke off and form a canyon**... I don't know. (laughs)

INT: And after the earthquake occurred when do you think the river got into the bottom?

RSP: Depending on when the weather - depending on what the weather was doing, like maybe there was a river on the ground before the earthquake and it split it and then the river went down in to it. Like if it rained the water from the land up here [pointing to the top of the canyon] would trickle down into this, it would need somewhere to go and so obviously it all just collects. I mean it just goes in the naturally carved out area where it can go.

No formation process group.

There was one student in the no formation process group. R05-14 thought that a canyon did not undergo a formation process. Several probes were used in the interview to explore her understanding of the canyon formation process, and consistently R05-14 gave responses that indicated that she thought that the canyon did not have a formation process.

Initially, when asked how the "canal" formed (R05-14 used the term canal to refer to the canyon) and how the river got to the bottom of the canyon, R05-14 said that the water ran off the slope of the canyon under the influence of gravity and gathered at the bottom of the canyon (bold text). She did not identify any process that created the canyon.

R05-14

INT I'm going to show you a picture - picture D. First, I'll have you start by describing what's in the picture, or just describe the picture.

RSP A lot of mountains, rocks, large mountains, rocks. There's a stream of water here and it's kind of like a canal through the mountains, a canal of water.

INT So how do you think this canal formed (that you see in the picture)?

RSP **Water came from possibly rain. And the water's obviously not going to stay up here on a steep slope [of the canyon wall] so it has to stay down on the surface, because water's not going to just sit up here on a slant, it has to be down below.**
INT How did the river get down at that level?
RSP Well, it's the flattest surface to the ground - and like where did the water come from?
INT Yeah, if you look at the picture it's down kind of at the bottom of the mountain that you described, so why is it down here, how did it get down there?
RSP **Just because of like gravity forces again. The water, like I said, isn't going to just sit up on a steep slant, it's going to stay down on a flat surface. Most likely, well it is, because of gravity.**

To probe further to find out what, if any, process R05-14 thought created the canyon, she was asked if she thought that the setting had always looked the way it does in the picture. She said that there have been changes to the canyon setting, but that those changes were minor and included rocks falling from the canyon wall (underlined text). Again, she did not describe a formation process. The rock falling processes she described were not canyon formation processes, but only slight modifications to the canyon.

R05-14
INT Did you think that this setting here always looked this way?
RSP Like from a long time ago?
INT Yes.
RSP <u>For a while, but not, like the rocks have obviously like changed. And who knows if there's always been water there or not? So maybe once there wasn't even water there.......</u>
INT So tell me how the rocks may have changed.
RSP <u>Just like fallen debris off the rocks, fallen, it changed the formation of the rocks, they're not really moving. I'm just saying like little differences - debris falling off. Not like actually clear movement of them.</u>

To find out if R05-14 truly did not understand that the canyon had undergone a formation process, she was asked how the setting would look if there had been no water in the setting in the past. R05-14 said that water does not affect the rocks, so the absence or presence of water in the canyon had no bearing on the canyon setting (double underlined text). Her statement is an alternative conception about the effect flowing water has on rock.

R05-14

INT	So what would it look like if there wasn't any water - you said there may not have even been water [in the canyon in the past]. So let's assume there wasn't water. How would this picture look?
RSP	I guess probably just the same, there just wouldn't be water in there. I don't think the water's doing very much to the rocks so whether it was there or not, I don't think it would make that much of a difference.

R05-14's responses indicated that she did not think that the canyon underwent a formation process. She held an alternative conception about canyon formation because she consistently provided responses that indicated she did not think that there was a formation process.

Summary

Students had incomplete scientific conceptions, incomplete scientific-alternative conceptions, or alternative conceptions about the role of rivers in canyon formation. Most students correctly described the role of river erosion in canyon formation. However, other students had blended or alternative conceptions about the processes that formed canyons. None of the students described the role of base level change in canyon formation.

Happs (1982) found some similar results when investigating elementary, middle, and high school students' conceptions of a origin of a glacial valley. Happs found that some students correctly attributed glacial activity to the formation of the valley. This is similar to the students with incomplete scientific conceptions in this study who correctly associated canyon formation to river erosion. Similarly, like the students in this study with incomplete scientific-alternative conceptions and alternative conceptions, Happs found that some students in his study thought that a glacial valley had always existed (i.e., there was no formation process) and other students thought that catastrophic processes like volcanic eruptions created the glacial valley.

Erosion

Erosion is the process of removing particles (e.g., sediment, rock, and soil). Over time, a river erodes its bed and banks, which modifies the size and shape of its channel. Velocity, volume of water, sediment characteristics (sediment size, cohesiveness of sediment, sediment shape) are three common factors that affect the rate at which erosion occurs, the size of sediment that can be eroded, and volume of sediment that can be eroded.

Students' understanding of three erosion subtopics was analyzed to determine their conception category for erosion. The three subtopics are described in Table 55. Students held scientific conceptions, scientific-alternative conceptions, and alternative conceptions about the process of river erosion (Table 55 and Table 56). Students did not need to use the terms "erode" or "erosion" to demonstrate their understanding of the concept of river erosion if they could describe the process of erosion using other non-technical terms. For example, R05-08 described how a river channel (she used the term canal for channel) forms through erosion by using the terms "cut away" (bold text) to describe the process of erosion.

R05-08

INT: How does the canal form? How does that get there?

RSP: I think where it would first start to run off, that would **cut away** over time and then it would make more of a canal, so I guess there wouldn't be a canal at the very beginning.

INT: So what would it look like at the beginning?

RSP: I just think it would run off where it was steepest, and then that would **cut away** over time into a canal and then I think it would make a place for all the rest of the water to flow through, but yeah, I think it would start off and run off first.

Table 55

Criteria to Place Students into Conception Categories for Erosion

Scientific Conception
1. Student expressed the understanding that rivers pick up and move sediment.
2. Student expressed the understanding that through erosion, river channels are created or modified.
3. Student expressed the understanding that the ability of a river to erode is affected by at least one of the following factors: velocity, volume, and sediment characteristics.

Scientific-Alternative Conceptions
1. Student expressed the understanding that rivers pick up and move sediment.

Student had an alternative conception related to subtopic 2 or 3.

2. Student expressed the understanding that through erosion, river channels are created or modified.
3. Student expressed the understanding that the ability of a river to erode is affected by at least one of the following factors: velocity, volume, and sediment characteristics.

Alternative Conceptions
1. Student expressed an alternative understanding related to the process in which rivers pick up and move sediment.
2. Student expressed an alternative understanding about the process that through erosion, river channels are created or modified.
3. Student expressed an alternative understanding about the factors that affect river erosion.

Scientific Conceptions

Students held a scientific conception of river erosion if they understood the rivers erode sediment; by the erosion of sediment, river channels are created or modified; and that factors affect the nature of erosion (Table 55 and Table 56). The factors that affect erosion were not investigated in the interview with R05-09, so her conception category was determined based on her understanding of criteria one and two. She held a scientific conception of erosion based on her understanding of those criteria.

Rivers erode sediment.

Students demonstrated their understanding that rivers erode sediment by describing the process of erosion. R05-02 and R05-11 provided typical explanations of the process of erosion. During two different parts of her interview, R05-02 said that a river picks up and moves sediment (bold text). R05-11 described how a river carved a canyon saying that a river "cut away at this land mass," "cuts away at earth," and "picks up sediment and carries it along" (underlined text). In these interview segments, both students correctly described that erosion removes sediment.

R05-02

INT: OK, and how does the sediment get in - you talked about sediment - how does the sediment get into a river?

RSP: A lot of the sediment is there before the river even starts flowing because there is a bed underneath it. Some of um are rocky and some of um are more granulous, like sand, and **it [the river] just picks it up and moves it, the sediment.**

Table 56

Students' Conceptions for Erosion Subtopics and their Overall Conception Category

Participant	Rivers erode sediment[a]	Erosion modifies channels[a]	Factors affect erosion[a]	Factors[a]				Category[b]
				Velocity	Volume	Sediment characteristics	Alternative factor	
R05-02	Y	Y	Y	Y	Y	Y		SC
R05-03	Y	Y	Y	Y	Y	Y		SC
R05-04	Y	Y	Y	Y	Y	Y		SC
R05-05	Y	Y	Y	Y	Y	Y		SC
R05-06	Y	Y	YA	Y	Y		Y	SAC
R05-07	Y	A	Y	Y	Y	Y		SAC
R05-08	Y	Y	A				Y	SAC
R05-09	Y	Y	NA	NA	NA	NA		SC
R05-10	Y	Y	Y	Y	Y	Y		SC
R05-11	Y	Y	Y	Y	Y	Y		SC
R05-12	Y	Y	Y	Y		Y		SC
R05-13	Y	Y	Y	Y	Y	Y		SC
R05-14	A	A	A		A			AC
R05-15	Y	Y	Y		Y			SC
R05-16	Y	Y	Y	Y		Y		SC
R05-17	Y	YA	Y		Y	Y		SAC
R05-18	Y	Y	Y	Y	Y			SC

Table 56 (continued)

Participant	Rivers erode sediment[a]	Erosion modifies channels[a]	Factors affect erosion[a]	Factors[a]				Category[b]
				Velocity	Volume	Sediment characteristics	Alternative factor	
R05-19	Y	A	Y	Y	Y			SAC
R05-20	Y	Y	Y		Y	Y		SC
R05-21	Y	Y	Y			Y		SC
R05-22	Y	Y	Y	Y	Y	Y		SC
R05-23	Y	Y	Y		Y	Y		SC
R05-24	Y	A	Y	Y	Y	Y		SAC
R05-25	Y	Y	Y	Y	Y	Y		SC

Note. A blank cell for a particular factor indicates that the student did not discuss that factor The factors that affect erosion (criterion three) were not investigated in the interview with R05-09 so her conception category was determined based on her understanding of criterion one and two. [a] NA = non-applicable, subtopic not discussed in interview, Y = yes, student understood how this concept related to river erosion, YA = yes, student understood this subtopic, but also held an alternative conception about it. A = student had an alternative conception about the subtopic. [b] AC = Alternative Conception, SAC = Scientific-Alternative Conception, SC = Scientific Conception

Later in the interview, R05-02 drew a picture of a river and said that sediment, rock, and silt were in the river in her drawing.

INT: Tell me more about how that [sediment, rock, and silt] gets in there.

RSP: It comes from the erosion, **the water picks those things up as it flows along, it picks up the different things that are loose in different areas and picks them up and moves them** and carries them to a new location.

R05-11

RSP: It's a large canyon and it looks like it was created from a river. It looks like just over millions of years that this river has cut away at this land mass and it's gone down hundreds of feet. Kinda like the Grand Canyon.

INT: You said it [a canyon] was created by the river, so tell me about how the river created it?

RSP: Through erosion. As the river goes constantly throughout the year, it picks up sediment and carries it along. Depending on how fast the river is flowing, it carries sediment along with it and deposits it further down. So in this picture, it takes millions of years to do this but it cuts away at earth and keeps carrying it away to further distances and deposits it, deposits it and that's how a canyon is formed.

Erosion modifies channels.

To hold a scientific conception of river erosion, students had to describe how, through the process of river erosion, the river channel is created or modified. For example, R05-25 said a river erodes its banks (bold text) and deposits the sediment elsewhere. He said that the erosion and deposition processes could change the shape of the river (underlined text). I asked him why the shape of the river would change and he explained that water is constantly moving and eroding sediment. This constant erosion will eventually remove a large segment ("whole chunk") of the bank (double underlined text).

R05-25

INT: And let's say it floods, what would it look like a day later?

RSP: I would say like rocks being deposited like that, and then **some of this [here he points to the banks of the river in a drawing] being eroded away** so it would redirect – like change almost the shape of the whole river.

INT: And why would that happen?

RSP: Since the water is constantly moving this way, it's going to take some of this [pointing to the bank] soil away every time that it passes by. And then sooner or later then it's just going to take out that whole chunk if it keeps flowing like that.

Factors affect erosion.

Students with scientific conceptions of erosion correctly described how at least one factor (velocity, volume, or sediment characteristics) affects a river's ability to erode. For example, R05-04 showed his understanding that the ability of the river to erode is affected by river water volume and velocity. He said that the river in a photograph shown to him was not eroding large rocks because the river did not look like it was flowing fast enough and did not have a large enough volume ("big enough" and "high enough") (bold text). He said that the river would need to flow with more water (i.e., need larger volume) and at a higher velocity to erode the large rocks (underlined text).

R05-04

INT: And do you think that the river could carry the rocks right now, like in the picture as it is now?

RSP: **No, it doesn't look big enough or strong enough.**

INT: What doesn't look big enough?

RSP: Well, it doesn't look like it's **flowing fast enough or high enough** basically.

INT: OK, so it would have to flow - how would it have to change in order to carry those big rocks?

RSP: It looks like there would have to be a lot more water and it would have to be flowing a lot faster, I guess.

In addition to velocity and volume, several students explained how sediment characteristics (size, weight, cohesiveness) affect river erosion. For example, R05-03 explained that a river eroded smaller and less cohesive sediment, exposing larger boulders (bold text). R05-03 said that in its current condition, the river could erode sand sized grains but not large boulders (double underlined text). He said that it was easier for the river to erode the smaller sediment because the smaller sediment weighed less than the larger sediment (underlined text).

R05-03 Note, in this interview segment, R05-03 is referring to large rocks in a photograph of a river.

INT: OK, how do you think the rocks got in the river and to the sides of the river?

RSP: I would say that maybe they were just in the ground and **the water sort of washed the more loose dirt and smaller things away leaving these bigger rocks which are, look all cleaned off and everything, that the water has just sort of taken away all the dirt and stuff and cleaned them [the larger rocks] off.**

INT: Ok. You talked about the river kind of moving around, kinda moving the stuff around it, moving the dirt around the rocks, tell me how it does that, tell me more about that part.

RSP: Um. Well, it seems to me that there would be a rock - even on the shore you can see some rocks that look like they are sort of even embedded in the dirt and you can only see the top part of it. And I would picture that before this river was here maybe it was all covered over with more dirt. Where you can see these edges over here that looks like dirt has sort of crumbled off um and that the rock was just surrounded by looser dirt, it wasn't formed into bigger rocks. <u>I guess they'd still be rocks, just really tiny rocks um that - the uh um they [the smaller rocks] obviously weigh a lot less [than the larger rocks] and the water can, with movement and stuff, can carry them away a lot easier, and sort of just clean them off of the rock, the bigger ones.</u>

INT: So you think that the river right now could carry these large rocks?

RSP: <u>I would say no.</u>

INT: Do you think that it's carrying any kind of size rocks right now?

RSP: <u>I would just say really small, like sand grains and just sediment type, real small little bits.</u>

Scientific-Alternative Conceptions

Six students had scientific-alternative conceptions about erosion (Table 56). All six students correctly understood that rivers picked up and moved sediment (criterion one in Table 55). The students generally had scientific conceptions for criteria two and three (how erosion creates and modifies channels and the factors that affect erosion). However, they also had alternative conceptions for either criteria two or three (Table 55). For example, R05-06 had scientific conceptions for all three criteria but also had an alternative conception for criterion three (factors that affect erosion).

Because the scientific conceptions held by students with scientific-alternative conceptions were similar to those held by students with scientific conceptions, the focus of this discussion will be on the alternative conceptions that students with scientific alternative conceptions held. Table 25 lists the alternative conceptions held by students with scientific-alternative conceptions of erosion.

Table 57

List of Alternative Conceptions Students Had about Erosion

Alternative conception	Student
• Rivers erode sediment because water is heavier than the sediment.	R05-06
• Tectonic plate motion is a factor that affects the rate of erosion on a short time scale.	R05-08
• Rivers can erode solid rock canyons in a couple of months.	R05-17
• Erosion is not involved in channel modification.	R05-07, R05-19, R05-24

Factors affect erosion.

R05-06 and R05-08 had alternative conceptions about the factors affecting erosion (Table 56 and Table 57). R05-06 correctly described how volume and velocity affect a river's ability to erode sediment, however, she also an alternative conception about the factors that affect erosion. R05-06 thought that a river erodes into the ground because river water is heavier than the underlying sediment, and the heavier river water sinks into the mud and cuts a channel (bold text).

R05-06

INT: OK, and you said that it [the river] cuts down into the ground, tell me more about how that happens.

RSP: **Well, water is really heavy and therefore it has a lot of force, and so it's weight and it's motion can cut - to make room for it's weight it'll cut around** - like you know the mud's not a big deal, a lot of things can cut through mud, but it can also cut through rocks. This isn't answering your question is it? I guess just because it [the river] needs a place to go and so it [the river] makes a place for it to go. I guess through laws of physics? I'd assume just because of it's weight and motion.

INT: OK, so tell me about how the weight of the water cuts.

RSP: ... **Just it's [the river] like heavy, it's going to need a place to go and it's heavier than the mud so instead of just like rolling over the mud it cuts a crevice in it.** And since it's moving it has a arrow, it has a direction, and so therefore like it makes it go to one spot instead of to spread out and settle because of the motion. And so therefore, it has to have a route, and **since it's heavy and going, it cuts it out.**

R05-08 was shown a photograph of a river with large boulders sitting in the river. She did not think the river was currently moving the boulders and she thought that large-scale tectonic shifts were the factors that would allow the river to erode large boulders (bold text).

R05-08

INT: Do you think the river can carry these right now?

RSP: No.

INT: What would have to change so that it could carry them?

RSP: **It would have to be -- the ground, I think, would have to be tilted more**, or just a long period of time. I think it's like **if the plate shifted and brought it [the river] more of an angle again, it would come down more.** It would come down more but, I don't know, it seems pretty flat though. I think it's hard to tell in the picture.

Erosion modifies channels.

R05-07, R05-17, R05-19, R05-24 had alternative conceptions about how erosion creates or modifies river channels (Table 57). R05-07, R05-19, R05-24 thought that river formation or modification occurred without the process of river erosion. For example, R05-17 thought that an earthquake formed a canyon with a river flowing at the bottom of it. She did not think that other processes, like erosion, were involved in the past formation process (bold text). I asked her how the river got to the bottom of the canyon and she explained that melting snow "caused the river" (single underlined text). She did not describe river erosion as a process by which the river got to the bottom of the canyon. Additionally, she did not think that erosion would be involved in future processes related to the river and canyon. I asked R05-07 how the canyon would look in the future. She explained that rocks would weather and erode from the sides of the canyon because of erosion by wind or rain, but there would be no other change that was brought on by river erosion (double underlined text). R05-07 lacked an understanding of the role of river erosion in the creation and modification of canyons formed by rivers.

R05-07

INT: OK, so like if this formed – so let's say it did form a long time ago, so like how would it have formed a long time ago then?

RSP: **In an earthquake and then it split the land.**
INT: OK. So let's say that you – so like this picture was taken this year and you came back like in time – like you went back in time, let's say a million years, what do you think it would look like?
RSP: It would be put together.
INT: What do you mean put together?
RSP: Like that piece [pointing to one side of the canyon] would be with that piece [pointing to the other side of the canyon], it would be one, there wouldn't be a river there or a canyon so you could like just walk across.
INT: So how like from a million years to now like what happened that made it look like this?
RSP: **An earthquake.**
INT: OK, so tell me again how the river would get there [i.e., get to the bottom of the canyon]....
RSP: Oh, just that snow melted. Like if there was like a mountain somewhere in the distance and snow was melting off of it then that caused the river.
INT: OK, so like let's say now you've come – you can take like a time machine into the future and how would it look like a million years in the future?
RSP: I don't think the landscape would really change. These [pointing to rocks on the canyon wall] might be like eroded away because of weathering, because of like the wind and rain and that type of thing. So then these might be like less farther in. But that's all I can figure that would change.

R05-17 had scientific and alternative conceptions about how river erosion modifies channels. He correctly described how river erosion could widen and deepen river channels over a time period. However, he had an alternative conception about how long it would take river erosion to create a 2000-foot deep canyon through solid rock. He explained that river erosion would create a deep canyon over a couple of months (bold text), which is an incorrect idea about the spatial and temporal scale over which river erosion operates.

R05-17
INT: And how did the canyon form?

RSP: There's a lot of - I know of two theories. The first one is the widely accepted geological theory, that over a long period of time this river has carved out this piece of land, and that through millions of years it's carried the sediment away from its current place as it's dug itself deeper into the mountain. **The other one that I've heard is the one like where it's a giant flood, like in the Bible, and in many cultures they've described a giant flood. And when you do have a lot of water it can carve out a massive chunk of land all at once. So if you have a massive amount of water coming through this area all at once then it can carry a lot of dirt and sediment away very rapidly. So I would tend to think of the large flood one being true because a lot of societies have described events of a big flood happening, and large chunks of - canyons being formed with that. And I just subscribe to that theory a little bit more.**

INT: And how long would that process take? You know, like a large flood.

RSP: **Probably just a couple months, very rapidly.**

Alternative Conceptions

One student had an alternative conception about erosion. Throughout the interview, R05-14 was asked questions to probe her understanding of river erosion. She consistently described rivers as unchanging bodies of water that do not undergo change or modification due to erosion.

Water has no effect on channel.

R05-14 thought that river water has no effect on the channel in which it flows. When asked what a river would look like hundreds of years in the future, she explained that there might be an increase in water from climate change (bold text). When asked what would happen if there was more water in the river, she said that there would be no change because the river does not affect the rocks (underlined text).

R05-14

INT: Let's say you could come and visit this place like hundreds of years in the future, what do you think it would look like?

RSP: **Maybe an increase of water.**

INT: And why is that?

RSP: I was just thinking of more droughts and stuff. With like global warming and stuff, **there's going to be like more thunderstorms and like severe drought and stuff so in the future maybe more water increase overall.** I don't know.

INT: And what would happen if there was more water there?

RSP: <u>Probably not very much action other than the increase in water. I really don't think it's affecting the rocks very much so not very much difference if there were an increase.</u>

During a different part of the interview, R05-14 again emphasized her understanding that river water has no effect on rocks in the river channel. When asked how a river and canyon would look if there had been no water there in the past, she said that water does not affect the rocks, so the absence or presence of water in the canyon had no bearing on the canyon setting (bold text).

INT So what would it [the river and canyon] look like if there wasn't any water - you said there may not have even been water [in the canyon in the past]. So let's assume there wasn't water. How would this picture look?

RSP **I guess probably just the same, there just wouldn't be water in there. I don't think the water's doing very much to the rocks so whether it was there or not, I don't think it would make that much of a difference.**

Rivers are unchanging.

In addition to her alternative conception that river water has no effect on its channel, R05-14 thought that rivers are stable, unchanging bodies of water. She described rivers as "stable" and "unchanging" (bold text). Additionally, when asked what would change so that a river would change, she only described changes to the volume of water in a river (underlined text).

INT: How long do rivers last?
RSP: A long time as well. **Rivers have been known to be pretty stable so they last a real long time.**
INT: What do you mean by they're stable?
RSP: **They don't really -- they are pretty unchanging because they are such large pools of water that there has to be like drastic changes for the water to change. And they seem pretty stable.**
INT: What would have to change in order for a river to have a change?
RSP: <u>A huge drought, rain, drought - flood, or it won't make it dissipate.</u>

R05-14 expressed a similar idea that rivers are unchanging features during a discussion of canyon formation (see also the "alternative conception" section in the "canyon formation" section). When asked if she thought that the canyon had always looked the same, she said that the only changes that have occurred are rocks falling from the canyon wall (bold text) and water volume changes (underlined text).

INT Did you think that this setting here always looked this way?
RSP Like from a long time ago?
INT Yes.
RSP **For a while, but not, like the rocks have obviously like changed.** <u>And who knows if there's always been water there or not? So maybe once there wasn't even water there.......</u>
INT So tell me how the rocks may have changed.
RSP **Just like fallen debris off the rocks, fallen, it changed the formation of the rocks, they're not really moving. I'm just saying like little differences - debris falling off. Not like actually clear movement of them.**

R05-14 consistently expressed her understanding that river water has no effect on river channels and that rivers are unchanging features. On several occasions, R05-14 explained that river volume has changed in the past or could change in the future. However, she said that these changes in volume had no effect on river channels. She did not understand that through the process of erosion, river water erodes sediment in the channel. She also did not understand that through erosion, river channels are created and are modified. Additionally she did not understand the affect factors such as volume have on erosion.

Summary

Students with scientific conceptions for erosion understood that rivers erode sediment, river erosion modifies and creates river channels, and factors affect the nature of erosion. Students with scientific-alternative conceptions understood that rivers erode sediment, but they had alternative conceptions about either how erosion modifies and creates channels or about the factors that affect erosion. The student with an alternative conception about erosion did not understand that rivers erode sediment or that river erosion creates and modifies river channels.

No other study was found that investigated college students' conceptions of river erosion, however two studies investigated students' conceptions of erosion related to glaciers and other surficial processes. Cohen (1968) found that most fifth and sixth grade students in his study were aware of the concept of erosion caused by wind, water, and gravity. Most of the students in this study were also aware that erosion was caused by rivers. Happs (1982) found that elementary, middle school, and high school students in his study did not understand that glaciers erode sediment and create landforms. This study, also found that students (most of the students with scientific alternative-conceptions and the one student with an alternative conception for erosion) did not understand the role of erosion in creating and modifying landscape features, specifically river channels and canyons.

Discussion of Research Question 1 Results

The previous sections presented detailed results of the analysis of students' conceptions for the nine river topics. The following sections examine the broad patterns of students' conceptions by investigating the range of conceptions held by students, the range of conception categories across topics, and the patterns between students' alternative conceptions and the subtopics of the nine river topics.

Range of Conceptions Categories held by Students

Three patterns emerged regarding the range of conception categories held by students. The first pattern is that individual students held a range of conceptions for the nine river topics (Table 34 at the beginning of the chapter shows the conception category for each student for each river topic). For example, R05-12 held scientific conceptions for definition of a river, floods, and erosion; incomplete scientific conceptions for sediment type and origin, destination of water, and source of water; an incomplete scientific-alternative conception for canyon formation; and an alternative conception for cause of flow. Blake (2005) found a similar pattern when investigating elementary students' conceptions of several geology topics. He found that individual students held one conception category for one geology topic (e.g., Earth's interior structure) and a different conception category for other geology topics (e.g., weathering). The pattern found in this study may be related to the characteristics of the subtopics for each topic, which will be discussed in Patterns between Alternative Conceptions and Subtopics section later in this chapter.

The second pattern is that five students, R05-07, R05-14, R05-17, R05-19, R05-24, held more alternative and blended conceptions than the rest of the students (Table 34). These five students held four to five alternative and blended conceptions each; whereas the other 19 students held zero to two alternative and blended conceptions (Table 34). There were 41 total occurrences of alternative and blended conceptions and 24 of these occurrences were held by R05-07, R05-14, R05-17, R05-19, R05-24 (to see the occurrences for individual students see Table 34, to see the total occurrences for each conception category see Table 58). The remaining 17 alternative and blended conception occurrences were spread across the other 19 students.

The third pattern is that students held some conception categories more frequently than they held other categories (Table 58). The number of occurrences refers to the sum of all the incidences of each conception category for all students for all topics in Table 34. For example, the number of occurrences for the alternative conception category is eight because R05-07 held two alternative conceptions, R05-12 held one alternative conception, R05-14 held two alternative conceptions, R05-19 held two alternative conceptions, R05-24 held one alternative conceptions. There were 24 students and 9 topics, therefore there were 216 occurrences for all conception categories combined (this includes the category Not Applicable, which refers to each time a particular topic was not covered in an interview with a student). The number of occurrences for each conception category shows that scientific conceptions and incomplete scientific conceptions were the most commonly held conceptions, while alternative conceptions were the least commonly held conception (Table 58).

Table 58

Number of Occurrences for each Conception Category

Conception category	Number of occurrences
Scientific Conception	72
Incomplete Scientific Conception	83
Scientific-Alternative Conception	18
Incomplete Scientific-Alternative Conception	15
Alternative Conception	8
Not Applicable[a]	20
Total	216

[a] Refers to the number of times that a topic was not investigated with a student.

Range of Conception Categories across Topics

Two patterns emerged regarding the range of conception categories held across river topics and the number of students holding each conception category. The first pattern is that for each individual river topic there was a range of conceptions held by students (Table 59). For example, students held scientific, incomplete scientific, and incomplete scientific-alternative conceptions for source of river water. Scientific and incomplete scientific conceptions were held for all river topics. Blended conceptions were held for all but two of the river topics (sediment type and origin and definition of a river). Alternative conceptions were held for only four of the topics: cause of flow, erosion, canyon formation, and channel formation.

Table 59

Range of the Conception Categories held for each River Topic

Topic	Conception categories[a]				
	SC	ISC	ISAC	SAC	AC
Sediment Type and Origin		x			
Definition of River	x	x			
Destination of Water		x	x		
Source of Water	x	x	x		
Floods	x	x		x	
Cause of Flow	x			x	x
Erosion	x			x	x
Canyon Formation		x	x		x
Channel Formation	x	x	x		x

[a] SC = scientific conception, ISC = incomplete scientific conception, ISAC = incomplete scientific-alternative conception, SAC = scientific-alternative conception, AC = alternative conception.

The second pattern emerged by combining the range of conception categories held for each topic with the percentage of students who held those conception categories for each topic (Figure 6). More alternative and blended conceptions were held for some river topics more than for others. Students held no alternative, scientific alternative-conception, and incomplete scientific-alternative conceptions for sediment type and origin and definition of a river. Students held the most alternative, scientific-alternative, and incomplete scientific-alternative conceptions for canyon formation and channel formation.

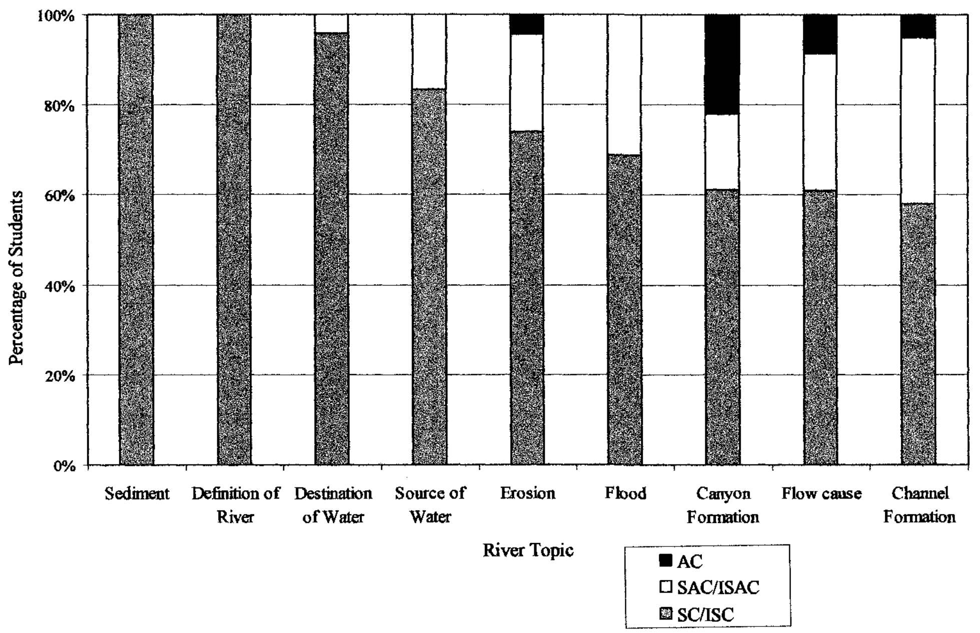

Figure 6. Percentage of students holding conception categories for each river topic. The scientific and incomplete scientific conception categories were combined and the scientific-alternative and incomplete scientific-alternative conceptions were combined. The river topics were ordered left to right based on the percentage of alternative, scientific-alternative, and incomplete scientific-alternative conceptions held by students for each topic. Topics with the lowest percentage of alternative, scientific-alternative, and incomplete scientific-alternative conceptions are toward the left; topics with the highest percentage of alternative, scientific-alternative, and incomplete scientific-alternative conceptions are toward the right.

This study is not the first study to recognize that students' ideas are more complicated than two categories and that students hold a range of conceptions for a specific topic. Other researchers have found that K-12 and college students hold more diverse conceptions than scientific and alternative, and students have a range of conceptions for river and non-river geology topics. Piaget (1929, 1930) and Cin and Yazici (2002) found that students had more than two categories of understanding about river topics. Steer, Knight, Owens, and McConnell (2005) found that college students had naïve views, limited views, or acceptable views of earth's interior layers. Blake (2005) found that elementary school students had non-scientific, proto-scientific, and scientific ideas about several geology topics.

No other study was identified which found that college students hold mostly scientific and incomplete scientific conceptions for rivers and other geology topics. However, several researchers reported that most college students held alternative or blended conceptions prior to formal instruction (and in some cases after formal instruction) for the following geology topics: groundwater (Reinfried, 2006), magnetism and sea floor banding (McKenney & Webster, 2004), radioactive decay (Prather, 2005), various geology topics (Black, 2005; Libarkin & Anderson, 2005), earth's interior structure (Steer et al., 2005), plate tectonics (Sibley, 2005). More research is needed to investigate the pattern that college students hold mostly scientific and incomplete scientific conceptions for rivers.

Pattern between Alternative Conceptions and Subtopics

As described in the Data Analysis section in Chapter 4, criteria were developed to place students into the conception categories for the nine topics based on the students' cumulative understanding of one or more subtopics. Students' conceptions for all the subtopics of each topic were examined to investigate further the pattern that students held more alternative and blended conceptions for some topics than they did for others.

The subtopics were categorized as observable feature, observable process/cause, difficult to observe feature, or difficult to observe process/cause (Table 60). Observable features and observable processes/causes are those river features or processes/causes that students could perceive by their senses during the context of their normal day-to-day experiences over a human time span. Difficult to observe features and processes/causes are those that students cannot or do not commonly perceive during their normal day-to-day experience over a human time span. They cannot be observed, for example, because the process happened millions of years in the past, the cause is invisible (e.g., gravity), or the feature is inaccessible (e.g., earth's interior layers). Students might be able to observe some difficult to observe features and processes/causes with assistance from geoscientists or instructors, but without this assistance these features and processes/causes are not commonly observable by students. Some subtopics had more than one characteristic. For example, subtopic 8, the destination of river water, is an observable and difficult to observe feature.

Students held scientific or incomplete scientific conceptions for all of the subtopics in Table 60 (also tables associated with each topic describe students' understanding of the subtopics, see Table 36, Table 38, Table 42, Table 44, Table 46, Table 49, Table 50, Table 52, Table 54, Table 56). The following discussion focuses on the patterns of the characteristics of the subtopics for which students did not hold alternative conceptions (subtopics 1-7) and the patterns of the characteristics of the subtopics for which students did hold alternative conceptions (subtopics 8-17) (Table 60).

Subtopics with no Alternative Conceptions

The subtopics for which students did not hold any alternative conceptions fell into two categories: observable features and observable processes/causes. The two observable features (subtopics 1 and 3 in Table 60) were that a river is a linear body of water and the type of sediment in a river. Five subtopics were observable processes: two related to the general nature of river flow (subtopics 4 and 5), two to the process of river flooding (subtopics 6 and 7), and one to the origin of sediment in a river (subtopic 2).

Subtopics with Alternative Conceptions

One subtopic for which students held alternative conceptions was both an observable and difficult to observe feature. The remaining subtopics for which students held alternative conceptions were both observable and difficult to observe processes.

Observable and difficult to observe features.

The destination of rivers (subtopic 8 in Table 60) was the only feature for which students held alternative conceptions. The destination of rivers was categorized as both an observable and difficult to observe feature. Destinations like lakes and other rivers are observable destinations. Destinations like air and underground are difficult to observe destinations. Only one student, R05-14, held an alternative conception about the destination of rivers. She said, "I guess rivers do have to end ...but a lot of times you never see the end of it." Based on her comment, R05-14 may have never seen the end of a river; thus possibly making destination of rivers a difficult to observe feature for this particular student.

Observable process/cause only.

Three subtopics for which students held alternative conceptions were categorized only as observable processes/causes. The first subtopic was the cause of river flooding (subtopic 10 in Table 60). Students provided several alternative conceptions about the cause of river flooding (see the Flood section in this chapter). The other two subtopics were related to erosion (subtopics 12 and 14 in Table 60). Students held alternative conceptions about the process of erosion and about the factors that affect erosion.

Observable and difficult to observe process/cause.

Two subtopics for which students held alternative conceptions were classified as processes/causes that had both observable characteristics and difficult to observe characteristics. The subtopic source of river water (subtopic 9 in Table 60) has observable components like the contribution of rain or snowmelt to rivers, as well as difficult to observe components like the contribution of groundwater to a river. Four students had alternative conceptions about the source of river water. For example, one student explained that the ocean directly contributed water to a river.

The other process/cause subtopic with both observable and difficult to observe components was that through erosion river channels are created or modified (subtopic 13 in Table 60). For example, river channels can be modified in the short term by floods. Students could observe this process. However, channels are also slowly modified over large time spans. For example, rivers can take millions of years to create canyons. This is a difficult to observe process. Students with alternative conceptions about the role of river erosion in channel formation or modification gave alternative explanations about how river channels are modified. For example, one student explained that an earthquake was the primary cause of river channel modification and that erosion was not a process involved in channel modification.

Table 60

Characteristics of the Subtopics for all the River Topics

Subtopic[a]	Characteristic of subtopic			
	Observable feature	Observable process/cause	Difficult to observe feature	Difficult to observe process/cause
1. The common sediment types include solid sediment and dissolved sediment. Other types of materials in a river include organic materials (e.g., leaves, fish, and algae) and human materials (e.g., trash). (Sediment)	X			
2. Sediment in river gets into rivers in various ways including through mass movement, river transport, and being exposed by river. (Sediment)		X		
3. A river is a linear body of water. (Definition)	X			
4. A river flows. (Definition)		X		
5. A river flows from high to low elevation. (Definition)		X		
6. A flood is a temporary overabundance or increase of water in a river. (Flood)		X		
7. The temporary overabundance or increase of water causes a river to overflow its banks by getting wider and/or deeper. (Flood)		X		
8. The common specific destinations of river water include lakes/reservoirs, other rivers, ocean, air (through evaporation), underground (through absorption), and human use (e.g., irrigation). (Destination)	X		X	
9. The common sources of river water include rain, snow/snow melt/glacier, lake/reservoir, groundwater/spring, tributaries. (Source)		X		X
10. The common weather causes for flooding include high levels of rain, snow, or precipitation in general; or rapid melting of snow associated with high temperatures. Uncommon causes of flooding include dam failure, flooding related to landslides or obstructions in a river, or flooding related to a river eroding its banks and breaking through its banks due to continual erosion. (Flood)		X		

Table 60 (continued)

Subtopic[a]	Characteristic of subtopic			
	Observable feature	Observable process/cause	Difficult to observe feature	Difficult to observe process/cause
11. River flow is due to gravity. (Cause)				X
12. Through erosion, rivers pick up and move sediment. (Erosion)		X		
13. Through erosion, river channels are created or modified. (Erosion)		X		X
14. The ability of a river to erode is affected several factors including velocity, volume, sediment characteristics. (Erosion)		X		
15. River erosion causes canyon formation. (Canyon)				X
16. A river starts when water gathers and forms a river. (Formation)				X
17. The river erodes and creates its channel. (Formation)				X

Note. The topics for each subtopic are indicated by shortened versions of the topic at the end of each subtopic. For example, "Sediment" is listed after Subtopic 1. Sediment refers to the topic Sediment type and origin. [a] Sediment = Sediment type and origin, Definition = Definition of a River, Flood = Flood, Destination = Destination of river water, Source = Source of river water, Cause = Cause of river flow, Erosion = Erosion, Canyon = Canyon formation, Formation = Channel formation.

Difficult to observe processes/causes only

Four subtopics were categorized only as difficult to observe processes/causes. One subtopic was the cause of river flow. The other three subtopics were related to the processes involved in canyon and channel formation.

Rivers flow due to the force of gravity (subtopic 11 in Table 60). The force of gravity itself is not observable, it is an invisible force, only the effect of gravity (i.e., river water flowing) is observable. Students held alternative conceptions about the cause of river flow. For example, one student explained that a river flows because of currents.

The other three subtopics (subtopics 15-17) were related to the processes of canyon and channel formation. These processes typically occur over long time spans (i.e., orders of magnitude greater than a human lifespan) and are difficult to observe. Students expressed various alternative conceptions about how canyons and river channels form.

Comparison with previous research on conceptions of geologic processes/causes and difficult to observe features.

Examination of the subtopics showed that, with one exception, students held alternative conceptions for river processes, many of which were completely or partially difficult to observe. The one exception was that one student held an alternative conception for a feature (destination of rivers) that was categorized as a difficult to observe feature for the student. Other researchers have also found that college students develop alternative conceptions for geology processes and difficult to observe geologic features. For example, college students have difficulty understanding processes related to plate tectonics (Sibley, 2005); the rock cycle (Stofflett, 1994); magnetism and seafloor banding (McKenney & Webster, 2004); radioactivity (Prather, 2005), and earthquakes (Libarkin et al., 2005). College students also have difficulty understanding difficult to observe features like groundwater (Dickerson, Callahan, Van Sickle, & Hay, 2005; Reinfried, 2006) and Earth's interior layers (Libarkin et al., 2005; Steer et al., 2005).

Many geologic processes (e.g., landscape evolution, metamorphism, and seafloor spreading) and features (e.g., plate boundaries, groundwater, and destination of rivers) are difficult to observe. Some researchers suggest that a student's direct experience with the natural world influences his or her conceptual development and that direct experience with a natural phenomena can increase a student's understanding of that phenomena (for example Cin & Yazici, 2002; Harwood & Jackson, 1993). In fact, Raab and Frodeman (2002) argue that geologists' experience with the natural world through fieldwork is critical for their development in understanding geologic phenomena. Therefore, it is possible that students' inability to experience directly some geologic processes and features (like those river processes and features described in this study) lead them to develop alternative conceptions about them. However, another possible explanation exists.

College students' mental models (i.e., students' mental explanation for how the world works) of geologic phenomena may be inadequate for them to understand some geologic processes and features. For example, Libarkin et al. (2005), Libarkin and Kurdziel (2006), and Raia (2005) found that most college students in their studies could not explain geologic processes or the mechanisms responsible for those processes because they did not have appropriate mental models of earth processes. It is not possible to determine from the data collected in this study if a lack of direct experience, inappropriate mental models, or some other factor influenced the students' development of alternative conceptions for river processes and difficult to observe features. Multiple factors may simultaneously influence conceptual development process. Future research should further investigate the possible factors that influence students' conceptual development and interaction among the factors.

Research Question 1 Summary

Students' conceptions about nine river topics were classified into five conception categories. Students mostly held scientific and incomplete scientific conceptions about the nine river topics. There were few occurrences of students holding an alternative conception for a river topic. Instead of holding an alternative conception, students more commonly held blended conceptions (i.e., scientific-alternative or incomplete scientific-alternative conceptions) for river topics.

An analysis of the subtopics for all of the topics revealed that the subtopics for which students did not hold any alternative conceptions were observable features and processes/causes. Although there were a few observable features and processes/causes for which students did hold alternative conceptions, the majority of the subtopics for which students held alternative conceptions were difficult to observe processes and causes.

Research Question 2 Results: Patterns between Conceptions and Demographic Characteristics

The second research question was to investigate the patterns of students' conceptions and their demographic characteristics, specifically gender and ethnicity. To investigate this question, within-gender and within-ethnicity relative frequencies for each conception category were determined. The relative likelihood (i.e., the relative difference in proportions between gender and ethnic groups for each conception category) were also determined. The results of the analysis will be presented followed by a discussion and interpretation of the results.

Gender

Counts, within-gender relative frequencies, and relative likelihoods of each conception category held by students are presented in Table 61. The relative frequencies are within-gender percentages (calculated across the row); therefore, the sum of the relative frequencies for a particular conception category (i.e., a sum of the column percentages) does not equal 100%. In other words, only the within-gender relative frequencies (i.e., the row percentages in the tables) should sum to 100%. Note that the counts represent the total number of occurrences of female and male students holding a particular conception category. All relative likelihood statistics presented here are comparisons of women to men. Relative likelihoods greater than one indicate that a higher proportion of women held a particular conception. A relative likelihood less than one indicates a higher proportion of men held a particular conception.

Men in this study held more scientific conceptions, incomplete scientific conceptions, and scientific alternative conceptions than did women (relative likelihoods of 0.84, 0.93, and 0.74 respectively) (Table 61). Women in this study held more incomplete scientific-alternative conceptions and alternative conceptions than did men (relative likelihoods of 1.69 and 10.37 respectively) (Table 61).

Table 61

Conception Category by Gender

	Conception category[a]					
	SC	ISC	SAC	ISAC	AC	Total
Female count	26	32	6	8	7	79
Within female relative frequency (%)	32.9	40.5	7.6	10.1	8.9	100
Male count	46	51	12	7	1	117
Within male relative frequency (%)	39.3	43.6	10.3	6.0	0.9	100
Relative likelihood	0.84	0.93	0.74	1.69	10.37	--

[a] AC = Alternative Conception, ISAC = Incomplete Scientific Alternative Conception, ISC = Incomplete Scientific Conception, SAC = Scientific Alternative Conception, SC = Scientific Conception.

Ethnicity

Counts, within-ethnicity relative frequencies, and relative likelihoods of each conception category held by students are presented in Table 62. The relative frequencies are within-ethnicity percentages (calculated across the row); therefore, the sum of the relative frequencies for a particular conception category (i.e., a sum of the column percentages) does not equal 100%. In other words, only the within-ethnicity relative frequencies (i.e., the row percentages in the tables) should sum to 100%. Note that the counts represent the total number of occurrences of Hispanic and White students holding a particular conception category. All relative likelihood statistics presented here are comparisons of Hispanic to White. Relative likelihoods greater than one indicate that a higher proportion of Hispanic students held a particular conception. A relative likelihood less than one indicates a higher proportion of White students held a particular conception.

White students in this study held more scientific conceptions, incomplete scientific conceptions, and scientific alternative conceptions than did Hispanic students (relative likelihoods of 0.91, 0.90, and 0.76 respectively). Hispanic students in this study held more incomplete scientific-alternative conceptions and alternative conceptions than did White students (relative likelihoods of 1.89 and 2.27 respectively).

Table 62

Conception Category by Ethnicity

	Conception category[a]					
	SC	ISC	SAC	ISAC	AC	Total
Hispanic count	14	16	3	5	3	41
Within Hispanic relative frequency (%)	34.1	39.0	7.3	12.2	7.3	100
White count	58	67	15	10	5	155
Within White relative frequency (%)	37.4	43.2	9.7	6.5	3.2	100
Relative likelihood	0.91	0.90	0.76	1.89	2.27	--

[a] AC = Alternative Conception, ISAC = Incomplete Scientific Alternative Conception, ISC = Incomplete Scientific Conception, SAC = Scientific Alternative Conception, SC = Scientific Conception.

Summary

Men in this study held scientific, incomplete scientific, and scientific-alternative conceptions more frequently than did the women. Women held incomplete scientific-alternative and alternative conceptions more frequently than did men. White students in this study held scientific, incomplete scientific, and scientific-alternative conceptions more frequently than did the Hispanic students. Hispanic students held incomplete scientific-alternative and alternative conceptions more frequently than did White students.

Discussion of Question 2 Results

The findings in this study show a pattern between the students' conceptions and their gender and ethnicity. No other study has investigated the pattern between students' conceptions of river topics and their gender and ethnicity. Therefore, the patterns found in this study were compared with studies that investigated other geology topics.

Gender

In this study, male students held scientific conceptions, incomplete scientific conceptions, and scientific alternative conceptions more frequently than did female students. Female students held incomplete scientific-alternative conceptions and alternative conceptions more frequently than did the male students.

Four other studies investigated the patterns between gender and students' conceptions of geology topics. Black (2003, 2005) and Steer, Knight, Owens, and McConnell (2005) found no differences between the conceptions of geology topics held by male and female students. Philips (1992) concluded that male students held more scientific conceptions than female students did on questions that involved spatial and temporal concepts. Female students held as many scientific conceptions as male students did on questions that did not contain spatial and temporal concepts. Schoon (1988, 1992) analyzed students' conceptions by gender and ethnicity (White, Black, and Hispanic) subgroups, finding that White and Hispanic female students held more alternative conceptions than did White and Hispanic male students. However, Black female students held fewer alternative conceptions than did Black male students.

Ethnicity

This study found a difference between the types of conceptions held by White and Hispanic students. White students in this study more frequently held scientific and incomplete scientific conceptions than did Hispanic students. Hispanic students in this study more frequently held alternative conceptions than did white students. The patterns for blended conception categories are interesting. White students more frequently held scientific alternative conceptions; however, Hispanic students more frequently held incomplete scientific alternative conceptions.

This pattern between ethnicity and conceptions is similar to the pattern found by Schoon (1988, 1992). Schoon found that White students held significantly more scientific conceptions than did Black and Hispanic students combined and fewer alternative conceptions than did the Black and Hispanic students combined. Unlike the Schoon study, however this study identified additional conception categories (incomplete scientific conception, scientific-alternative conception, and incomplete scientific-alternative conception).

Research Question 2 Summary

The findings in this study show a pattern between students' conceptions and gender and ethnicity. However, these findings do not prove a causal relationship between ethnicity and gender and students' conceptions. These findings only identify patterns that exist with this unique group of students. Other extrinsic and intrinsic factors not investigated in the study may also correlate with students' conceptions (see the literature review).

This study adds to a very small number of studies that have investigated patterns between students' conceptions and their demographic characteristics. The patterns between gender and ethnicity and students' conceptions of geology topics generally are not consistent across studies. More research is needed to investigate the relationship between students' conceptions of geology topics and their demographic characteristics.

CHAPTER 6: SUMMARY OF FINDINGS, IMPLICATIONS, AND FUTURE RESEARCH

The goal of this study was to identify college students' conceptions of river topics and to investigate the patterns between students' conceptions and their gender and ethnicity. Four major findings emerged from the examination of the results and discussion. The findings from this study have implications for instruction and lead to future research.

Findings

Four major findings summarize the results of this study.

Finding 1: Students Held mostly Scientific and Incomplete Scientific Conceptions

Students held mostly scientific and incomplete scientific conceptions for all nine river topics. Of the possible 216 occurrences of conception categories for all students across all nine river topics, 155 were scientific and incomplete scientific conceptions. Only 33 occurrences were blended conceptions and eight were alternative conceptions. Additionally, the majority of alternative and blended conceptions were held by only a handful of students. Students held scientific and incomplete scientific conceptions for all topics and subtopics. However, students particularly held more scientific and incomplete scientific conceptions for subtopics that were observable features and observable processes/causes.

Finding 2: Students' Conceptions Were Complex

Students' conceptions of river topics were more complex than the two conception categories scientific and alternative. In addition to scientific and alternative conceptions, the students also held incomplete scientific, incomplete scientific-alternative, and scientific-alternative conceptions. Individual students held a range of conceptions across the river topics. For example, R05-13 held scientific conceptions for definition of a river, cause of the river flow, and erosion; incomplete scientific conceptions for sediment type and origin, destination of water, source of water, and canyon formation; scientific-alternative conceptions for floods; and incomplete scientific-alternative conceptions for river formation. Similarly, for each topic there was generally a range of conceptions held by students (e.g., students held scientific conceptions, incomplete scientific conceptions, and scientific-alternative conceptions for floods).

Finding 3: Students Held Alternative Conceptions for Processes and Causes and Difficult to Observe Features

Examination of the subtopics showed that, with one exception, the students held alternative conceptions for river processes and causes, many of which were completely or partially difficult to observe. The exception was that one student held an alternative conception for a difficult to observe feature. A growing number of studies also indicate that students have difficulty with geologic processes and causes and difficult to observe features.

Finding 4: Patterns Were Observed between Conceptions and Gender and Ethnicity

This study found a pattern between students' conceptions of river topics and their gender and ethnicity. Men in this study held scientific, incomplete scientific, and scientific-alternative conceptions more frequently than did the women. Women held incomplete scientific-alternative and alternative conceptions more frequently than did men. White students in this study held scientific, incomplete scientific, and scientific-alternative conceptions more frequently than did the Hispanic students. Hispanic students held incomplete scientific-alternative and alternative conceptions more frequently than did White students.

Research in the field of science conceptions has found that multiple intrinsic (including gender and ethnicity) and extrinsic factors (e.g., teaching strategies and direct experience with the natural world) may influence students' conceptual development. The findings of this study do not prove a causal relationship between gender, ethnicity, and students' conceptions. However, the findings indicate an interesting pattern that requires additional investigation to determine if this pattern can be replicated and how the pattern affects students' future conceptual development.

Implications for Teaching

Students use their pre-existing conceptions as a lens to learn about new topics in the classroom. Researchers have found that many of students' alternative conceptions are difficult to change even with instruction (Scott et al., 2007; Wandersee et al., 1994). This study did not investigate the process of conceptual change; it identified students' conceptions about several river topics prior to instruction of the river topics. However, it is possible to suggest three implications that the findings from this study have on classroom approaches to modifying students' alternative conceptions for river topics.

Implication 1: Recognize Complexity of Students' Conceptions

It is important for educators to recognize that students' conceptions are complex and may be more diverse than scientific and alternative conceptions. Knowing the diversity of students' conceptions, instructors can design instructional strategies to target students' conceptions. For example, if an instructor knows that students have incomplete scientific conceptions about a topic then the instructor can focus instruction on helping students acquire the pieces they are missing. Similarly, if students hold blended conceptions (i.e., they have a scientific conceptions were part of a topic and alternative conception for part of a topic seem topics) then the instructor can use students' scientific conceptions as a foundation for future learning.

Implication 2: Use Scientific Conceptions as Basis for Future Learning

Students in this study held mostly scientific or incomplete scientific conceptions of river topics. Additionally, few students held pure alternative conceptions; students were more likely to hold a blended conception in which they had scientific and alternative conceptions for a topic. Students' pre-existing scientific conceptions of science topics can serve as a foundation for their future learning (Clement, 1993; Clement, Brown, & Zietsman, 1989; Palmer, 2001). The conception research field primarily focuses on identifying and modifying students' alternative conceptions. However, students' alternative conceptions represent only a part of their understanding of a topic (Clement, 1993; Clement et al., 1989; Palmer, 2001). Instructional strategies that are based on using students' scientific conceptions as a foundation for learning may be effective for teaching the students in the study and other students with similar conceptions (for examples see Clement, 1993; Clement et al., 1989; Grayson, 1994).

Implication 3: Determine Strategies to Modify Alternative Conceptions

Almost all of the subtopics for which students held alternative conceptions were processes and causes—many of these were difficult to observe. To help students modify their alternative conceptions, it would be useful first to determine which of students' alternative conceptions are resistant to change and second to determine which instructional strategies are effective at helping students modify their alternative conceptions of processes and causes (observable and difficult to observe) and difficult to observe features. Educators could conduct action research to investigate which conceptions are resistant to change and which instructional strategies are effective at modifying students' alternative conceptions.

Little research has been conducted to identify instructional strategies that modify college students' alternative conceptions of geology topics in general (Libarkin & Kurdziel, 2001) and there has been no study to investigate how to modify college students' alternative conceptions of river topics specifically. Reinfried (2006) and Stofflett (1994) examined the effectiveness of various teaching strategies on modifying students' conceptions of geologic processes and difficult to observe geologic features. More studies similar to these need to be conducted to determine how to best modify students alternative ideas of processes and difficult to observe features.

Future Research

Future geology conceptions researchers could follow one general recommendation that would strategically help shape the growing number of geology conceptions studies. The general recommendation is to conduct research that builds on previous studies and designed so that their findings can be compared across studies. This recommendation is based on observations and critique made in the literature review for this study. There have been few, if any, follow-up studies to previous studies investigating students' conceptions of rivers and the factors that influence students' conceptual development of geology topics. Without follow-up studies that build on previous studies, it is difficult to build a theory of students' conceptual development in geology. Similarly, many previous studies inadequately described their research methods or synthesized their results so that the findings could easily be compared with other studies. Researchers need to describe carefully their research methods and their results in a manner that allows their findings to be compared across studies. In addition to this general recommendation for future researchers of geology conceptions, four other research directions follow from the study.

Research of River Topics

This is the first in-depth study investigating college students' conceptions of rivers. As previously discussed, follow-up studies should be conducted to explore further the patterns identified in this study. For example, researchers should investigate if other college students hold similar conceptions of river topics as found in the study and if the same conception categories emerge for the same river topics. Additionally, researchers should investigate the conceptions of river topics along the expert-novice spectrum. Research of conceptions held along the expert-novice spectrum helps educators understand the differences between experts and novices and aids in the development of instructional strategies that bring novice learners closer to having the knowledge and skills of experts (Petcovic & Libarkin, 2007).

College students taking introductory geology classes should understand river features and processes (Englebrecht et al., 2005; Kelso et al., 2000). Therefore, students' conceptions of river topics that were either not explored or did not emerge as major topics during analysis in this study should be investigated. Those topics include deposition, transportation, fluvial landforms, relationship between rivers and other geologic processes, causal factors for various river processes, and types of rivers (e.g., meandering and braided).

Factors that Influence Students' Conceptual Development

Several intrinsic and extrinsic factors have been shown to correlate or influence students' conceptions of geology topics. This study only investigated the pattern between two factors (gender and ethnicity) and students' conceptions. Future research should investigate further the factors that influence students' conceptual development of river topics.

Instructional Strategies to Modify Students' Alternative Conceptions

Future research should investigate if the alternative conceptions identified in this study can be easily be modified by instruction and if there are some conceptions that are difficult to change. Additionally, researchers should identify how students in the five conception categories are affected by instruction. For example, do students with incomplete scientific-alternative conceptions respond to instruction in the same way that students with alternative conceptions do? Are the strategies to move a student successfully from an alternative conception to a scientific conception the same or different from ones that successfully move a student from a blended conception to a scientific conception or from an incomplete scientific conception to a scientific conception? Future conceptual change studies should also investigate which instructional strategies can best enable students to understand geologic processes and difficult to observe features.

Use Similar Methods and Typology

Students' conceptions were investigated in this study using in-depth interviews and a modified version of constant comparative analysis. These methods were effective at identifying the type and complexity of conceptions held by students. Additionally, the typology (i.e., the five conception categories) developed in this study was useful at capturing the range and complexity of students' conceptions. When conducting future studies, researchers should consider using similar data collection and analysis methods and adopting the five conception categories. Using similar methods will enable researchers to make comparisons easily across studies.

Conclusion

This study used systematic and rigorous research methods to investigate college students' conceptions of rivers and the patterns between their conceptions and their gender and ethnicity. It is a significant contribution to the small but growing number of studies that investigate college students' conceptions of geology topics. It is the only study to investigate college students' conceptions of rivers in depth. The results, which reveal the complexity and range of students' conceptions about river topics, can serve as the basis for future research investigating students' conceptions of rivers and the patterns between conceptions and demographic characteristics. The results also can help educators design approaches for teaching geology topics.

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APPENDIXES

Appendix A: Inclusion Criteria Used to Identify River Conceptions Studies

Inclusion criteria used during search for studies investigating students' conceptions of rivers.

Inclusion Criteria

- Study must investigate students' conceptions of rivers.
- Study must investigate students' conceptions and/or their conceptual development.
- Study must be in English.
- Study must be empirical.
- Study must be peer-reviewed (an exception was made for the classical works by Jean Piaget, which appear to be published as non-peer-reviewed books).

Appendix B: Database and Search Terms Used to Identify River Conceptions Studies

Table B1 lists the databases searched and terms used to identify studies that investigated students' conceptions of rivers.

Table B1

Database and Search Terms Used to Identify River Conceptions Studies

Database	Search Terms
ERIC Cambridge	Search 1: (Rivers or streams or hydrogeology or hydrology or floods or fluvial) and (conception or concept or conceptual or preconception or misconception or idea or belief or concept formation or cognitive development) Search 2: Misconceptions and earth science Search 3: Concept formation and earth science
Education Abstracts	(Rivers or streams or hydrogeology or hydrology or floods or fluvial or earth science) and (conception or concept or conceptual or preconception or misconception or idea or belief or cognitive development) and English
Georef	Search 1: (education or educational or k-12 education or college-level education) and (rivers or streams or geomorphology or fluvial or hydrology), narrowed by education and English language
Social Science Abstracts	(Rivers or streams or hydrogeology or hydrology or floods or fluvial or earth science) and (conception or concept or conceptual or preconception or misconception or idea or belief or cognitive development) and English
Applied Science and Technology Abstracts	Search 1: (Rivers or streams or hydrogeology or hydrology or floods or fluvial or earth science) and (conception or concept or conceptual or preconception or misconception or idea or belief or cognitive development) and English Search 2: (Rivers or streams or hydrogeology or hydrology or floods or fluvial or earth science) and education Search 3: Geology and study and teaching
PsychInfo	(Concept formation or Cognitive Processes or Learning) and (Science education or geography) and English, narrowed by and DE "Science Education" and DE "Learning" and DE "Concept Formation"

Table B1 (continued)

Database	Search Terms
Web of Science: Science Citation Index, social science citation index, arts and humanities citation index	Search 1: (Rivers or streams or hydrogeology or hydrology or floods or fluvial or earth science) and (conception or concept or conceptual or preconception or misconception or idea or belief or cognitive development) and English and article, narrow by the following subject categories EDUCATION & EDUCATIONAL RESEARCH, EDUCATION, SCIENTIFIC DISCIPLINES, PSYCHOLOGY, EDUCATIONAL Search 2: (geography or earth science) and (conception or concept or conceptual or preconception or misconception or idea or belief or cognitive development or prior knowledge) and English and article, narrowed by education and educational research
Dissertation Abstracts database	(Rivers or streams or hydrogeology or hydrology or floods or fluvial or earth science or geology) and (conception or concept or conceptual or preconception or misconception or idea or belief or cognitive development or prior knowledge, narrowed by searching for keyword "education"

Appendix C: Inclusion and Exclusion Criteria Used to Identify Studies that Investigated Factors

Inclusion and exclusion criteria used during search for studies investigating the factors that influence students' conceptions of geology topics.

Inclusion Criteria

- Study must investigate a geology topic. The study can investigate topics in other earth science disciplines (e.g., astronomy) so long as it also includes geology topics.
- Study must investigate students' conceptions and/or their conceptual development.
- Study must examine at least one factor (e.g., gender, instructional method) that affects students' conceptions.
- Study must have been published between 1980 and 2006.
- Study must be in English.
- Study must be empirical.
- Study must be peer-reviewed.

Exclusion criteria

- Study investigates earth science topics (including topics in geology, oceanography, meteorology, and astronomy) but does not give enough detail to determine if geology topics were included.
- Study describes possible origins for or factors affecting the development of students' conceptions but does not empirically investigate the relationship between origin or factors and conceptions.

Appendix D: Database and Search Terms Used to Identify Studies that Investigated Factors

Table D1 lists the databases searched and terms used to identify studies that investigated the factors that influence students' development of conceptions about geology topics.

Table D1

Database and Search Terms Used to Identify Studies that Investigated Factors

Database	Search Terms
ERIC Cambridge	(Geology or geoscience or "earth science") and (conception or concept or conceptual or preconception or misconception or idea or belief or concept formation or cognitive development)
Education Abstracts	(Geology or geoscience or "earth science") and (conception or concept or conceptual or preconception or misconception or idea or belief or cognitive development)
Georef	(conception or concept or conceptual or preconception or misconception or idea or belief or cognitive development) and (Geology or geoscience or "earth science") and (education or educational or k-12 education or college-level education)
Social Science Abstracts	Search 1: (geology) and (conception or concept or "concept formation" or perception or belief or "cognitive development")
	Search 2: (physical science) and (conception or concept or "concept formation" or perception or belief or "cognitive development")
Applied Science and Technology Abstracts and Academic Search Premier	(geology or geoscience or earth science) and (conception or concept or conceptual or preconception or misconception or idea or belief or cognitive development) and education
	Search 2: ((((Concept formation or Cognitive Processes or Learning) and (Science education or geography)))) and DE "Teaching"
	Search 3: Earth science or geology or geoscience

Table D1 (continued)

Database	Search Terms
PsychInfo	Search 1: ((Concept formation or Cognitive Processes or Learning) and (Science education or geography)) and DE "Science Education" and DE "Learning" and DE "Sciences" Search 2: ((((Concept formation or Cognitive Processes or Learning) and (Science education or geography)))) and DE "Teaching" Search 3: Earth science or geology or geoscience
Web of Science: Science Citation Index, social science citation index, arts and humanities citation index	(geology or geoscience or earth science) and (conception or concept or conceptual or preconception or misconception or idea or belief or cognitive development), narrow by subject categories: "education & educational research, geography, psychology, educational, social sciences, interdisciplinary, psychology, experimental"
Dissertation Abstracts database	(earth science or geology or geoscience) and (conception or concept or conceptual or preconception or misconception or idea or belief or cognitive development or prior knowledge) and education

Appendix E: Recruitment Statements

Recruiting statement to recruit students for interviews and questionnaire in Spring 2005
"My name is Julie Sexton and I am conducting a research project along with Brian Cobb at Colorado State University called "Students' conceptions about rivers." We are interested in exploring students' ideas about rivers. We also want to explore how demographic characteristics, like recreational activities and what rivers you lived next to, shape students ideas about rivers. We are looking for students enrolled in introductory college-level geoscience classes to participate. We would like to interview students about their ideas of rivers. We also would like students to complete a demographic questionnaire. The instructor of your class has agreed to provide you extra credit points in the class for your participation in the study. Your instructor will provide _______ (list the number of points) points. If you choose not to participate in this study, your instructor has an alternative extra credit project that you can complete. You will receive the same number of points for the alternative extra credit project as the number you would receive if you participate in our study.

If you are interested in learning more about the study and possibly volunteering please contact Julie Sexton at 970-491-2702 or ju.sexton@colostate.edu."

Recruiting statement to recruit Hispanic students for interviews and questionnaire in Fall 2005
"My name is Julie Sexton and I am conducting a research project along with Brian Cobb at Colorado State University called "Students' conceptions about rivers." We are interested in exploring students' ideas about rivers. We also want to explore how demographic characteristics, like recreational activities, what rivers you lived next to, and ethnicity shape students ideas about rivers. We are looking for Hispanic students currently enrolled in introductory college-level geoscience classes to participate. We would like to interview Hispanic students about their ideas of rivers and compare their ideas with the ideas of other Hispanic and non-Hispanic students. We also would like students to complete a demographic questionnaire.

The instructor of your class has agreed to provide you extra credit points in the class for your participation in the study. Your instructor will provide _______ (list the number of points) points. If you choose not to participate in this study, your instructor has an alternative extra credit project that you can complete. You will receive the same number of points for the alternative extra credit project as the number you would receive if you participate in our study.

If you are interested in learning more about the study and possibly volunteering please contact Julie Sexton at 970-491-1700 or ju.sexton@colostate.edu."

Appendix F: Consent Forms

Consent form used for students recruited during Spring 2005

CONSENT TO PARTICIPATE IN A RESEARCH STUDY
COLORADO STATE UNIVERSITY

Title of Study:	Students' conceptions about rivers
Principal Investigator:	Brian Cobb, Professor of Education, Colorado State University, 970-491-6835 or cobb@cahs.colostate.edu
Co-Principal Investigator:	Julie Sexton, Doctoral Fellow, Center for Learning and Teaching in the West, Ph.D. Student, Colorado State University, 970-491-2702 or ju.sexton@colostate.edu
Co-Principal Investigator:	Eric Riggs, Assistant Professor of Geoscience, San Diego State University, 619-594-5592, eriggs@geology.sdsu.edu
Sponsor of Project:	National Science Foundation

WHAT IS THE PURPOSE OF THE STUDY?
We want to learn about what college students enrolled in introductory geoscience classes think about rivers. We also want to explore the relationship between students' demographic characteristics and their ideas about rivers.

WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH?
You are enrolled in an introductory geoscience class at a college or university.

WHO IS DOING THE RESEARCH?
Julie Sexton is the primary person who will conduct most of the research. Eric Riggs and Brian Cobb may also assist in conducting research. This research is being conducted by the Center for Learning and Teaching in the West, which is funded in part by the National Science Foundation.

WHAT WILL I BE ASKED TO DO?
Interview
You will be asked to participate in a 60- to 90-minute long interview. During the interview, you will be asked about your ideas and understanding of rivers. The interviews will take place in a classroom or office setting. You may be asked to return for a 30-minute follow-up interview after your initial 60- to 90-minute interview. During this follow-up interview, you will be asked questions about the responses that you gave in the first interview. This follow-up interview will also take place in a classroom or office setting. During both interviews, you will be asked questions about your ideas about rivers. You will be asked to respond to the questions verbally, in writing, through drawings, and/or by arranging photographs and props.

We would like to videotape and audiotape the interview. If you do not want to be videotaped and/or audiotaped, then you will be asked not to participate in the study.

You will not be identified by name in any of the videotapes and audiotapes. The audiotapes and videotapes will be stored for five years after the study. After five years, the audiotapes and videotapes will be destroyed.

Please initial below if we may videotape and audiotape you.

_________ • I am willing to be audiotaped during the interview for use in this project.

_________ • I am willing to be videotaped during the interview for use in this project

We would like to use the videotapes and audiotapes at research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects. Please initial below if we may use the videotapes and audiotapes for these purposes. You may still participate in the study if you do not agree to allow your audiotape and videotape to be used at research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects

_________ • I <u>do</u> approve the use of the audiotape in research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects.

_________ • I <u>do</u> approve the use of the videotape in research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects.

Demographic Questionnaire
During the interview, you will be asked to complete a questionnaire that asks demographic and background questions. The questionnaire will take 10 to 20 minutes to complete. You will complete the questionnaire in a classroom or office setting.

WILL I RECEIVE ANY COMPENSATION FOR TAKING PART IN THIS STUDY?
For your participation in this study, you will receive extra credit points in the geoscience class from which you were recruited. The number of extra credit points will be specified by your instructor. After completing your participation in the study (and before the end of the semester/quarter during which you were recruited), we will provide your name to the instructor of the class from which you were recruited. In this way, your instructor will know that you should receive extra credit for participating in this study.

WHERE IS THE RESEARCH GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?
The interviews will take place in a classroom or office setting. The initial interview will last 60 to 90 minutes. Follow-up interviews will last 30 minutes.

ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS RESEARCH?
There are no reasons that you should not take part in the study.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?
There are three potential risks associated with this study. These risks are minimal.

1. You may feel uncomfortable or uneasy about answering questions about rivers if you lack knowledge in this topic area. This risk is similar to what you might feel in a class situation while taking a test.
2. You may feel uncomfortable answering questions on the demographic questionnaire.
3. You may feel uncomfortable being audiotaped and/or videotaped.

It is not possible to identify all potential risks in research procedures, but the researcher(s) have taken reasonable safeguards to minimize any known and potential, but unknown, risks.

WILL I BENEFIT FROM TAKING PART IN THIS STUDY?
There are no known benefits to you for participating in this study, but we hope to gain more knowledge about what students think about rivers. This knowledge may benefit educators of geoscience classes who will be able to target curricula to address these ideas.

DO I HAVE TO TAKE PART IN THE STUDY?
Your participation in this study is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.

WHAT WILL IT COST ME TO PARTICIPATE?

There are no costs for you to participate in the study.

WHO WILL SEE THE INFORMATION THAT I GIVE?
We will keep private all research records that identify you, to the extent allowed by law.

Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials. We may publish the results of this study; however, we will keep you name and other identifying information private.

Your audiotape and/or videotape may be used at research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects **only** if you granted approval in the section of this consent form titled "What Will I Be Asked To Do?" by initialing next to one or both of the following statements: "I am willing to be audiotaped during the interview for use in this project. I do approve the use of the audiotape in research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects." or "I am willing to be videotaped during the interview for use in this project. I do approve the use of the videotape in research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects." We will not use your name or other information that will make you identifiable when we report our results if we do use the videotapes and/or audiotapes at research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects

When highlighting a specific interview or case study, fictitious names, initials, or numbers will be used to protect your identity.

Your name will be shared with the instructor of the geoscience class from which you were recruited so that you can receive extra credit for your participation in the study. However, your specific responses to all questions in the study will not be shared with the instructor. Your responses will be combined with information from other people taking part in the study.

CAN MY TAKING PART IN THE STUDY END EARLY?
Your participation in the study may end early if you decide that you do not want to be videotaped and/or audiotaped during the interviews.

WHAT HAPPENS IF I AM INJURED BECAUSE OF THE RESEARCH?
The Colorado Governmental Immunity Act determines and may limit Colorado State University's legal responsibility if an injury happens because of this study. Claims against the University must be filed within 180 days of the injury.

WHAT IF I HAVE QUESTIONS?
Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you can contact the investigator, Brian Cobb at 970-491-6835 or cobb@cahs.colostate.edu or Julie Sexton at 970-491-2702 or ju.sexton@colostate.edu

If you have any questions about your rights as a volunteer in this research, contact Celia Walker, Director of Regulatory Compliance, at 970-491-1553. We will give you a copy of this consent form to take with you.

WHAT ELSE DO I NEED TO KNOW?
Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing ____ pages.

______________________________ ________________

Signature of person agreeing to take part in the study Date

____

Printed name of person agreeing to take part in the study

______________________________ ________________

Name of person providing information to participant Date

____

Signature of Research Staff

PARENTAL SIGNATURE FOR MINOR

As parent or guardian, you authorize ______________________ (print name) to become a participant for the described research. The nature and general purpose of the project have been satisfactorily explained to you by ____________________ and you are satisfied that proper precautions will be observed.

____

Minor's date of birth

____

Parent/Guardian name (printed)

______________________________ ________________

Parent/Guardian signature Date

Consent form used for students recruited during Fall 2005 (recruitment of Hispanic students)

CONSENT TO PARTICIPATE IN A RESEARCH STUDY
COLORADO STATE UNIVERSITY

Title of Study:	Students' conceptions about rivers
Principal Investigator:	Brian Cobb, Professor of Education, Colorado State University, 970-491-6835 or cobb@cahs.colostate.edu
Co-Principal Investigator:	Julie Sexton, Doctoral Fellow, Center for Learning and Teaching in the West, Ph.D. Student, Colorado State University, 970-491-2702 or ju.sexton@colostate.edu
Co-Principal Investigator:	Eric Riggs, Assistant Professor of Geoscience, San Diego State University, 619-594-5592, eriggs@geology.sdsu.edu
Sponsor of Project:	National Science Foundation

WHAT IS THE PURPOSE OF THE STUDY?

We want to learn about what college students enrolled in introductory geoscience classes think about rivers. We also want to explore the relationship between students' demographic characteristics and their ideas about rivers.

WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH?
You are a Hispanic student enrolled in an introductory geoscience class at a college or university or you are a Hispanic student who is not taken in introductory geoscience class at the college or university.

WHO IS DOING THE RESEARCH?
Julie Sexton is the primary person who will conduct most of the research. Eric Riggs and Brian Cobb may also assist in conducting research. This research is being conducted by the Center for Learning and Teaching in the West, which is funded in part by the National Science Foundation.

WHAT WILL I BE ASKED TO DO?
Interview
You will be asked to participate in a 60- to 90-minute long interview. During the interview, you will be asked about your ideas and understanding of rivers. The interviews will take place in a classroom or office setting. You may be asked to return for a 30-minute follow-up interview after your initial 60- to 90-minute interview. During this follow-up interview, you will be asked questions about the responses that you gave in the first interview. This follow-up interview will also take place in a classroom or office setting. During both interviews, you will be asked questions about your ideas about rivers. You will be asked to respond to the questions verbally, in writing, through drawings, and/or by arranging photographs and props.

We would like to videotape and audiotape the interview. If you do not want to be videotaped and/or audiotaped, then you will be asked not to participate in the study.

You will not be identified by name in any of the videotapes and audiotapes. The audiotapes and videotapes will be stored for five years after the study. After five years, the audiotapes and videotapes will be destroyed.

Please initial below if we may videotape and audiotape you.

_________ • I am willing to be audiotaped during the interview for use in this project.

_________ • I am willing to be videotaped during the interview for use in this project

We would like to use the videotapes and audiotapes at research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects. Please initial below if we may use the videotapes and audiotapes for these purposes. You may still participate in the study if you do not agree to allow your audiotape and videotape to be used at research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects

_________ • I do approve the use of the audiotape in research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects.

_________ • I do approve the use of the videotape in research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects.

Demographic Questionnaire
During the interview, you will be asked to complete a questionnaire that asks demographic and background questions. The questionnaire will take 10 to 20 minutes to complete. You will complete the questionnaire in a classroom or office setting.

WILL I RECEIVE ANY COMPENSATION FOR TAKING PART IN THIS STUDY?
For your participation in this study, you will receive extra credit points in the geoscience class from which you were recruited. The number of extra credit points will be specified by your instructor. After completing your participation in the study (and before the end of the semester/quarter during which you were recruited), we will provide your name to the instructor of the class from which you were recruited. In this way, your instructor will know that you should receive extra credit for participating in this study.

WHERE IS THE RESEARCH GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?
The interviews will take place in a classroom or office setting. The initial interview will last 60 to 90 minutes. Follow-up interviews will last 30 minutes.

ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS RESEARCH?
There are no reasons that you should not take part in the study.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?
There are three potential risks associated with this study. These risks are minimal.

4. You may feel uncomfortable or uneasy about answering questions about rivers if you lack knowledge in this topic area. This risk is similar to what you might feel in a class situation while taking a test.
5. You may feel uncomfortable answering questions on the demographic questionnaire.
6. You may feel uncomfortable being audiotaped and/or videotaped.

It is not possible to identify all potential risks in research procedures, but the researcher(s) have taken reasonable safeguards to minimize any known and potential, but unknown, risks.

WILL I BENEFIT FROM TAKING PART IN THIS STUDY?
There are no known benefits to you for participating in this study, but we hope to gain more knowledge about what students think about rivers. This knowledge may benefit educators of geoscience classes who will be able to target curricula to address these ideas.

DO I HAVE TO TAKE PART IN THE STUDY?
Your participation in this study is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.

WHAT WILL IT COST ME TO PARTICIPATE?
There are no costs for you to participate in the study.

WHO WILL SEE THE INFORMATION THAT I GIVE?
We will keep private all research records that identify you, to the extent allowed by law.

Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials. We may publish the results of this study; however, we will keep you name and other identifying information private.

Your audiotape and/or videotape may be used at research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects **only** if you granted approval in the section of this consent form titled "What Will I Be Asked To Do?" by initialing next to one or both of the following statements: "I am willing to be audiotaped during the interview for use in this project. I do approve the use of the audiotape in research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects." or "I am willing to be videotaped during the interview for use in this project. I do approve the use of the videotape in research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects." We will not use your name or other information that will make you identifiable when we report our results if we do use the videotapes and/or audiotapes at research meetings, during workshops, in other scholarly formats for education, and for other institutionally approved projects

When highlighting a specific interview or case study, fictitious names, initials, or numbers will be used to protect your identity.

Your name will be shared with the instructor of the geoscience class from which you were recruited so that you can receive extra credit for your participation in the study. However, your specific responses to all questions in the study will not be shared with the instructor. Your responses will be combined with information from other people taking part in the study.

CAN MY TAKING PART IN THE STUDY END EARLY?
Your participation in the study may end early if you decide that you do not want to be videotaped and/or audiotaped during the interviews.

WHAT HAPPENS IF I AM INJURED BECAUSE OF THE RESEARCH?
The Colorado Governmental Immunity Act determines and may limit Colorado State University's legal responsibility if an injury happens because of this study. Claims against the University must be filed within 180 days of the injury.

WHAT IF I HAVE QUESTIONS?
Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you can contact the investigator, Brian Cobb at 970-491-6835 or cobb@cahs.colostate.edu or Julie Sexton at 970-491-2702 or ju.sexton@colostate.edu

If you have any questions about your rights as a volunteer in this research, contact Celia Walker, Director of Regulatory Compliance, at 970-491-1553. We will give you a copy of this consent form to take with you.

WHAT ELSE DO I NEED TO KNOW?
Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing ____ pages.

_______________________________________ ____________________

Signature of person agreeing to take part in the study Date

____

Printed name of person agreeing to take part in the study

_______________________________________ ____________________

Name of person providing information to participant Date

____

Signature of Research Staff

PARENTAL SIGNATURE FOR MINOR
As parent or guardian, you authorize ______________________ (print name) to become a participant for the described research. The nature and general purpose of the project have been satisfactorily explained to you by ____________________ and you are satisfied that proper precautions will be observed.

Minor's date of birth

Parent/Guardian name (printed)

Parent/Guardian signature

Date

Appendix G: Textbooks Reviewed to Identify Major River Topics

Chernicoff, S., & Fox, H. A. (2000). *Essentials of geology* (2nd ed.). Boston, MA: Houghton Mifflin Company.

Chernicoff, S., & Venkatakrishnan, R. (1995). *Geology: An introduction to physical geology*. New York: Worth Publishers, Inc.

Marshak, S. (2001). *Earth: Portrait of a planet*. New York: W. W. Norton & Company, Inc.

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Monroe, J. S., & Wicander, R. (1998). *Physical geology: Exploring the earth* (4th ed.). New York: Wadsworth Publishing Company.

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Appendix H: Interview Protocol

Interview Protocol with the river topics addressed in each set of questions and the instructions on how the questions were administered.

Question 1
River Topic: Definition of a river
Instructions: Students were asked the question without props.
Main Question: What is a river?
Follow-up Question: How would you describe a river to someone who has never seen one?

Question 2
River Topics: Definition of a river, Features associated with and created by rivers, Rivers are dynamic and change in time and space, Rivers move water and sediment from the land to the sea.
Instructions: Students were given a 2'x2' piece of butcher paper and asked to draw and label a picture of a river. They were given 10 minutes to draw their picture. Students were asked follow-up questions based on their drawing and responses.
Main Question: Draw a picture of a river. Describe your picture.
Follow-up Questions:

a. What are these features? Can you label them?
b. What is in a river?
c. Where does the water come from in a river?
d. Where does the water go?
e. Does the water always flow in the river?
f. Besides water, is there anything else in a river? What?
g. Where does the sediment/dirt/pieces of stuff (use the term that the student uses) come from and where does it go?
h. Is there anything else in a river?
i. In which direction does the water flow?
j. Draw north, south, east, west arrows on the picture.
k. What month/time of year is represented by the drawing of the river? How would the river look different in the spring, summer, fall, winter?
l. What color is the river? How did the river get that color?
m. How wide is the river?
n. How long is the river?
o. How deep is the river?
p. Imagine that you dropped a bucket into a river and scooped up a sample of water. What would be in your bucket? Where did that come from?

Question 3

River Topic: River Processes, Rivers are dynamic and change in time and space

Instructions: For Part A, show student a picture of a slow moving river with visible boulder-, pebble, and sand-sized in and next to the river. For Part B, show pictures of two more rivers: one picture of a river with rapids and another picture of a river without rapids. Have students compare all three pictures.

Part A. Main Questions:

a. Describe what you see in this picture.
b. How did the big boulders get into the river?
c. Can the river move the big boulders? Why/Why not?

Part A. Follow-up Questions:

a. Is it ever possible for the river to move the boulders?
b. If there was less water, could the river move the boulders?
c. If there was more water, could the river move the boulders?
d. If the slope was flatter/steeper, could the river move the boulders?
e. If the water was moving faster, could the river move the boulders?
f. If the water was moving slower, could the river move the boulders?
g. What size would the boulders have to be in order for the river to move them?

Part B. Main Questions:

a. Describe each picture.
b. Which river is flowing faster?
c. Explain why you think that.

Question 4

River Topic: Features associated with and created by rivers, River Processes, Rivers are dynamic and change in time and space.

Instructions: Show student a picture of a river flowing through a deep rock canyon.

Main Questions: Describe the picture. How did the canyon form?

Follow-up Questions:

a. Did the canyon always look like this?
b. How did it look before?
c. Why does it look different now; what happened?
d. Was the canyon always there?
e. What did it look like before the canyon was there?
f. How long did it take the canyon to form?

Question 5

River Topic: River Processes, Rivers are dynamic and change in time and space, Features associated with and created by rivers

Instructions: Students were asked the following questions without props.

Main Question: What is a flood?

Follow-up Questions:

a. What causes a river to flood? Probe their answer.
b. Compare an unflooded river with a flooding river. How are they different? How are they the same?

c. When do rivers flood?
d. Where do rivers flood?
e. What is a floodplain?
f. Does a river always have a floodplain?
g. What is a river levee?
h. Does a river always have a river levee?
i. How does a river levee form?
j. How often do rivers flood?
k. Can we predict when rivers flood?
l. Can we prevent rivers from flooding?

Question 6

River Topic: River Processes, Rivers are dynamic and change in time and space, Rivers are important to plants and animals.

Instructions: Place large piece of butcher paper on table. The paper will have a meandering river drawn on it (just two lines that outline the edge of the river). The drawing will serve as the basis for a series of questions. Possible main questions include (questions not in order of how they would be asked):

a. In which direction does the river flow? Draw an arrow to indicate the direction of flow.
b. Draw arrows to indicate where north, south, east, and west are.
c. Imagine that you are in a boat here at Point A and you want to maneuver the point to Point B through the water using the fastest path. Use this marker and draw path to show how you move the boat in the river to Point B following the path that would be the fastest. Why did you pick that path? How long would the trip take you?
d. Place mountains on the paper. If it rains in the mountains, how would the rainwater get to the river?
e. If you were to build a bridge over the river, draw where you would build it? Over time, what would happen to the bridge and river?
f. Where would you build a city/town? Draw where you would build a house or city?
g. Ask the student to indicate on the drawing where the river would be deepest, shallowest, fastest, slowest.
h. You are in the canoe in the middle of the river (in a meander bend). Where would you maneuver the boat to get out?
i. Describe/draw what would happen to the setting during a flood.
j. What would this setting look like if you came back and visited 5, 10, 50, 100, 500 years in the future?

Question 7

River Topic: Rivers are dynamic and change in time and space

Instructions: Students were asked the following questions without props.

Main Question: What is the age of the river? How old is the river?

Appendix I: Interview Question Assignment to Participants

Table I1 shows the initial assignment of interview questions to each participant. Table I2 shows the actual questions that were asked of students during the interviews.

Table I1

Initial Interview Questions Assignment

Participant	Question						
	1	2	3	4	5	6	7
R05-02	x	x	x				
R05-03	x	x	x				
R05-04	x	x	x				
R05-05	x	x	x				
R05-06	x	x	x				
R05-07	x	x	x				
R05-08	x	x		x		x	
R05-09	x	x		x		x	
R05-10	x	x		x		x	
R05-11	x	x		x		x	
R05-12	x	x		x		x	
R05-13	x	x		x		x	
R05-14	x	x		x		x	
R05-15	x	x			x		x
R05-16	x	x			x		x
R05-17	x	x			x		x
R05-18	x	x			x		x
R05-19	x	x			x		x
R05-20	x	x			x		x
R05-21	x	x			x		x
R05-22	x	x	x				
R05-23	x	x	x				
R05-24	x	x		x		x	
R05-25	x	x			x		x

Table I2

Actual Interview Questions Asked During Interviews

Participant	Question						
	1	2	3	4	5	6	7
R05-02	x	x	x			x	
R05-03	x	x	x			x	
R05-04	x	x	x		x	x	
R05-05	x	x	x		x	x	x
R05-06	x	x	x			x	
R05-07	x	x	x	x	x	x	
R05-08	x	x	x	x		x	
R05-09	x	x		x			
R05-10	x	x	x	x		x	
R05-11	x	x	x	x	x	x	
R05-12	x	x	x	x	x	x	
R05-13	x	x	x	x	x	x	
R05-14	x	x		x	x	x	x
R05-15	x	x		x	x	x	
R05-16	x	x		x	x	x	x
R05-17	x	x		x	x	x	x
R05-18	x	x		x	x		x
R05-19	x	x	x	x	x	x	
R05-20	x	x	x	x	x	x	x
R05-21	x	x		x	x	x	
R05-22	x	x	x			x	
R05-23	x	x	x			x	
R05-24	x	x	x	x		x	x
R05-25	x	x	x		x	x	

Appendix J: Demographics Questionnaire

Participant Code _____

Instructions: Please answer the questions as completely as possible.

Background

1. What is your gender? Check one.
   __Male
   __Female
2. To which ethnic or racial group(s) do you belong or identify with? Write the name of the group(s).
   ____
3. In what year were you born? _______
4. Do you currently live or have you ever lived next to or near a river? Check one.
   ___Yes ___No
   If yes, please list the names of river(s) if you know it (them).
   ____
   ____
   ____
5. Are you enrolled in a degree-granting program? Check one. ___Yes ___No
   If yes, what is your declared or anticipated major? If you do not know, please write, "Do not know."
   ____
6. Circle the letter next to your highest degree achieved. If applicable, list what your major was in the line provided.
   a. High School diploma (HS)
   b. Associate in Arts (AA) __________________
   c. Associate in Science (AS) __________________
   d. Bachelor of Arts (BA) __________________
   e. Bachelor of Science (BS) __________________
   f. Master of Arts (MA) __________________
   g. Master of Science (MS) __________________
   h. Doctor of Philosophy (Ph.D.) __________________
   i. Other Degree (specify) ________________

7. List the places that you have lived (up to 10 places). List the places in chronological order with the most recent one first.

	City / Town/ Village/ County	State / Province	Country	For how long?	For each, check the box that is your best estimate for the population size of the city when you lived there		For each, check the box that provides your best guess for the distance you lived from a river while you lived there.			
					Less than 2,500	More than 2,500	Less than 1 mile	1-10 miles	11-50 miles	More than 50 miles
1.	(currently)			___yrs ___mos						
2.				___yrs ___mos						
3.				___yrs ___mos						
4.				___yrs ___mos						
5.				___yrs ___mos						
6.				___yrs						
7.				___yrs						
8.				___yrs						
9.				___yrs						
10.				___yrs						

Previous Science Coursework

8. High School (grades 9-12). List the number of high school science classes you took and successfully completed in each science. If you do not know the exact number, give your best estimate.

High School Science	**# of Classes**
Biology	____
Chemistry	____
Earth Science/Geology	____
Geography	____
Physics	____
Other (specify)____________	____
Other (specify)____________	____

9. College Science Courses. List the number of college classes you took and successfully completed in each science. If you do not know the exact number, give your best estimate.

College Science Courses	**# of Classes**
Biology	____
Chemistry	____
Earth Science/Geology	____
Geography	____
Physics	____
Other (specify)____________	____
Other (specify)____________	____
Other (specify)____________	____

10. List the college **geology** courses you have taken (including any in which you are currently enrolled).

____
____
____
____

11. Have you had any **geology** research experience? yes _____ no _____
Please briefly describe this research experience.

____
____
____

12. List the college **geography** courses you have taken (including any in which you are currently enrolled).

____

Outdoor Recreational Activities and Hobbies

13. Complete the chart below to indicate in which outdoor recreational activities and hobbies you participate and how frequently you participate in them. If you have other recreational activities or hobbies that are not listed, please list them in the space provided.

Activity	How often have you engaged in this activity? Check the appropriate box.			
	Never	Once	2-4 times	5 or more times
Canoe in a river				
Canoe in a lake/reservoir				
Kayak in a river				
Kayak in a lake/reservoir				
Kayak in the ocean				
Tube/Raft in a river				
Swim in a river				
Swim in a lake/reservoir				
Swim in the ocean				
Fish in a river				
Fish in a lake/reservoir				
Fish in the ocean				
Hike near a river				
Camp near a river				
Walk/Run/Bike/Rollerblade next to a river				
Skip stones in a river				
Rope swing into a river				
Other (specify)				
Other (specify)				
Other (specify)				

Thank you for completing this questionnaire!