INDUCTIVE VERSUS DEDUCTIVE INSTRUCTIONAL APPROACHES:

DETERMINING THEIR EFFECTIVENESS IN THE CLASSROOM

by

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Abstract

This study consisted of using inductive and deductive models of approach in a high school chemistry classroom to compare the effectiveness of the two instructional approaches on students' learning. Eleven students in two different classrooms participated in the study. The first model (deductive) provided students with a PowerPoint presentation and homework, followed by a lab in the next class with a discussion to bring closure to each topic. The second model (inductive) provided students with a lab and a discussion, followed by a PowerPoint presentation and homework in the next class. A nonequivalent quasi-experimental design was imposed, administering a pretest and posttest at the beginning and end of each unit. Semester exams were compared to determine if a model of approach is related to the students' comprehension of the material. The data was collected and the means, standard deviations, and standard errors were calculated. Each pre-test, post-test, and final exam score for the two groups were put through a t-test. The data shows that the two approaches are equivalent in terms of effectiveness. However, due to a small sample size, no definitive conclusions could be made based from the results.

Keywords: deductive model of approach, inductive model of approach

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Introduction

For many years, teachers and researchers have examined the best way to teach (Eggen, P. & Kauchak, D., 1996). Attempts to answer this question include multiple studies that have investigated different variables, from authoritarian vs. democratic techniques, to teacher versus student-centered learning, to direct vs. indirect teaching methods. Each study has yielded different results, suggesting that there is no single best way to teach. This may be due to students' learning styles being so diverse. This makes it important for teachers to be able to use different instructional strategies.

Research indicates that teachers plan instruction in ways that are consistent with their assumptions about class material, the type of students they have, and their personal beliefs of teaching the content area (Bruning R., Schraw, G, & Norby, M, 2011). In science education, teachers approach to the material is usually based on either a traditional or constructivist belief. Fenzioglu (2012) found that most new teachers to the profession tended to initially have a constructivist belief. As time went on, teachers were more likely to convert back to a traditional point of view. Fenzioglu (2012) suggested that teaching science, learning science, and managing behavior problems are interrelated and that the conversion could be due to lack of a constructivist perspective on the learning of science or the struggle of classroom management from a constructivist perspective. The teachers agreed on the importance of hands-on learning, but shifted back to a teacher-centered (traditional) method of teaching when difficulties were encountered in the classroom.

Bruning et al. (2011) states that teacher's beliefs are quite stable and resistant to change. Their beliefs were more affected by their experience and practice in the classroom than by continuing education. Additionally, when preservice teachers leave their teacher training programs, they have many of the same beliefs and attitudes that they initially had at the beginning of the program. Usak, M., Ozden, M., & Eilks, I. (2011) found that preservice teachers' attitudes in their study concentrated on acquisition of facts, rather than the process-oriented skills. The preservice teachers also held traditional and teacher-centered beliefs. These beliefs were not in agreement with the modern (constructivism) beliefs that were desired by the researchers.

Wong & Wong (1998) found that most beginning teachers will tend to teach as they were taught. This could be due to how the preservice teachers have been learning in their classes at their universities. A preservice teacher will have some educational experience through classes and field experience, but most of their experience in their content area comes through their university classes. Traditionally, science classes have been taught through lectures and notes with labs to help aid the learning of the lecture. This becomes the preservice teacher's last educational experience. When they eventually have their own students, they tend go back to teaching how they were last taught.

It has been found that teachers play an important role in student education (Eggen & Kauchak, 1996, Bruning et al., 2011, Chiappetta, E.L., Koballa Jr., T.R., Collette, A.L., 1998). Beginning teachers need to know how to teach a specific content area, rather than just how to teach in general (Usak, M., Ozden, M., & Eilks, I., 2011). To reach a diverse array of student learning styles, a teacher must have multiple strategies to meet all students' needs. Teachers must practice different instructional strategies by planning, performing, reflecting, and altering those strategies for future use.

Purpose of the Paper

This is an exploratory study aimed at studying the effectiveness of deductive and inductive teaching approaches in an effort to diversify instructional strategies for the teacher. Both teaching approaches are strategies designed to help students learn content at the same time as they practice thinking skills under the guidance and direction of an active learner (Eggen & Kauchak, 1996). In both models, generalizations, concepts, and principles are identified, but have a different order in which they are received by the students. Generalizations help students develop a broad knowledge base that is able to be transferred more readily to new or different situations. (Marzano, 2001) Situations, in this case, are specific examples within the generalization and can be seen in specific problems, homework, classroom discussion, and more importantly, in the laboratory. Laboratory work has a central role in science education (Tatar & Buldur, 2013, Chiappetta et al., 1998) that is intended to provide concrete, real experiences to help students comprehend the material or phenomena. The following research question posed in this study is:

Is one model of approach more effective than the other initially?

Hypotheses

Alternative Hypothesis: The inductive model of approach will produce a higher average score increase on the posttest questions as compared to the deductive model.

Null Hypothesis: There is no difference in the effects between the deductive and inductive model of approach

Deductive Model of Approach

The deductive model of approach is the most common and traditional way of teaching science (Prince, 2006/2007, Chiapetta et al, 1998). In this approach, students are given general information and then work on more specific examples. Eventually, the concept is then applied in a real-life application. In the science classroom, this is typically a laboratory activity that verifies the concept learned in class. According to Wong & Wong (1999), most first year teachers will perform this model of teaching because it was the most recent experience they had with education.

The deductive model is a very beneficial approach in the classroom. It is an easier approach when encountering difficulties in the classroom due to giving students the generalizations (Feyzioglu, 2012) and the fastest way to cover material (Wang, 2010, Gollin, 1998). It is a teacher-centered approach and is easier to prepare and control the route of learning. The two most common models are the Direct-Instruction model and the Lecture-Discussion Model (Eggen & Kauchak, 1996). Both models follow Vygotsky's zone of proximal development (Eggen & Kauchak, 1996, Bruning et al., 2011, Chiappetta et al., 1998). The teacher can present new information in logical and clear steps, provide guided practice, give feedback, and give independent practice (Direct-Instruction) or connect previous-knowledge, presentation, comprehension-monitoring, review, and closure (Lecture-Discussion). The content is presented in a way that scaffolds new material and makes it easier to understand for the students.

While this may be the easiest way to relay knowledge unto students, there are some problems that can come with the deductive approach. The students tend to be more passive in their learning (Chiapetta et al., 1998, Prince & Felder, 2006, Prince & Felder, 2007, Shaffer, 1989). Teachers can overwhelm students by giving too much information at once, making the main ideas seem less important than the smaller details (Chiapetta et al., 1998). Students also tend to fail to connect the content to the real world (Prince, 2007).

Inductive Model of Approach

The inductive model of approach is in contrast to the deductive model in part that the students are first provided specific examples and then work towards the generalization, concept, or principle. The idea is that the students play an active role in their education by discovering or forming the concept or principle. This gives the student a more concrete experience and makes it meaningful. Students are then able to recall evidence from real events and data, making sense of what was seen rather than relying on abstract information received in a lecture (Chiappetta et al., 1998).

Inductive teaching methods come in many forms. Some of the most common types are discovery learning, inquiry-based learning, and problem-based learning (Prince & Felder, 2007). Christensen (1969) outlined the main steps in the inductive approach as:

1.) Experimentation,

2.) Observation,

3.) Forming a hypothesis, and

4.) Further experimentation in order to test the hypothesis.

After these steps are completed, the deductive approach can be used to give the students the generalization to assess their hypothesis. The laboratory activity in the inductive approach becomes the initial experience. It is the background knowledge to the student, so that after the students have analyzed their data and come to a conclusion, what would be considered an abstract idea would seem more meaningful to the student. The inductive approach can promote deeper learning (Prince & Felder, 2006, Gollin, 1998, Narjaikawe, Emarat, Arayathanitkul, & Cowie, 2009) and gives students greater confidence in their problem-solving skills (Wang, 2010, Prince & Felder, 2007). Additionally, inductive teaching has been shown to be a better way to increase interest and motivation in students (Chiappette et al. 1998, Narjaikaew et al, 2009, Prince & Felder, 2007)

The inductive approach can be very beneficial in the classroom. However, when not taught correctly or given an adequate amount of scaffolding, it can have its setbacks. The less explicit the instruction is, the more likely the students are to be hostile and resistant. Students may find it difficult to know the right thing to pay attention to in a laboratory setting (Löfgren, R., Schoultz, J., Hultman, G., & Bjorklund, L., 2013). Students tend to be resistant initially when they are more responsible for their learning, so extensive support should be given when first attempting this approach, with a gradual withdrawal of guidance. Additionally, this approach may need more planning and resources, so teachers should take that into account before attempting the inductive model.

Literature Review

Comparisons of inductive vs. deductive models of approach have been studied for years. However, the variables and content of the studies differed as time went on. Early studies comparing inductive and deductive methods of instruction used programmed instruction with students. In these studies (Krumboltz & Yabroff, 1965, Koran, 1971, Sakmyser, 1974), students were given booklets to complete and were requested to either state the generalization or solve more problems. Though these studies didn't involve the students getting direct instruction from their instructor, it did provide a good basis for the studies of inductive and deductive approaches to learning.

Krumboltz et al. (1965) studied the effect of frequency of the variation between problem-solving and rule-stating and found that both methods were equally efficient when time was considered and that both methods were about equally effective in producing accurate transfer of training. It was also noted that his inductive groups were less enthusiastic about the inductive method than were the deductive groups about the deductive method. This could be due to an inappropriate amount of guidance by a teacher, which was later studied and mentioned by Prince & Felder (2006/2007) about how less guidance could affect the outcome of the student and cause them to be more resistant to learning the content. Koran (1971) studied individual differences in learning using an aptitude test and found that both inductive and deductive methods were equally effective when it came to the time required to teach the information and in promoting the transfer of the information. Additionally, Koran found that the inductive subjects made more errors on the assessment than the deductive group. Sakmyser's (1974) study suggested that a student's ability in reading and algebra helped play an important role in that student's success in either approach used. Students with higher reading scores performed better on the deductive model, while students with higher algebra scores performed better on the inductive model.

Multiple studies of the inductive vs. deductive approaches (Shaffer, 1989, Gollin, 1998, Erlam 2003, Takimoto, 2008, Owen, 2009, Vogel, Herron, Cole, & York, 2011, Mohmmed & Jaber, 2008) involved teaching a language rather than a science. While it doesn't add to the effects of the methods as they are taught in science, the model of approach is similar. Additionally, findings have differed from study to study, yielding different conclusions on which is better when comparing the effectiveness of the two models.

Shaffer (1989) found that there were no significant differences between the results of the two methods. However, the inductive method showed to be more successful when dealing with difficult concepts for all ability levels of learning. Additionally, Takimoto (2008) found that the inductive approach was more effective when using problem-solving tasks and structured-input tasks. Vogel et al. (2011) also studied the effects of deductive and guided inductive approaches on short- and long-term learning and found that although students stated that they preferred to be taught deductively, their short-term retention for the guided inductive approach yielded a significant positive effect. All three pointed in the direction that inductive is more effective than deductive, making reference to the fact that students were being more active in their learning which attributes to the higher-order of thinking for the inductive model of approach.

Erlam (2003), Mohammed et al. (2008), and Owen (2009) all had different findings. All three studies argued that the deductive approach was much more effective than the inductive. Erlam (2003) studied the effectiveness of the two types of instruction by measuring both comprehension and production of the language, paying particular attention to certain features in the French language on 14 year old students. No discussion as to why deductive was better was made, rather that it just was and further research would be needed. Mohammed et al. (2008) studied the effects of each approach and the interaction between the approach and the content in adults. The deductive approach was suggested to be better due to the cognitive ability of the adults to understand abstract concepts and handle a faster-paced instruction. Owen (2009) studied the effects of the two approaches with the production, generalization, and retention of the novel verb morphemes by school-age children with language impairment. However, Owen still recommended using a mixture of inductive and deductive teaching techniques.

In recent years, a few studies (Yuruk, 2000, Narjaikawe, Emarat, Arayathanitkul, & Cowie, 2009) were found that dealt with the study of teaching methods in science-related education. Yuruk (2000) studied the comparison of the content sequence on students' achievement, attitudes, and academic self-concept and found that students in the inductive content sequence group achieved higher than the students in the deductive content sequence group. It was suggested that this could be due to the inductive content sequence being more effective in establishing relationships between concepts in students' cognitive structures. Narjaikawe et al. (2009) performed a three year study to investigate the impact on student motivation and understanding each year, starting with the deductive approach for the first two years and the third year using the inductive approach. Narjaikawe et al. found that most students had a positive perception on the inductive approach, while some still preferred the traditional method. Students also were more active in the classroom for the inductive approach as compared to the previous years.

The two approaches have proven to both be effective in previous studies. However, Prince & Felder (2006/2007) argued that inductive methods of approach promoted a deeper understanding of the content, as opposed to just memorizing the information for a period of time.

Learning with the inductive model can have positive feedback, but can create hostility from the students when taught without a correct amount of guidance. As an initial educator, it is important to practice different strategies, such as the inductive and deductive models of approach to give students instructional alternatives.

Methodology

Research Design

A nonequivalent group quasi-experimental design was used, administering a pretest at the beginning of each unit and posttest at the end of each unit. Two treatments were administered within each unit. The first and second treatments were administered to compare the groups. The third and fourth treatments were administered to compare the models of approach between the classes. Semester exams were compared to determine the equivalency of the two sections.

The classroom schedule was a modified block schedule, consisting of an 89 minute class period, each class meeting every other day. Within a class period, the students had a reflection of the previous day, a description of daily objectives, and then either a lecture and homework, or a laboratory experiment and discussion. This was exposure to the material in at least four different ways to make it meaningful to the students (Marzano, 2000).

The study consisted of inductive and deductive models of approach in a high school chemistry classroom to compare the effectiveness of the two instructional approaches on students' learning. The deductive model (X_1) provided students with a lecture and homework day on day 1, and a laboratory experiment and discussion on day 2. The inductive model (X_2) provided students with a laboratory experiment and discussion on day 1, followed by a lecture and homework on day 2. Due to having class every other day, alternating both classes, all treatments began on days when the first class was on a Monday or Tuesday. This made the time between the two exposures to the material not greater than two days (Marzano, 2000).

On the days with lecture and homework, students took notes and asked questions based from the PowerPoint presentation. Lectures were approximately 35-40 minute presentations, which included modeling and guided practice with math problems. Homework was assigned in class and students worked on their homework in their cooperative groups, asked questions, and then were given answers by the end of class with some extra time available for additional practice if necessary.

On the days that consisted of laboratory experiments and discussion, students worked in cooperative groups to answer pre-laboratory questions, performed the laboratory experiment, processed observations and data during classroom discussions, and answered post-laboratory questions. All laboratory experiments had questions at the beginning to help connect previous knowledge and form a hypothesis and questions at the end for reflection on what was seen and help in processing the information. Laboratory techniques were modeled for the students prior to the experiment and different aspects were mentioned of what to pay attention to throughout the experiment.

Sampling

The study was conducted with eleven students, ranging in age from 16-18 years old, from two different classes. Students were given the opportunity the semester before the 2012-13 school year began to select classes they wish to take. Schedules were made accordingly based on their performance in their classes by the end of the year and the number able to take the course.

The course chosen for the study was Advanced Chemistry, which is a second-year Chemistry course aimed at studying the different branches of chemistry more in-depth. The second semester consisted of the topics of Molecular Geometry, Solutions, Equilibrium, Solubility and Precipitation, and Acids and Bases. The topics of Equilibrium and Solubility and Precipitation are chosen due to the relationship with the equilibrium constant, the calculations for the constant, and the macroscopic visuals through chemistry phenomenon.

Table 1

Treatment of Each Group				
Group	Treatment 1	Treatment 2	Treatment 3	Treatment 4
1 (n=4)	Deductive	Inductive	Inductive	Deductive
2 (n=7)	Deductive	Inductive	Deductive	Inductive

Variables

The independent variable of the study was the model of approach, deductive and inductive, that was used in the two classes. The organization of how the students received the treatment can be seen in Table 1. The dependent variable was the outcome on the unit test. The teacher was in his third year of teaching Chemistry. The classroom procedures listed for both models of approach listed above were practiced throughout the school year for two reasons:

1. To give the students practice with the inductive model so that there would be less resistance than when first being introduced to it (Prince & Felder, 2006/2007).
2. To help the teacher gain better knowledge of the class in determining what would be the correct amount of scaffolding to help administer throughout each lesson.

Procedures

Treatment 1. The first treatment dealt with the understanding of and calculations with the equilibrium constant. Both groups were given a pretest (O_1) at the beginning of the unit, performed the deductive (X_1) method, and took a unit test (O_2). On day 1, the students were given a lecture on the equilibrium constant, with mathematical problems that were modeled for them. Homework was given in class and the students worked on it in their groups. Answers were provided at the end of the class. On day two, the students performed the laboratory experiment *Finding a Constant, K_c* (Holmquist, D., Randall, J., & Volz, D., 2007). A discussion of the results was held and students processed the data with calculations to obtain the equilibrium constant value for four trials. A diagram of the experimental procedure is provided below:

N_1: O_1 X_1 O_2

N_2: O_1 X_1 O_2

Treatment 2. The second treatment dealt with Le Châtelier's Principle. Both groups were given a pretest (O_1) at the beginning of the unit, performed the inductive (X_2) method, and took a unit test (O_2). On day 1, the students performed the laboratory experiment, *Le Châtelier's Principle Lab*. The students discussed their results as a class to ensure all of the correct observations were made. They processed their results within their cooperative groups and formed a hypothesis of Le Châtelier's principle. On day 2, students were given a lecture on Le Châtelier's principle and were given homework to work on the remainder of class. The concept of the principle was also connected back to the big idea of the equilibrium constant. A diagram of the experimental procedure is provided below:

N_1: O_1 X_2 O_2

N_2: O_1 X_2 O_2

Treatment 3. The third treatment dealt with precipitations and dissolution. In this treatment, the first group performed the laboratory experiment, *Precipitation Lab*, on day 1 to form a hypothesis on the ideas of precipitation, spectator ions, and net ionic equations. They then came up with an explanation of precipitation at the atomic level based on macroscopic observations. The next day, the students were given a lecture on dissolution, precipitation, and net ionic equations and provided homework to aid the lecture. The second group was given the lecture and homework on dissolution, precipitation, and net ionic equations on the first day. Day 2 consisted of performing the laboratory experiment, *Precipitation Lab*, to confirm the atomic explanation through macroscopic observations of dissolution and precipitation. Both groups were provided the same pretest at the beginning of the unit and posttest at the end of the unit. A diagram of the experimental procedure is provided below:

N_1: O_1 X_2 O_2

N_2: O_1 X_1 O_2

Treatment 4. The fourth treatment dealt with solubility rules. In this treatment, the first group was given a lecture with the solubility rules followed by homework to practice the solubility rules on day 1. On day 2, they were given the laboratory experiment, *Solubility Rules Lab*, to predict which chemical mixtures would precipitate and then confirmed the solubility rules given to them the previous class by performing the experiment. On day 1, the second group performed the laboratory experiment, *Solubility Rules Lab*. They discussed the results as a class, and attempted to form the solubility rules in their cooperative learning groups. On day 2, the second group was given a lecture that either confirmed or nullified their hypothesis of the solubility rules. This was followed by homework to practice the solubility rules. The previous knowledge of net ionic equations and spectator ions was connected with the solubility rules. Both groups were provided the same pretest at the beginning of the unit and posttest at the end of the unit. A diagram of the experimental procedure is provided below:

N_1: O_1 X_1 O_2

N_2: O_1 X_2 O_2

Table 2

Scoring Scheme	
Points	Justification
0 points	Nothing is mentioned/Answer is fully incorrect
1 point	Answer is partially correct
2 points	Answer is completely correct

Data Collection Processes

Pretests. Short-answer questions and calculation problems were given at the beginning of each unit to determine how much information students knew prior to each treatment. The questions and problems were taken from the current chapters in the textbook used in the classroom. The scoring of the pretest was based on a 0-2 scoring (as shown in Table 2) for assessing previous knowledge before the unit began. The pretests are available in the Appendices.

Posttests. Specific questions that connected to the treatments within the unit were sampled as key questions. They were based on both laboratory experiences (data analysis and observations) and lecture connections (mathematical calculations and conceptual questions). Tests consisted of multiple choice questions, short answer, and calculations. Multiple choice questions were scored as a 0 or 2 (No or Yes, respectively) based on whether the answer was correct or incorrect. Short answer and mathematical calculations were based on a 0-2 scoring (as shown in Table 2) for assessing knowledge. Overall test scores were recorded and measured over time to determine if trends in either group occurred. Scores were compared between both groups and between pretests and posttests to determine if growth was made.

Final Exams. Comparisons were made between the first and second semester final exam scores. The exams were used to help limit the internal validity threat of selection of the study.

The scores helped determine if any prior differences between the groups may have affected the outcome of the study.

Data Analysis

Averages, standard deviations, and standard errors were calculated on all questions and overall scores. Overall scores for students were put in a graph and table that indicated their pretest average (0-2) and posttest average (0-2) on all four treatments. The treatments were compared between both groups to determine the effectiveness each of the two models of approach had on the students by using standard error differences and a t-test between the pretests and the posttests of each group.

Ethical Considerations

The risks within the study were no different than what the subjects would experience on a typical school day. The subjects were given a parental consent form to be read, signed, and returned to be involved in the study. The consent forms and data were kept in secure locations, only accessible to the researcher. Names were removed from the data and numbers were assigned to each student. Both the consent forms and actual data were separated so connections could not be made.

Results

The means, standard deviations, and standard errors for the pretest and posttest average scores are given in Table 3. The difference between the pretest and posttest scores (gain) with the uncertainty was calculated and put in Table 3. The means of the group were put into a bar graph as shown in Figure 1. The pretests agreed with each other so a Reliability-Corrected ANCOVA was not needed. A t-test was administered between the two groups for each pretest and posttest in all four treatments. The p-values are given in Table 4. The sample size was low, so standard error comparisons between groups for each pretest and posttest were also calculated to determine if the scores were within one standard error of each other. The standard error difference values of the pretests and posttests are found in Table 4.

Treatment 1

In treatment 1, both groups were taught using the deductive model of approach. Both groups had an average value of zero on the pretest. Comparison values could not be calculated because values cannot be divided by zero, but are accepted as equal due to both groups not having any previous knowledge of the content in the study. In the posttest, groups 1 and 2 had an average test score value of 1.55 ± 0.10 and 1.53 ± 0.10, respectively. Both groups had a positive increase from their pretest to their posttest. The two test values agree with each other. ($p = 0.89$; and the means were $= 0.21\ \sigma$ apart).

Treatment 2

In treatment 2, both groups were taught using the inductive model of approach. Both groups had an average value of zero on the pretest. Comparison values could not be calculated because values cannot be divided by zero, but are accepted as equal due both groups not having any previous knowledge of the content in the study. On the posttest, group 1 had an average test score value of 0.70 ± 0.18 and group 2 had an average test score value of 1.01 ± 0.17. Both groups

Table 3

Descriptive Statistics										
Treatment 1										
	Pretest				*Posttest*					
Group	*N*	*Mean*	*SD*	*SE*	*N*	*Mean*	*SD*	*SE*	*Gain*	*SE*
1	4	0	0	0	4	1.55	0.21	0.10	1.55	0.10
2	7	0	0	0	7	1.53	0.27	0.10	1.53	0.10
Treatment 2										
	Pretest				*Posttest*					
Group	*N*	*Mean*	*SD*	*SE*	*N*	*Mean*	*SD*	*SE*	*Gain*	*SE*
1	4	0	0	0	4	0.70	0.36	0.18	0.70	0.18
2	7	0	0	0	7	1.01	0.45	0.17	1.01	0.17
Treatment 3										
	Pretest				*Posttest*					
Group	*N*	*Mean*	*SD*	*SE*	*N*	*Mean*	*SD*	*SE*	*Gain*	*SE*
1	4	0.59	0.42	0.21	4	1.59	0.19	0.10	1.00	0.36
2	7	0.52	0.50	0.19	7	1.75	0.15	0.06	1.23	0.45
Treatment 4										
	Pretest				*Posttest*					
Group	*N*	*Mean*	*SD*	*SE*	*N*	*Mean*	*SD*	*SE*	*Gain*	*SE*
1	4	0	0	0	4	1.69	0.39	0.19	1.69	0.19
2	7	0.10	0.25	0.10	7	1.63	0.60	0.23	1.53	0.21

did have a positive increase from their pretest to their posttest. The p-value was greater than 0.05 ($p = 0.24$) showing that the two classes agreed with each other. However, the two scores were 1.76 σ apart, so there were no significant differences between the two classes for the inductive model. Both classes had a pretest score of zero, so a reliability correction is not needed.

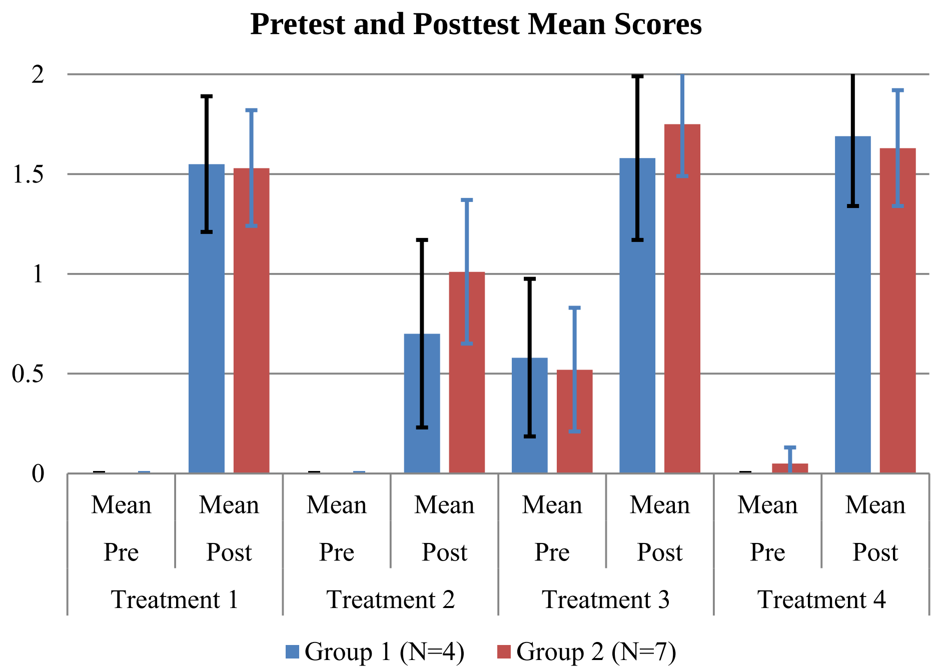

Figure 1: The pretest and posttest mean scores for all the treatments.

Treatment 3

In treatment 3, group 1 was taught using the inductive model of approach, while group 2 was taught using the deductive model of approach. On the pretest, group 1and group 2 had an average test score value of 0.59±0.21 and 0.52±0.19, respectively. The two values agreed with each other ($p = 0.83$, S.E. = 0.15). On the posttest, group 1 and group 2 had an average test score value of 1.58±0.10 and 1.75±0.06, respectively. Both groups had a positive increase from their pretest to their posttest. The two posttest average test score values agreed with each other according to the t-test ($p = 0.35$). The two posttest scores were more than one standard error apart (S.E. = 1.70 σ), but did not differ enough to indicate a statistically meaningful difference. The improvement that both groups made from the pretest to the posttest agreed with each other (0.50 σ apart).

Table 4

Inferential Statistics					
	Pretest		*Posttest*		*Gain*
	# of σ apart	*p*	*# of σ apart*	*p*	*# of σ apart*
Treatment 1	–	–	0.21	0.89	0.21
Treatment 2	–	–	1.76	0.24	1.76
Treatment 3	0.30	0.83	1.70	0.20	0.50
Treatment 4	1.00	0.31	0.28	0.83	0.75
Final Exam	0.32	0.81	–	–	–

Treatment 4

In treatment 4, group 1 was taught using the deductive model of approach, while group 2 was taught using the inductive model of approach. On the pretest, group 1 had an average value of zero on the pretest, while Group 2 had an average score 0.10±0.10. On the posttest, group 1 and group 2 had an average test score value of 1.55±0.68 and 1.53±0.78. Both groups had a positive increase from their pretest to their posttest. The t-test (p = 0.83), number of sigma between the pretest and posttest (0.28 σ), and the standard error for the gain from the pretest to posttest scores for both groups (0.75 σ apart) all agreed with each other.

Final Exams

The final exams for the first and second semester were compared. The scores were 0.31 σ apart and the p-value from a t-test was 0.81.

Analysis

The first and second final exam scores were compared. It was determined that there were no prior differences between the groups that affected the outcome of the study. In treatments 1 and 2, both groups used the same approach (deductive and inductive, respectively). This was performed to determine the equivalency among the two groups. In both treatments, both groups agreed with each other (0.21 σ and 1.76 σ apart, respectively)

All of the t-tests for the pretests and posttests indicate that the two groups' mean test scores agree with each other ($p = 0.89$, $p = 0.24$, $p = 0.20$, $p = 0.83$, respectively). The posttests from treatments 1 through 4 agreed with each other (0.21 σ, 1.76 σ, 1.70 σ, and 0.28 σ apart, respectively). According to Figure 1, the deductive model of approach scored higher in treatments 3 and 4. However, treatments 3 and 4 both showed that the average test score increased within one sigma of each other. The comparisons of the standard errors agreeing with each other suggest that both the deductive and inductive models of approach are equivalent to each other, just as Krumboltz et al. (1965), Koran (1971), and Shaffer (1989) had found.

The difference between the pretest and posttest (gain) was used to help determine the effectiveness of the two programs. It was calculated and the standard errors were used to propagate the uncertainty for both groups. The gains for treatments 1 and 2 were the same as the posttest due to students having no previous knowledge of the content (pretest scores averaging 0). In treatments 3 and 4, students had some previous knowledge of the material, so the gain was calculated and accounted for (0.50 σ and 0.75 σ apart, respectively). This lowered the difference in sigma, suggesting that the deductive and inductive models of approach were even more equivalent within each class.

The widest gap between average posttest scores for both groups 1 and 2 was in treatment 2 (0.70 ± 0.18 and 1.01 ± 0.17, respectively), but the difference is not statistically significant. The same test and treatment (inductive) was provided for the students, but group 2, on average, scored higher. Theoretically, they should be the same. This could account for having a small sample size in both groups (N_1=4, N_2=7) or the experience level of the student. Although Prince & Felder (2006, 2007) praised the inductive method, they also emphasized the problems that can arise when not taught with an adequate amount of scaffolding. Teachers need to know how to effectively teach to diverse students, so different teaching methods and techniques are imperative to have in the classroom. Usak et al. (2011) emphasized that teachers need to know how to teach their content rather than just knowing how to teach in general. The level of scaffolding needed is different because the level of difficulty and common misconceptions are different among the different topics.

The inductive model of approach has been becoming more common to use in today's classrooms (Prince & Felder, 2006/2007, Wang, 2010, Narjaikaew et al, 2009, Chiappette et al. 1998). It has been shown to make the content more meaningful to the students (Prince & Felder, 2006/2007, Gollin, 1998, Narjaikawe, Emarat, Arayathanitkul, & Cowie, 2009) and gives students greater confidence in their problem-solving skills (Wang, 2010, Prince & Felder, 2007). This does not discredit the deductive model, which still is a common and concise way of teaching science. Both approaches are valid techniques. Teachers should consider the needs of the students and the level of difficulty when choosing how they are going to teach material.

The data in the treatments indicate that the null hypothesis would be accepted, that there is no difference in the effectiveness between the inductive and deductive model. However, due to a small sample size, no definitive conclusion can be made. Further studies should be made to help determine the effectiveness in content specific areas. A bigger sample size should be studied as well. Additionally, to limit the threat of construct validity, the same questions should be used in both the pretest and posttest, as well as limiting the time between the pretest and posttest with respect to the treatment (i.e. pretest and posttest not administered at the beginning and end of the unit, but rather before and after each lesson) as well as practicing the models of approach for different content areas more frequently to determine generalizations among the different models that work best. This will come with more teaching experience.

Summary

This was an exploratory study aimed at studying the effectiveness of deductive and inductive teaching approaches. According to the data, the null hypothesis was correct and the two approaches appeared to be equivalent. However, with the sample size being so low (N_1=4, N_2=7), a definitive conclusion between the effectiveness between the two models of approach cannot be made. Further investigation with a larger sample would have to be performed. One implication for the classroom from this study is that teachers should practice different approaches in an effort to diversify instructional strategies to reach different learners' needs.

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APPENDIX A

Consent Form

Subject Consent Form for Participation of Human Subjects in Research
University of Wisconsin-River Falls

Project Title: Outcomes with Deductive vs. Inductive Approaches in Chemistry
Researcher: Christopher R. Smith, Masters of Science Education, 920/648-2355 *322

Description: The purpose of this research is to determine if the order of lecture and lab is related to students' ability to comprehend content in Chemistry. It will take place during second semester of the 2012-13 school year. The research will involve two approaches to learning the material: deductive and inductive.

For the deductive approach, students will approach the material with a "top-down" method and learn the content first in lecture and then prove it in the lab. For our inductive approach, we will approach the material with a "bottoms-up" method and make observations in lab, and work towards identifying the theory and proving it in lecture. Both methods will include a discussion to help connect the knowledge learned in lab and lecture. All students will be doing the same assignments and activities regardless of participation.

The results of each individual's participation will be strictly confidential. The results of your son/daughter's participation will be recorded as a number. No names or individual identifying information will be maintained. The results that will be studied will include classroom test scores, individual questions, and the final exam scores for both first and second semester. Consent to have your child participate in this study strictly allows for permission to have data collected about their performance based on the approach. By choosing not to give consent, your child will not have data collected about their performance, but will still have to do the same assignments and activities.

The risks are minimal for your son/daughter. Students in the other section may approach the content differently. This could cause confusion with discussion among peers. However, everyone will receive the same lecture notes, labs, and main points in discussion. Additional help will still be available if needed or wanted. All students are encouraged to come in for help if they have questions. The course will cover the same content and lab safety will continue to be practiced throughout the duration of the year.

The overall nature of the study will be explained after the semester is over. A summary report and explanation of the results will be made available to you when the study is completed if you so request.

Authorization: I have read the above and understand the nature of this study and agree to let my son/daughter participate. I understand that by agreeing to let them participate in this study, I have not waived any legal or human rights. I also understand that I have the **right to refuse to participate** and that **my right to withdraw from participation at any time during the study will be respected with no coercion or prejudice.**

If you have concerns about how you were treated in this study, please contact:

Dr. Molly Van Wagner
Director of Grants and Research, 104 North Hall, UW-River Falls
River Falls, WI 54022 telephone: 715/425-3195

This project has been approved by the UW-River Falls Institutional Research Board for the Protection of Human Subjects, protocol # H2013-W002.

______________________	______________________	__________
Parent/Guardian Name	Parent/Guardian Signature	Date

APPENDIX B

Proposal Approval Letter

APPENDIX C

Principal Letter of Approval

APPENDIX D

Equilibrium Pretest

Equilibrium Pre-Test

Advanced Chemistry

1. Is a reaction able to go backwards? Explain.

2. How you determine if dynamic equilibrium is reached graphically?

3. State the difference between homogeneous and heterogeneous equilibrium.

4. Determine the Equilibrium expression from the following chemical reactions:
   a. $2\ NO_2\ (g) \leftrightarrow N_2O_4\ (g)$
   b. $2\ CO\ (g) + O_2\ (g) \leftrightarrow 2\ CO_2\ (g)$
   c. $2\ SO_2\ (g) + O_2\ (g) \leftrightarrow 2\ SO_3\ (g)$
   d. $NH_4Cl\ (s) \leftrightarrow NH_3\ (g) + HCl\ (g)$

5. Calculate the equilibrium constant (K_{eq}) for the following reaction if you begin with $[NO_2] = 0.0200$ and $[N_2O_4] = 0.0$, and end with $[NO_2] = 0.0172$ and $[N_2O_4] = 0.00140$.

   $$2\ NO_2\ (g) \leftrightarrow N_2O_4\ (g)$$

6. What does a reaction quotient do with respect to equilibrium?

7. In your own words, describe Le Châtelier's Principle. Make reference to how changing the concentration, pressure, and temperature affect a reaction at equilibrium.

8. Describe the Haber Process with reference to Le Châtelier's Principle.

APPENDIX E

Le Châtelier's Principle Lab

Le Châtelier's Principle Lab

Objective: To qualitatively determine what a stress on equilibrium is and how it is relieved.

Introduction:

Le Châtelier's principle states that equilibrium will attempt to shift in a direction that will counteract a stress that is placed on it. Make a prediction about what this means by answering the following questions:

1. If you increase the concentration of a reactant or a product in a chemical equilibrium, what do you think will happen to the equilibrium?

2. If you decrease the concentration of a reactant or a product, what do you think will happen to the equilibrium?

On the following pages, you will find a brief explanation with the balanced chemical equations and some previous knowledge explaining the reaction. Follow the procedure for Parts 1, 2, and 3 and fill in your Observations in the data tables for each well. Record qualitatively what occurs after each change.

Safety: Wear eye protection at all times. Solutions of acid and base are corrosive to eye tissue.

Materials:

24 well plate
Bromothymol blue indicator
0.10 M HCl
0.10 M $NaOH$
0.10 M $Fe(NO_3)_3$
0.01 M $KSCN$
0.1 M $CoCl_2$
0.1 M $AgNO_3$
Concentrated HCl (in the fumehood)
Distilled water

Conclusion:

Organize your data from the matrix from all three parts. Study your results and draw conclusions about each section and how it relates to the objective and the changes that occurred in each.

Part 1: Acid-Base indicators

The behavior of the dye, bromothymol blue, in acid and basic solutions is an example of an equilibrium system. We will represent bromothymol blue with the formula, HIn. In water solution the reaction that takes place is:

$$\mathbf{HIn\ (aq) \rightleftharpoons H^{+}\ (aq) + In^{-}\ (aq)}$$

We will also want to consider this equilibrium:

$$\mathbf{H^{+}\ (aq) + OH^{-}\ (aq) \rightleftharpoons H_2O}$$

Procedure:

1. Place your 24 well plate on a white background. Add 3 drops of distilled water to each of three wells in the well plate.
2. Add 1 drop of bromothymol blue solution to each of the wells. View the colors against a white background. Note and record the color. Add 1 drop of 0.10 M HCl to the first well. Mix. Note and record any color change.
3. Add 1 drop of 0.10 M NaOH to the third well and mix it. Note and record any change.
4. Add 0.10 M NaOH, one drop at a time, to the first well, with mixing after each addition, until you notice any change. Add 0.10 M HCl, one drop at a time, to the third well with mixing after each addition, until you notice any change. Note and record all changes.
5. Try to reverse the colors of the first and the third wells again. Record your procedure and results.

Data/Observations:

Part 1:

Well 1	Well 2	Well 3

Part 2: **Iron (III) thiocyanate Equilibrium**

Iron (III) nitrate solution reacting with a potassium thiocyanate solution also is involved in an equilibrium reaction.

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$$

Also important are:

$$Fe^{3+}(aq) + 3OH^{-}(aq) \rightleftharpoons Fe(OH)_3$$

$$H^{+}(aq) + OH^{-}(aq) \rightleftharpoons H_2O$$

Procedure:

1. Place your 24 well plate onto a white background again. Place 1 drop of 0.01 M KSCN into each of 5 wells. Add one drop of 0.10 M $Fe(NO_3)_3$ to each well.
2. Make no additions to the first well, but make the following additions to the subsequent wells:
   a. To the second well, add one drop of 0.10 M $Fe(NO_3)_3$.
   b. To the third well, add one drop of 0.01 M KSCN.
   c. To the fourth well, add one drop of 0.1 M NaOH. Stir with a toothpick. Note any changes.
   d. To the fifth well, add one drop of 0.1 M NaOH. Stir with a toothpick. Then add 1 drop 0.1 M HCl.
3. Stir and note any changes.
4. Wait a few minutes. Reexamine the fourth and fifth wells. Note any changes. Add 1 drop of 0.01 M KSCN to each. Note any changes.

Data/Observations:

Part 2:

Well 1	Well 2	Well 3	Well 4	Well 5

Part 3: **Cobalt (II) chloride equilibrium** Cobalt (II) chloride solution with water also produces an equilibrium reaction with the water. The cobalt (II) and chloride ion will dissociate, allowing the water to react with the ions differently:

$$Co(H_2O)_6^{2+}\ (aq) + 4\ Cl^-\ (aq) \rightleftharpoons CoCl_4^{2-}\ (aq) + 6\ H_2O\ (l)$$
pink blue

Also important are:

$$HCl \rightleftharpoons H^+\ (aq) + Cl^-\ (aq)$$

$$Ag^+\ (aq) + Cl^-\ (aq) \rightleftharpoons AgCl$$

Procedure:

1. Using the 24 well plate, put 5 drops of 0.1 M $CoCl_2$ in each of four wells in the top row of the plate. Use the first well as a control. The ion present is $Co(H_2O)_6^{2+}$
2. Go to the fume hood and **have your teacher add the concentrated HCl drop wise** to the second, third, and fourth wells in the row until a color change occurs. Use the fourth well as a basis for comparison. The ion present is $CoCl_4^{2-}$ **DO NOT TAKE THE CONCENTRATED M HYDROCHLORIC ACID DROPPER FROM THE FUME HOOD.**
3. Return to your lab station. Add distilled water drop wise to the second well and observe what happens.
4. Add 0.1 M $AgNO_3$ to the third well until no further color change occurs

Data/Observations:

Part 3:

Well 1	Well 2	Well 3	Well 4

APPENDIX F

Equilibrium Test

Name:

Equilibrium Test

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Advanced Chemistry

Directions: For each question, choose the answer you consider to be the best and indicate your choice by circling the letter of the correct answer.

1. Chemical equilibrium exists when
   - **A.** no processes occur.
   - **B.** two similar forward processes occur.
   - **C.** two opposing processes occur at different rates.
   - **D.** two opposing processes occur at the same rate.

2. Any chemical reaction in which the products can regenerate the reactants is called a(n)
   - **A.** double-replacement reaction.
   - **B.** single-replacement reaction.
   - **C.** reversible reaction.
   - **D.** irreversible reaction.

3. At chemical equilibrium, which of the following is always true of the concentrations of reactants and products?
   - **A.** They are constant.
   - **B.** They are equal.
   - **C.** Reactant concentration is zero.
   - **D.** Product concentration is zero.

4. The equilibrium constant provides information on all of the following except the
   - **A.** relative concentrations of reactants and products.
   - **B.** equilibrium position.
   - **C.** extent to which reaction proceeds to completion.
   - **D.** time required to reach equilibrium.

5. The statement "Equilibrium lies to the left" means that, at equilibrium,
   - **A.** product concentrations are much greater than reactant concentrations.
   - **B.** reactant concentrations are much greater than product concentrations.
   - **C.** reactant concentrations equal product concentrations.
   - **D.** no reactants are present.

6. When equilibrium lies to the right, K_{eq} is
   - **A.** approximately 1.
   - **B.** negative.
   - **C.** much greater than 1.
   - **D.** nearly zero.

7. A heterogeneous equilibrium is one in which the substances are
   - **A.** at different temperatures.
   - **B.** unevenly mixed.
   - **C.** of different concentrations.
   - **D.** in different states.

/7

8. The reaction quotient is used to determine if a reaction
   - A. is at equilibrium.
   - B. is reversible.
   - C. occurs rapidly.
   - D. releases heat.

9. If a stress is imposed on a system at equilibrium, the equilibrium position will always
   - A. remain the same.
   - B. shift to favor products.
   - C. shift to increase the stress.
   - D. shift to reduce the stress.

10. A change in which of the following affects the value of the equilibrium constant?
    - A. concentration
    - B. temperature
    - C. pressure
    - D. none of the above

11. In the Haber process for the synthesis of ammonia, NH_3 (equation shown below), what effects does the catalyst have?

$$N_2\,(g) + 3\,H_2\,(g) \leftrightarrow 2\,NH_3\,(g)$$

	Rate of formation of $NH_3(g)$	Amount of $NH_3(g)$ formed
A.	Increases	Increases
B.	Increases	Decreases
C.	Increases	No change
D.	No change	Increases

12. Which changes cause an increase in the equilibrium yield of SO_3 (g) in this reaction?

$$2\,SO_2\,(g) + O_2(g) \leftrightarrow 2\,SO_3\,(g) \qquad \Delta H° = -196\text{ kJ}$$

   I. increasing the pressure
   II. decreasing the temperature
   III. adding oxygen

   - A. I and II only
   - B. I and III only
   - C. II and III only
   - D. I, II and III

13. For the reaction below, at a certain temperature, the equilibrium concentrations are (in mol/L) $[H_2] = 0.30$, $[I_2] = 0.30$, $[HI] = 3.0$

$$H_2\,(g) + I_2\,(g) \leftrightarrow 2HI\,(g)$$

   What is the value of K_{eq}?
   - A. 5.0
   - B. 10
   - C. 15
   - D. 100

/6

14. What is the equilibrium constant expression for the reaction above?

$I_2(g) + 3\ Cl_2(g) \leftrightarrow 2\ ICl_3(g)$

A. $K_{eq} = \dfrac{[ICl_3]}{[I_2][Cl_2]}$

B. $K_{eq} = \dfrac{2[ICl_3]}{3[I_2][Cl_2]}$

C. $K_{eq} = \dfrac{2[ICl_3]}{[I_2] + 3[Cl_2]}$

D. $K_{eq} = \dfrac{[ICl_3]^2}{[I_2][Cl_2]^3}$

15. For a gaseous reaction, the equilibrium constant expression is:

$$K_{eq} = \frac{[O_2]^5[NH_3]^4}{[NO]^4[H_2O]^6}$$

Which equation corresponds to this equilibrium expression?

A. $4\ NH_3 + 5\ O_2 \leftrightarrow 4\ NO + 6\ H_2O$
B. $4\ NO + 6\ H_2O \leftrightarrow 4\ NH_3 + 5\ O_2$
C. $8\ NH_3 + 10\ O_2 \leftrightarrow 8\ NO + 12\ H_2O$
D. $2\ NO + 3\ H_2O \leftrightarrow 2\ NH_3 + 5/2\ O_2$

16. Which changes will shift the position of equilibrium to the right in the following reaction?

$$2\ CO_{2\,(g)} \leftrightarrow 2\ CO_{(g)} + O_{2\,(g)}$$

I. Adding a catalyst
II. Decreasing the oxygen concentration
III. Increasing the volume of the container

A. I and II only
B. I and III only
C. II and III only
D. I, II, and III

17. What changes occur when the temperature is increased in the following reaction at equilibrium?

$Br_{2\,(g)} + Cl_{2\,(g)} \leftrightarrow 2\ BrCl_{(g)}$ $\quad \Delta H° = +14\ kJ/mol$

	Position of equilibrium	Value of equilibrium constant
A.	Shifts towards the reactants	Decreases
B.	Shifts towards the reactants	Increases
C.	Shifts towards the products	Decreases
D.	Shifts towards the products	Increases

/4

18. The manufacture of sulfur trioxide can be represented by the equation below.

$$2\ SO_2\ (g) + O_2\ (g) \leftrightarrow 2\ SO_3\ (g) \qquad \Delta H° = -197\ kJ/mol$$

What happens when a catalyst is added to an equilibrium mixture from this reaction?

A. The rate of the forward reaction increases and that of the reverse reaction decreases.
B. The rates of both forward and reverse reactions increase.
C. The value of $\Delta H°$ increases.
D. The yield of sulfur trioxide increases.

19. The equation for a reaction used in the manufacture of nitric acid is:

$$4\ NH_3\ (g) + 5\ O_2\ (g) \leftrightarrow 4\ NO(g) + 6\ H_2O(g) \quad \Delta H° = -900\ kJ$$

Which changes occur when the temperature of the reaction is increased?

	Position of equilibrium	Value of K_{eq}
A.	shifts to the left	increases
B.	shifts to the left	decreases
C.	shifts to the right	increases
D.	shifts to the right	decreases

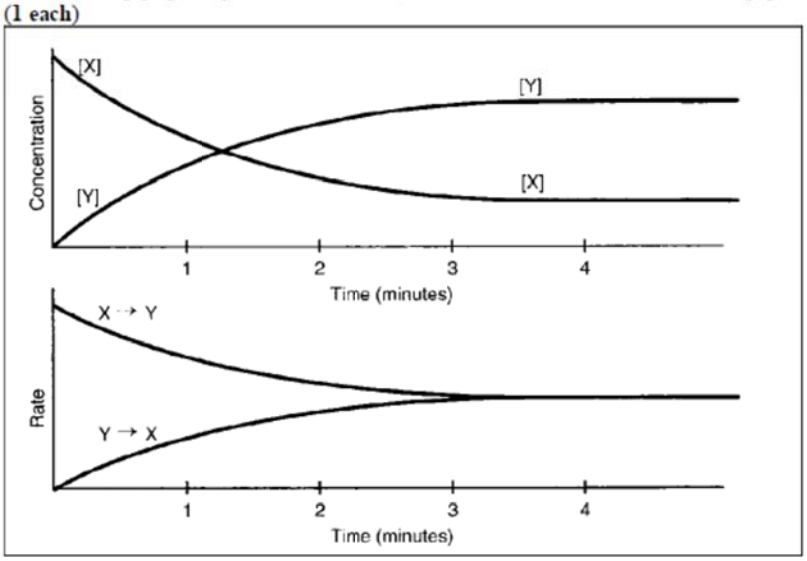
20. Which of the following equilibria would **not** be affected by pressure changes at constant temperature?

A. $4\ HCl\ (g) + O_2\ (g) \leftrightarrow 2\ H_2O\ (g) + 2\ Cl_2\ (g)$
B. $CO\ (g) + H_2O\ (g) \leftrightarrow H_2\ (g) + CO_2\ (g)$
C. $C_2H_4\ (g) + H_2O\ (g) \leftrightarrow C_2H_5OH\ (g)$
D. $PF_3Cl_2\ (g) \leftrightarrow PF_3\ (g) + Cl_2\ (g)$

/3

Directions: Answer all of the questions in the spaces provided.

21. The following graphs represent the reaction, X↔Y. Use it to answer the following questions. (**1 each**)



A. What substances are present initially, when time = 0 minutes?

B. At what time is equilibrium reached?

C. How do the rates of the forward and reverse reactions compare at equilibrium?

D. Does the equilibrium lie to the right or to the left?

E. If the value of Q were computed at time = 1 minute, how would it compare to the value of K_{eq}?

F. If the value of Q were computed at time = 4 minutes, how would it compare to the value of K_{eq}?

/6

22. Given the following reaction:

$$2\,NO\,(g) \leftrightarrow N_2\,(g) + O_2\,(g) \qquad K_{eq} = 2.5 \times 10^3.$$

Calculate the concentration of N_2 at equilibrium, if the concentration of NO is 5.1×10^{-5} *M* and that the concentration of O_2 (*g*) is 2.3×10^{-1} *M*. **(3)**

23. Given the reaction:

$$2\,NO\,(g) + Cl_2\,(g) \leftrightarrow 2\,NOCl\,(g)$$

Calculate the equilibrium constant if the equilibrium concentrations are: [NO] = 5.6×10^{-1} *M*, [Cl_2] = 6.0×10^{-1} *M*, and [NOCl] = 1.5 *M* **(3)**

24. Given the equation OF_2 (*g*) + H_2O (*g*) ↔ O_2 (*g*) + 2 HF (*g*) $\Delta H = -318$ kJ, predict the direction of shift in the equilibrium position if:

A. OF_2 is added **(1)**

B. H_2O is removed **(1)**

C. pressure is increased **(1)**

D. temperature is lowered. **(1)**

/10

25. Given the following reaction:

$$H_2\,(g) + I_2\,(g) \leftrightarrow 2HI\,(g) \qquad K_{eq} = 4.73.$$

If a 2.0 L container holds 1 mole of H_2, 1 mole I_2, and 3.5 moles HI:

A. What is the value of the reaction quotient? **(3)**

B. Is the system at equilibrium? If not, in what direction will the reaction proceed? **(2)**

C. Calculate the final concentrations of the reaction when it reaches equilibrium. **(3)**

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APPENDIX G

Solubility and Precipitation Pretest

Solubility and Precipitates Pre-Test

Advanced Chemistry

1. What is dissolution? Give examples in a chemical equation with the following chemicals: AgCl, NaCl, and $CaCl_2$.

2. Write the expression for the solubility product for $Fe(OH)_3$, given the equation is:

$$Fe(OH)_3\ (s) \leftrightarrow Fe^{3+}\ (aq) + 3\ OH^-\ (aq)$$

3. At 25°C, the concentration of Pb^{2+} ions in a saturated solution of PbF_2 is 1.9×10^{-3} M. What is the value of K_{sp}?

4. What will be the equilibrium concentrations of the dissolved ions in a saturated solution of $Mg(OH)_2$ at 25°C? ($K_{sp} = 8.9 \times 10^{-12}$)

5. What is precipitation?

6. What are spectator ions?

7. What is the common-ion effect?

8. Circle the precipitate in the following reaction:

   a. $2\ KI\ (aq) + Pb(NO_3)_2\ (aq) \rightarrow PbI_2\ (s) + 2\ KNO_3\ (aq)$

   b. $AgNO_3\ (aq) + KBr\ (aq) \rightarrow AgBr\ (s) + KNO_3\ (aq)$

9. Write the complete ionic equation and net ionic equation for the following problems:

   a. $2\ KI\ (aq) + Pb(NO_3)_2\ (aq) \rightarrow PbI_2\ (s) + 2\ KNO_3\ (aq)$
      i. Complete Ionic Equation:

      ii. Net Ionic Equation:

   b. $AgNO_3\ (aq) + KBr\ (aq) \rightarrow AgBr\ (s) + KNO_3\ (aq)$
      i. Complete Ionic Equation:

      ii. Net Ionic Equation:

10. Predict the following products:

   a. ___ $Cu(NO_3)_2\ (aq)$ + ___ $NaOH\ (aq) \rightarrow$

   b. ___ $NaNO_3\ (aq)$ + ___ $HCl\ (aq) \rightarrow$

   c. ___ $Ba(NO_3)_2$ + ___ $K_2SO_4\ (aq) \rightarrow$

APPENDIX H

Precipitation Lab

Purpose: To investigate the formation of precipitates

Introduction: Life on earth depends up the fact that certain substances dissolve in other substances. We constantly deal with solutions. We enjoy soft drinks because dissolved carbon dioxide gives them effervescence. Fish can life in water because oxygen gas is dissolved in lakes and oceans. We grow and develop because nutrients dissolved in our blood can reach cells and tissues.

Water is the closest thing we have to a universal solvent. A salt is any compound which produces positive and negative charged particles when dissolved in water. Solutions occur when bonds are broken and reformed, involving changes in energy. Solution formation is most likely to happen when the solute and solvent have certain similar chemical properties.

If we collect enough data regarding the solubility of certain substances, especially salts or ionic compounds, we can formulate a set of rules or generalizations that help us predict whether or not certain compounds will form solutions.

Materials: Pipettes Toothpicks Well Plate Distilled Water

Set X Solutions (all 0.1 M): lead (II) nitrate, silver nitrate, copper (II) chloride, ion (III) chloride, calcium nitrate, barium chloride.

Set Y Solutions (all 0.1 M): ammonium sulfate, potassium carbonate, sodium hydroxide, potassium phosphate, potassium iodide.

Safety: Wear safety goggles. All chemicals are solutions and could harm and cause discomfort to your eyes if the chemical splashes into them.

Waste: All chemicals can be dumped in the waste bin. Wells with silver can be dumped in the silver waste. Wells with lead can be dumped in the lead waste.

Procedure:

1. Take eleven pipettes and label them, using the marking pen, with the chemical formula of the eleven solutions.
2. Being careful to use the correct pipette, place a few drops of lead (II nitrate ino one well of the reaction plate.
3. Being careful to use the correct pipette, add a few drops of ammonium nitrate into the well containing lead (II) nitrate and stir with a toothpick. If a solid forms, place an "X" through the box. If not, place an "–" through the box.
4. Repeat the process of adding a few drops of each of the remaining solutions in set Y. Dispose of the chemicals properly. Be sure to use a new toothpick each time to avoic contamination.
5. Repeat steps 2-4, but with silver nitrate, and then continue with all the other chemicals.

Data/Observations: Place an "X" through all boxes that a solid forms. Place an "–" if no reaction occurs.

		← Set X →					
		A	**B**	**C**	**D**	**E**	**F**
	Set Y ↓	**Lead (II) nitrate**	**Silver nitrate**	**Copper (II) chloride**	**Iron (III) chloride**	**Calcium nitrate**	**Barium chloride**
1	**Ammonium sulfate**						
2	**Potassium Carbonate**						
3	**Sodium Chromate**						
4	**Sodium Hydroxide**						
5	**Potassium phosphate**						
6	**Potassium Iodide**						

Processing: In the space provided below, give a depiction to help explain what is occurring at the atomic level.

Prediction	**Actual**

Conclusion: Wherever you have an "X" in your results table, fill in a line in the table below and on the next couple of pages. Identify the possible products. When you have the solubility rules, select the insoluble solid and then write a balanced net ionic equation. If there was no reaction, write NONE in the column heated "Insoluble Solid" and write NO REACTION in the column headed "Net Ionic Equation". Two examples (A1 and C1) are completed for you.

Combination	Possible Products	Insoluble Solid	Net Ionic Equation
A1	Ammonium nitrate Lead (II) sulftate	Lead (II) sulfate	$Pb^{2+}{}_{(aq)} + SO_4^{2-}{}_{(aq)} \rightarrow PbSO_4{}^{(s)}$
A2			
A3			
A4			
A5			
A6			
B1			
B2			
B3			
B4			
B5			
B6			

Combination	Possible Products	Insoluble Solid	Net Ionic Equation
C1	Ammonium chloride Copper (II) sulfate	NONE	NO REACTION
C2			
C3			
C4			
C5			
C6			
D1			
D2			
D3			
D4			
D5			
D6			

Combination	Possible Products	Insoluble Solid	Net Ionic Equation
E1			
E2			
E3			
E4			
E5			
E6			
F1			
F2			
F3			
F4			
F5			
F6			

APPENDIX I

Solubility Rules Lab (Inductive)

Solubility Rules Lab

Purpose: Use the solubility rules to predict which reaction will form a precipitate.

Introduction: A precipitation reaction is when two solutions are mixed and a precipitate forms. The precipitate is formed by two ions within the chemical reaction. The precipitate will be an insoluble salt with a low K_{sp} value.

The identity of precipitates can be deduced from the results of combining pairs of salt solutions. A comparison of the products from the combination allows for the identification of any precipitates that form. Trends, called solubility rules, can also be found for some ions that tend to form precipitates more readily than others.

The ions are the cations and anions. The compounds are placed into groups, labeled by the anions. Hydroxides have an OH^-, Chlorides have a Cl^-, Sulfates have an SO_4^{2-}, Phosphates have a PO_4^{3-}, and Nitrates have an NO_3^-. The cations have a factor on the K_{sp} value; some cations have a stronger bond than others. However, most anions will have the same overall trend.

Materials:

Toothpicks or Stir Sticks	Well Plate	Distilled Water

The following chemicals should be used and have concentrations of 0.1 M:

$Fe(NO_3)_3$	Na_3PO_4	HCl
$Ba(NO_3)_2$	$Co(NO_3)_2$	NH_4OH
$CaCl_2$	Na_2SO_4	KOH
$AgNO_3$	$Cu(NO_3)_2$	

Safety: Wear safety goggles. All chemicals are solutions and could harm and cause discomfort to your eyes if the chemical splashes into them.

Waste: All chemicals can be dumped down the drain, except all chemicals with silver in them. Put chemicals with silver into their respective disposal container.

Prior Knowledge: Use the solubility rules to predict if a chemical reaction will occur and what the name of the precipitate will be. Place an "X" in the upper left corner.

Data/Observations: Place a *ppt* into the box if a precipitate forms. If the well remains a solution, leave it blank.

	K_2CO_3	KOH	NH_4OH	HCl	$Cu(NO_3)_2$	Na_2SO_4	$Co(NO_3)_2$	Na_3PO_4	$AgNO_3$	$CaCl_2$	$Ba(NO_3)_2$
$Fe(NO_3)_3$											
$Ba(NO_3)_2$											X
$CaCl_2$										X	X
$AgNO_3$									X	X	X
Na_3PO_4								X	X	X	X
$Co(NO_3)_2$							X	X	X	X	X
Na_2SO_4						X	X	X	X	X	X
$Cu(NO_3)_2$					X	X	X	X	X	X	X
HCl				X	X	X	X	X	X	X	X
NH_4OH			X	X	X	X	X	X	X	X	X
KOH		X	X	X	X	X	X	X	X	X	X

Processing/Conclusion: Based off of your results, were you correct? Write out the net ionic equations for the wells that formed a precipitate.

APPENDIX J

Solubility Rules Lab (Deductive)

Solubility Rules Lab

Purpose: Create a general list of rules for solubility based from observations of the precipitates with the chemical reactions.

Introduction: A precipitation reaction is when two solutions are mixed and a precipitate forms. The precipitate is formed by two ions within the chemical reaction. The precipitate will be an insoluble salt with a low K_{sp} value.

The identity of precipitates can be deduced from the results of combining pairs of salt solutions. A comparison of the products from the combination allows for the identification of any precipitates that form. Trends, called solubility rules, can also be found for some ions that tend to form precipitates more readily than others.

The ions are the cations and anions. The compounds are placed into groups, labeled by the anions. Hydroxides have an OH^-, Chlorides have a Cl^-, Sulfates have an SO_4^{2-}, Phosphates have a PO_4^{3-}, and Nitrates have an NO_3^-. The cations have a factor on the K_{sp} value; some cations have a stronger bond than others. However, most anions will have the same overall trend.

Materials:

Toothpicks or Stir Sticks	Well Plate	Distilled Water

The following chemicals should be used and have concentrations of 0.1 M:

$Fe(NO_3)_3$	Na_3PO_4	HCl
$Ba(NO_3)_2$	$Co(NO_3)_2$	NH_4OH
$CaCl_2$	Na_2SO_4	KOH
$AgNO_3$	$Cu(NO_3)_2$	

Safety: Wear safety goggles. All chemicals are solutions and could harm and cause discomfort to your eyes if the chemical splashes into them.

Waste: All chemicals can be dumped down the drain, except all chemicals with silver in them. Put chemicals with silver into their respective disposal container.

Prior Knowledge: Write up the dissolution reactions for the following chemicals above on a separate sheet of paper.

Data/Observations: Place a *ppt* into the box if a precipitate forms. If the well remains a solution, leave it blank.

	K_2CO_3	KOH	NH_4OH	HCl	$Cu(NO_3)_2$	Na_2SO_4	$Co(NO_3)_2$	Na_3PO_4	$AgNO_3$	$CaCl_2$	$Ba(NO_3)_2$
$Fe(NO_3)_3$											
$Ba(NO_3)_2$											X
$CaCl_2$										X	X
$AgNO_3$									X	X	X
Na_3PO_4								X	X	X	X
$Co(NO_3)_2$							X	X	X	X	X
Na_2SO_4						X	X	X	X	X	X
$Cu(NO_3)_2$					X	X	X	X	X	X	X
HCl				X	X	X	X	X	X	X	X
NH_4OH			X	X	X	X	X	X	X	X	X
KOH		X	X	X	X	X	X	X	X	X	X

Processing: Based off of your results, record your observations and compare when precipitates were formed and when they remained as a solution.

Nitrates: Hydroxides: Sulfates:

Phosphates: Chlorides:

Conclusion: On a separate sheet of paper, write up the solubility rules based off of the chemicals you've used and your observations.

APPENDIX K

Solubility and Precipitation Test

Name: **Solubility and Precipitation Test** /50

Advanced Chemistry

Directions: For each question, choose the answer you consider to be the best and indicate your choice by circling the letter of the correct answer.

1. The actual separation of ions that occurs when an ionic compound dissolves is called
   - **A.** dissociation.
   - **B.** ionization.
   - **C.** dissolution.
   - **D.** precipitation.

2. The process in which ions leave a solution and regenerate an ionic solid is called
   - **A.** ionization.
   - **B.** precipitation.
   - **C.** dissolution.
   - **D.** hydrolysis.

3. How many ions will one formula unit of $CaCl_2$ produce?
   - **A.** none
   - **B.** one
   - **C.** two
   - **D.** three

4. An aqueous solution is a solution in
   - **A.** alcohol.
   - **B.** water.
   - **C.** any ionic solvent.
   - **D.** any polar solvent.

5. Which of the following is an equation that represents dissolution?
   - **A.** $NaOH\ (s) \rightarrow NaOH(l)$
   - **B.** $NaOH\ (l) \rightarrow NaOH\ (s)$
   - **C.** $NaOH\ (s)\ \ > Na^{+}\ (aq) + OH^{-}\ (aq)$
   - **D.** $NaOH\ (s) <\ \ Na^{+}\ (aq) + OH^{-}\ (aq)$

6. The symbol for the solubility product is
   - **A.** ΔH^{o}.
   - **B.** Q.
   - **C.** K_{sp}.
   - **D.** K_{eq}.

7. How does the magnitude of K_{sp} relate to solubility?
   - **A.** K_{sp} equal to zero represents the highest solubility.
   - **B.** High K_{sp} indicates high solubility.
   - **C.** Low K_{sp} indicates high solubility.
   - **D.** K_{sp} values are completely unrelated to solubility.

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8. Which of the following is equal to K_{sp} for the reaction Na_2SO_4 (*s*) → 2 Na^+ (*aq*) + SO_4^{2-} (*aq*)?
   - **A.** $[2Na^+][SO_4^{2-}]$
   - **B.** $[Na^+][SO_4^{2-}]$
   - **C.** $[Na^+]^2[SO_4^{2-}]$
   - **D.** $[Na^+]^2[SO_4^{2-}]/[Na_2SO_4]$

9. A precipitation reaction is an example of a
   - **A.** double displacement reaction.
   - **B.** single displacement reaction.
   - **C.** synthesis reaction.
   - **D.** decomposition reaction.

10. Which of the following is a total ionic equation?
    - **A.** Cu^+ (*aq*) + NO_3^- (*aq*) + Li^+ (*aq*) + OH^- (*aq*) → CuOH (*s*) + Li^+ (*aq*) + NO_3^- (*aq*)
    - **B.** Cu^+ (*aq*) + OH^- (*aq*) → CuOH (*s*)
    - **C.** $CuNO_3$ (*aq*) + LiOH (*aq*) → CuOH (*s*) + $LiNO_3$ (*aq*)
    - **D.** none of the above

11. In the reaction below, which of the ions are spectator ions?
    Cu^+ (*aq*) + NO_3^- (*aq*) + Li^+ (*aq*) + OH^- (*aq*) → CuOH (*s*) + Li^+ (*aq*) + NO_3^- (*aq*),
    - **A.** NO_3^- and Li^+ only
    - **B.** Cu^+ and OH^- only
    - **C.** all of the ions
    - **D.** none of the ions

12. When the concentration of an ion that is part of the solubility expression is added to a saturated solution, what will occur?
    - **A.** Nothing will occur.
    - **B.** The solubility will increase.
    - **C.** The solution will become unsaturated.
    - **D.** Precipitation will occur.

13. What will happen when fairly concentrated sodium chloride and lead nitrate solutions are mixed?
    - **A.** Nothing will happen.
    - **B.** Sodium nitrate will form a precipitate.
    - **C.** Lead chloride will form a precipitate.
    - **D.** Both sodium nitrate and lead chloride will form a precipitate.

14. If fairly concentrated calcium sulfide and ammonium sulfate solutions are mixed, what will happen?
    - **A.** Nothing will happen.
    - **B.** Calcium sulfate will form a precipitate.
    - **C.** Ammonium sulfide will form a precipitate.
    - **D.** Both calcium sulfate and ammonium sulfide will form a precipitate.

/7

15. If fairly concentrated silver nitrate and lithium phosphate solutions are mixed, what will happen?

- **A.** Nothing will happen.
- **B.** Silver phosphate will form a precipitate.
- **C.** Lithium nitrate will form a precipitate.
- **D.** Both silver phosphate and lithium nitrate will form a precipitate.

16. Which cations tend not to form precipitates with sulfate ions?

- **A.** Alkali metal ions only
- **B.** Alkali metal, silver, and lead ions only
- **C.** Alkali metal and ammonium ions only
- **D.** ammonium, silver, and lead ions only

17. Which cations tend to form precipitates with sulfide ions?

- **A.** all the cations
- **B.** Alkali metal and ammonium ions only
- **C.** ammonium, silver, and lead ions only
- **D.** silver and lead ions only

18. Which anions tend to form precipitates with ammonium ions?

- **A.** all the anions
- **B.** nitrate and sulfide ions only
- **C.** sulfate and phosphate ions only
- **D.** none of the anions

19. Determine the net ionic equation that represents the reaction that occurs when fairly concentrated solutions of silver nitrate and sodium iodide are mixed.

- **A.** $Ag^{+}(aq) + I^{-}(aq) \rightarrow AgI(s)$
- **B.** $Ag^{+}(aq) + NO_3^{-}(aq) + Na^{+}(aq) + I^{-}(aq) \rightarrow AgI(s) + NaNO_3(s)$
- **C.** $Ag^{+}(aq) + NO_3^{-}(aq) + Na^{+}(aq) + I^{-}(aq) \rightarrow AgNO_3(s) + NaI(s)$
- **D.** There is no reaction.

20. Which of the following ions would produce the common-ion effect in the equilibrium system $BaSO_4(s) \leftrightarrow Ba^{2+}(aq) + SO_4^{2-}(aq)$?

- **A.** Ba^{2+}, but not SO_4^{2-}
- **B.** SO_4^{2-}, but not Ba^{2+}
- **C.** either Ba^{2+} or SO_4^{2-}
- **D.** neither Ba^{2+} nor SO_4^{2-}

21. In a net ionic equation, what ions do not appear?

- **A.** positive ions
- **B.** negative ions
- **C.** ions that produce the precipitate
- **D.** spectator ions

/7

Directions: Answer all of the questions in the spaces provided.

22. Use the following chart to answer the questions below:

Substance	***Cation*** **concentration (mol/L) in saturated solution**	K_{sp}
lead(II) sulfide, PbS		8.4×10^{-28}
cadium hydroxide, $Cd(OH)_2$	1.4×10^{-5}	
silver carbonate, Ag_2CO_3		8.1×10^{-12}

A. Write the dissolution equation for lead(II) sulfide. **(2)**

B. Write the solubility product expression for lead(II) sulfide. **(2)**

C. Fill in the table above for the missing blanks. Be sure that you read the table correctly. **(6)**

D. Write the precipitation equation for cadmium hydroxide? **(2)**

E. Which of the three compounds is the most soluble? **(1)**

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23. Using the solubility rules, fill in each box with an "S" for soluble and "I" for insoluble. **(5)**

Cations	**Anions**				
	NO_3^- & CH_3COO^-	Cl^-, Br^-, I^-	SO_4^{2-}	S^{2-} & OH^-	CO_3^{2-} CrO_4^{2-} PO_4^{3-}
Li^+, Na^+, K^+, Rb^+, Fr^+, Cs^+					
Ca^{2+}					
Sr^{2+} & Ba^{2+}					
NH_{4+}					
Ag^+					
Pb^{2+}					

24. Write the solubility product expression for the following:

A. calcium hydroxide ($Ca(OH)_2$) **(2)**

B. silver phosphate (Ag_3PO_4) **(2)**

25. How many ions are produced from one formula unit of each of the compounds:

A. strontium iodide (SrI_2)? **(1)**

B. copper(I) carbonate (Cu_2CO_3)? **(1)**

C. aluminum sulfide (Al_2S_3)? **(1)**

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Directions: Solve three of the following four problems. Circle the number of the three problems you want graded. The first 3 will be graded if none are circled.

26. Find the value of K_{sp} for nickel carbonate ($NiCO_3$), given that the concentration of Ni^{2+} in a saturated solution is 8.1×10^{-5} *M*. **(3)**

27. The concentration of Co^{2+} ions in a saturated solution of cobalt(II) hydroxide ($Co(OH)_2$) is 4.0×10^{-6} *M*. Calculate the value of K_{sp} for this substance. **(3)**

28. What are the equilibrium concentrations of Zn^{2+} and S^{2-} ions in a saturated solution of zinc sulfide (ZnS), given that K_{sp} is 1.1×10^{-21}? **(3)**

29. The value of K_{sp} for magnesium fluoride (MgF_2) is 6.4×10^{-9}. Calculate the equilibrium concentrations of Mg^{2+} and F^{-} ions in a saturated solution of this substance. **(3)**

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