Introducing Students to the “Game” of Science

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"We can imagine that this complicated array of moving things which constitutes 'the world' is something like a great chess game being played by the gods, and we are observers of the game. We do not know what the rules of the game are; all we are allowed to do is to watch the playing. Of course, if we watch long enough, we may eventually catch on to a few of the rules. The rules of the game are what we mean by fundamental physics." **(Feynman, Leighton and Sands, 1963, Vol 1 p 2-1)**

Introduction

For at least a century one of the major objectives of science instruction has been to help students develop a sense of the nature of scientific investigation. Calls for accomplishing this goal range from the reports of the Central Association of Science and Mathematics Teachers (1907) through the work during the 1960's on the development of the "alphabet" programs for elementary science (Science-A Process Approach: SAPA; Science Curriculum Improvement Study: SCIS; and Elementary Science Study: ESS for example) to the calls in the current Standards documents (AAAS, 1989; NRC, 1996) for a focus on the nature of science. Such calls continue, as demonstrated by Selby (2006).

In the common laboratory approach to teaching scientific processes students go through activities in which they complete directed demonstrations. There are many issues, such as the competing student foci on understanding apparatus, collecting data, and the concepts behind the system, involved in this type of investigation that make it less desirable for teaching about scientific processes. All of these simultaneous requirements result in students taking a minimalist approach to completing an investigation ("just tell me what I need to know and do") and the scientific processes involved are simply ignored, even among science majors. This situation is more difficult when dealing with non-science majors in general education science courses where the students may have a fear or dislike of science. What is needed to teach about the scientific process is an activity with which all students (science and non-science majors) can be comfortable so that they can concentrate on what we want them to learn: the basic processes and reasoning behind scientific endeavors.

In a related development there have also been strong calls for a number of years for students to be more actively engaged in exploring science. Such calls have come from both the National Research Council (NRC) (1996) and the American Association for the Advancement of Science (1989) Such approaches get the students involved with the phenomena and their peers to promote what is described as "hands-on and minds-on" exploration. One difficulty with this approach is that having the students active in this manner is uncommon, in some cases for the instructor as well as the students, so students need help to shed fears and develop the skills to participate readily and fully. The habits and perspectives most students have lead them to expect that they will be passive in courses, so getting them to actively participate in investigations and discussion can be a challenge.

The purpose of this paper is to describe an activity that can introduce the students to scientific processes and ease the students into active participation in a class. The key to the activity is that it utilizes *something* with which all students are familiar: game play. In this activity, the students are presented with a playing board, pieces and a series of moves, that describe the actual history of a game between two players. The goal in this activity is to use this information to determine the rules of the game. One can easily make the analogy that determining the rules of the game is similar to finding a "theory" of the game. In the process of determining this "theory," the participants must develop evidence based hypotheses of individual rules which are tested against the moves listed in the game history, much as a scientist might make observations of past events of a system, and then form hypotheses which are supported or refuted by further observations. To make the idea more concrete let's examine a specific example of the activity and the reasoning involved.

Example Game

Figure 1 shows a playing board and pieces for a two person game. Figure 2 is a list of the moves made by two novice, but reasonably intelligent players when they played the game. A logical start to determining the rules is to identify the questions that must be answered, a process that is simplified by the students' familiarity with games. These questions would include: 1) How many pieces does each player have? 2) Are the turns symmetric (that is do the players have similar roles in the game)? 3) Do the players take turns? 4) Do the pieces belong to individual players or are all the pieces "community" pieces? 5) What are the starting positions for the pieces? 6) How do the pieces move? 7) Do all of the pieces move the same way, or do different pieces have different move patterns? 8) If there are different move patterns, how many are there and what are they? 9) How does a player win the game? 10) Can the game end in a draw? Having identified preliminary questions one must determine how to answer them.

As this example is set up we can quickly infer that the first two questions are already answered. Figure 1 shows a total of six pieces, with two different shading patterns implying that each player has three pieces. With regard to question 2, given the identical shape of, and number of, pieces the implication here is for symmetry of play.

To answer the remaining questions we must examine the game history, or histories, that is/are provided. Unless an understanding of the game is developed from simply contemplating the game board and pieces, the only method available to resolve these questions is to trace one of the game histories as if one were an observer of the game being played. Taking the history given in Figure 2 we see the first move is **P1 to <u>1</u>**. Since the squares on the board are numbered we would infer that a player is moving piece P1 to square <u>1</u>. We would also infer that P1 is one of this player's three pieces. Because of the apparent symmetry to the game we might initially assume that play alternates between two players. Supporting these two hypotheses is the first move involving piece **G3 to 16,** which it is reasonable to infer is the first move of the other player. The second move by the first player is **P3 to 3**. Looking at the geography of the board, we are now in a position to make the reasonable inference that the starting positions for the pieces are the six unnumbered, patterned squares. We might infer that the pieces for the first player (P) are being labeled 1-3 from left to right and the pieces for the second player (G) are labeled 1 – 3 from top to bottom in the starting squares. Our comfort with this hypothesis should increase with the second move of G – **G2 to 12** – which is consistent with our hypothesis. Looking at the patterning on the squares and on the pieces we are likely to infer that the three pieces of player P start in the top three squares and the three pieces of player G start in the three dark squares at the right.

Reasonable hypotheses for starting position, alternation of play, initial positions of the pieces, how the pieces are labeled, and a labeling of the movement of the pieces have been developed. Now the movement of the pieces must be examined. To determine how the pieces move one must look at many, perhaps all, of the moves in the sample game. The pattern we find is that the pieces move one square at a time away from the starting positions or parallel to the starting positions. We find no diagonal moves or moves back toward the starting squares. So a reasonable hypothesis is that the pieces can move one square away from the starting squares, or "sideways" relative to the starting squares, but not diagonally or backwards.

However, we can't be certain that a player can't move "backwards" or diagonally. This hypothesis rests on the data, which was generated by two novice players. We cannot differentiate if such moves are possible and these novices just didn't make them or the moves are not allowed. While it is not possible for us to answer this question presently, we need to be aware that this question exists.

We still have a major unanswered question: how does a player win the game? Looking at the game history we see the winning move was **P2 off**. It would be natural to assume that this means piece P2 was moved off the board. Looking through the sample game we find that P2 was the last of player P's pieces to move off the board. Consequently a reasonable hypothesis about how to win is **the first player to get all of his/her pieces off the board is the winner.** But we need to know the mechanism by which pieces are allowed to exit the board.

The presence of the four triangles opposite each trio of starting positions may well make us suspect that those are the exit squares for the corresponding pieces, but how do we check on this? The obvious answer is to go back to the sample game and see if we can determine where the various pieces left the board. The first piece off was G3 which was in square 13. Obviously that piece could have gone off the board in two ways. Next off is P1 which was in square 14. The reasonable inference is that it went off the "bottom", through the corresponding patterned triangle, of the board. Next off is P3 which was in square 14. Again the reasonable inference is off the bottom of the board. Then G1, which was in square 1, goes off. Here the reasonable inference would be off the left side of the board through the triangle with the same pattern as the piece. Finally, P2 leaves from square 14, so we would expect off the bottom. Consequently, the data favors the idea that the pieces leave the board in the directions of the triangles with the same patterns as the pieces.

Similar to science in which we cannot be certain that a hypothesis is valid under all circumstances; we can't be positive that pieces have to move off the board according to our hypothesis. Also similar to science, examining additional game histories will not prove our hypothesis, but such examination can provide additional support, or clear evidence that something we have done is not right. This helps move the students beyond the belief that we can "prove" science. Finally it is important to note that we don't know if our hypothesis identifies the only way to win the game.

We can revisit the issue of backwards or diagonal moves now. Our hypothesis about how a player wins the game makes it clear that a backwards move would be counter-productive, but of course that doesn't tell us whether it is permitted by the rules. However, it does indicate that we are unlikely to find such a move in a game history since it would hurt the player making it, rather than help him/her. Diagonal moves would be useful, so their absence probably indicates that they are not allowed. The best we can do at this point is to say that both backward and diagonal moves may be allowed, but the evidence suggests that they are not.

At this point we have a fairly complete model (theory) of the game. At least it is complete enough that we could test play our model rule set to see if our rules are consistent, without any gaps. We may not feel especially confident of our model since it is based on a single sample game, but it is the best we can do with the data available. We can also examine additional game sets, if available, for supporting and refuting evidence of our theory of the game.

The Activity in a Classroom

One way to use this activity is to assign students to "research groups." In these groups, the students have to decide what questions they need to answer to develop a full "theory" of the game. For example: Where do the pieces start? How do the pieces move? What is the goal of the game, i.e., how does a player win? In trying to answer these questions the students engage in reasoning similar to what a scientist does when she is carrying out an investigation. They have to formulate hypotheses about the rules for piece movement from the data listing actual moves, and hypotheses about how certain movements contribute to a player winning the game. They also have to integrate the different hypotheses, about initial positions, legal moves, how one wins, etc, into a coherent whole—the "theory" of the game.

We believe the value of the activity can be enhanced by having a "research conference" when most of the groups have worked out their theories. In the research conference important aspects of the investigative process can be highlighted. The major research questions can be explicitly identified; different groups can propose hypotheses about rules, explain their evidence and have to defend their proposal against counterarguments. The whole class can be cycled back to reconsidering the data in light of the proposed hypotheses. Ideas for additional testing—test playing the set of rules the class as a whole has settled on to look for inconsistencies or gaps—can be tried. Revisions can be made in light of later information or discussion. All of these activities can help students see that the process of science is not a matter of following some linear sequencing of the steps in “the scientific method”, but is rather an iterative process with much give and take.

Furthermore, because this activity is understandable by all participants and is treated as a model of scientific inquiry, it helps the participants gain an understanding of the nature of science. The activity demonstrates the difference between theory and hypothesis. It makes it evident that we cannot prove a particular hypothesis or theory. Very importantly, it makes clear the ludicrous nature of a statement that a theory is a guess or is “**just a theory**,” by demonstrating that a theory is based on all of the observations and solid evidence. Because of the ease of participation in the project, without the incumbent science phobias, the participants in this activity discover that science is not a passive endeavor.

Possible Games and Variations

Since abstract strategy games run a very large gamut in terms of complexity, there are many game possibilities and frequently the way a particular game is presented can be varied to alter the challenge of the activity. As a first example consider what would happen if the game of Figure 1 had been presented with the board in Figure 3 instead. The starting positions of the pieces are now not obvious. It is still not very difficult for students, especially working in groups, to determine that the three squares at the top and the three at the right are the starting positions, but doing so requires more effort compared to starting with Figure 1 where there are visual clues. In this case the students have to draw inferences about the starting positions from the moves in the games. Also it is not immediately clear, as it was in Figure 1, that all of the G pieces go in the three squares at the right.

To give an idea about how varying the game can alter the activity, consider the game board and the move list in Figure 4. One difference is that this game is “two-stage” so each player has to place all three of his/her pieces on the board before any movement begins. A second difference is that draws are possible in this game. However, these two games share the characteristic of being relatively easy for students to solve.

One can also vary the issues that are discussed in the research conference by judicious choice of the game and moves. An example of this way to focus on specific issues uses the game situation shown in Figure 5. In this game the moves are to either place a piece on an open square on the board oriented horizontally or vertically, or to switch the orientation of a piece that has previously been placed on the board. By providing a set of sample games where the winning player has four in a row horizontally or diagonally, but not vertically, one can get into the issue of evidence-based hypotheses versus analogy-based hypotheses. Most groups working with this situation will construct the hypothesis that one wins by getting four in a row horizontally, diagonally or vertically even though they have no direct evidence for the latter case. The reason this happens is that students make the analogy between this game and the situation with Tic-Tack-Toe so vertical wins are expected. In the research conference discussion the difference in the basis for the hypothesis of horizontal and diagonal wins versus vertical win can be brought out. This will have to be done by the instructor through judicious questioning because the students often don't realize the difference exists.

One can highlight the process of collecting additional data to test a hypothesis as another variation. Once the students as a whole have settled on a set of rules, or when there are alternate possibilities for a particular rule, the instructor could let them set up a possible move and the instructor would tell them if the move is allowed. Or the instructor can have the moves for an additional game, or several, prepared and give them to the research groups to see if the initial hypotheses hold up in the face of added data. Depending on the instructor's goal, situations can be established in which the initial game "theory" is going to be correct or situations in which the preliminary theory is incomplete, and the added data will reveal either a problem with the initial rule set or a gap in the initial rule set. The cases where there are deficiencies in the initial game theory can be used to introduce and emphasize the tentative nature of scientific research.

Another variation is for the instructor to propose an alternative rule that the students had not thought of. This normally requires that the instructor has used the particular game before so he/she will know what rule set the students will probably produce. By careful adjustment of the sample game data an ambiguity can be introduced into the situation and that will allow the instructor to add a new possibility. There is also no requirement that all groups receive the same data sets so another variant is to give different groups different game histories. This then allows the instructor to provide one or two groups with a different insight than the remainder of the groups, perhaps even data that can challenge an accepted theory.

Two other challenging alternatives are (1) to give the students a set of scenarios that start several turns into the game, rather than having the example games always start at the beginning or (2) to provide sample games in which moves are missing. The students are still expected to develop full theories of the game including possible starting positions. These two alternative approaches were developed to assist students to understand that scientific conclusions can be reached from incomplete data sets, and that we can deduce what happens even in the absence of a complete data set. Of course, it is critical that not too much information is removed from a data set or the problem becomes unsolvable.

Conclusion

Our purpose in this paper was to present an activity that has been found to be useful by a number of science teachers around the country in grades 6 through college for introducing their students to the nature of scientific investigation and to promote interaction among the students. The activity uses materials that a majority of students find inherently interesting (or at least they can be comfortable with the concept): simple abstract strategy games. It gets the students engaged in analyzing patterns, formulating and testing hypotheses and other processes common to scientific investigation and helps them understand the scientific usage of terms such as hypothesis and theory. Because of the variety of games available, as well as variations in how they can be presented, the activity can be customized to fit a very large variety of situations. The range of grades with which the activity has been used successfully supports the contention of the flexibility of the activity. The model presented, in which game histories are provided to participants, is applicable to a science situation in which the events have occurred in the past. For modeling observational and experimental science, in which the observer watches events unfold in real time or the observer is an active participant in the game we are working on computerizing the game play. This will allow students to observe a game in real time or to move the pieces within the rules. .

We have supplied information, in two cases partial, in this paper for three games and we have a website ( ) which contains additional information about the games already presented as well as information about two other games. We are also working on additional games and variations which we will be posting to the website as they finish classroom testing. The materials on the website are those needed to run the activity. "Answers" for any of the games can be obtained by e-mailing one of the authors from an "edu" address.

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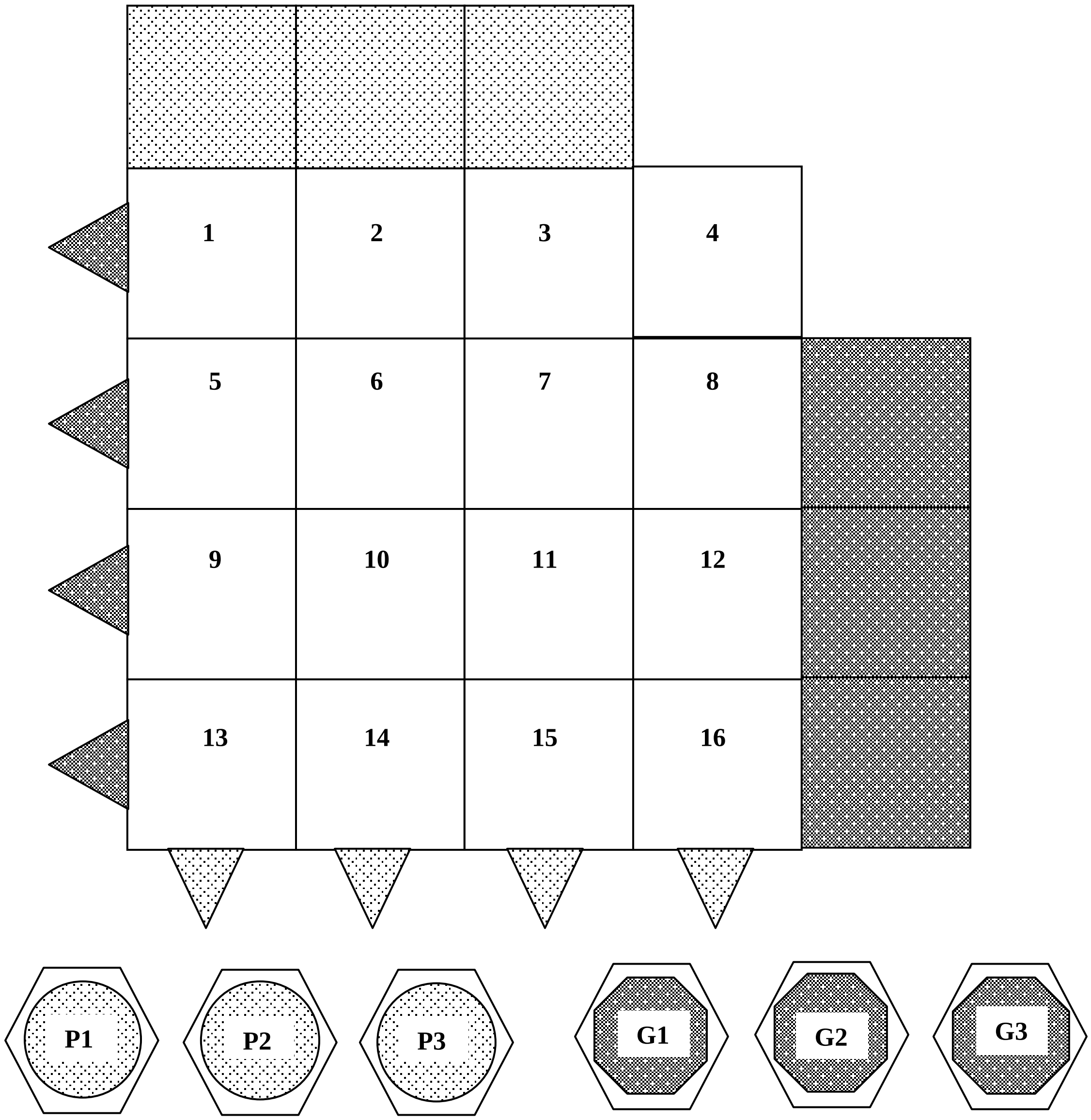


Figure 1

Sample Moves for an Actual Game

P1 to 1; G3 to 16; P3 to 3; G2 to 12; P3 to 7; G3 to 15; P1 to 5; G3 to 14; P1 to 9; G3 to 13; P3 to 11; G1 to 8; P2 to 2; G1 to 7; P2 to 6; G1 to 3; P1 to 10; G3 OFF; P1 to 14; G2 to 8; P1 OFF; G1 to 2; P3 to 15; G1 to 1; P3 OFF; G1 OFF; P2 to 10; G2 to 7; P2 to 14; G2 to 6; P2 OFF **P WINS.**

Figure 2

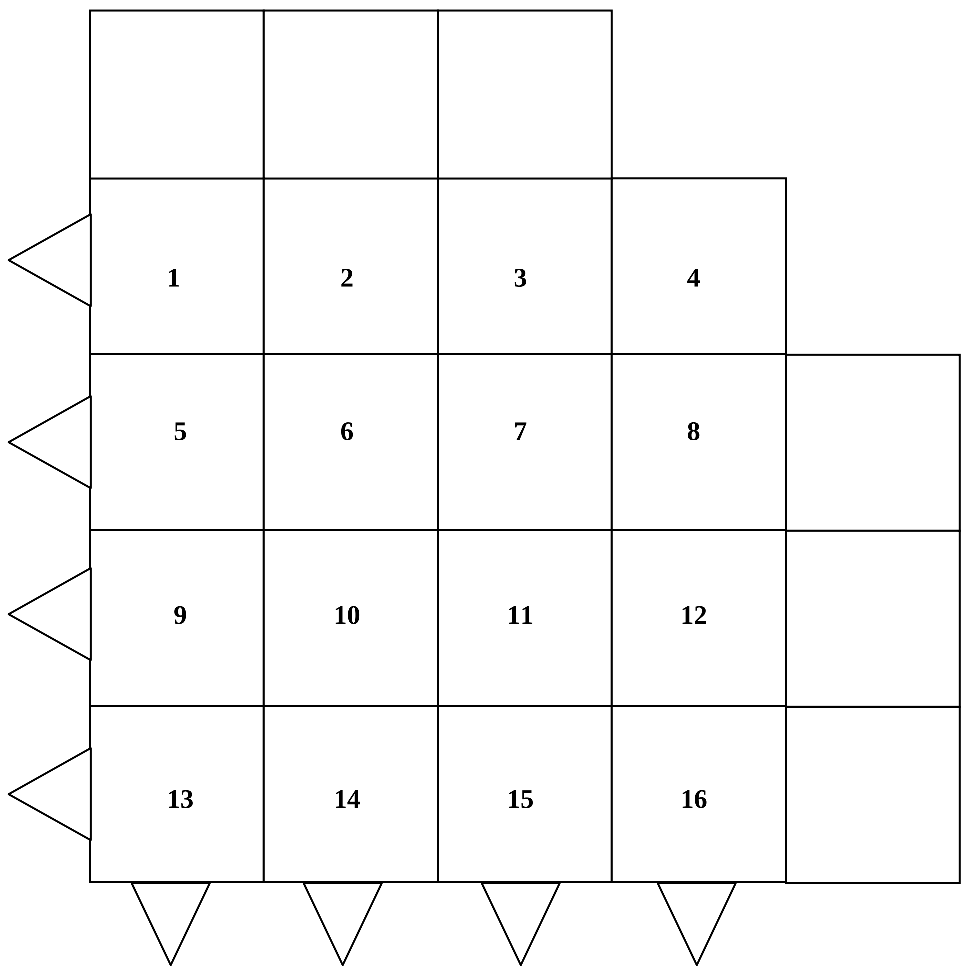
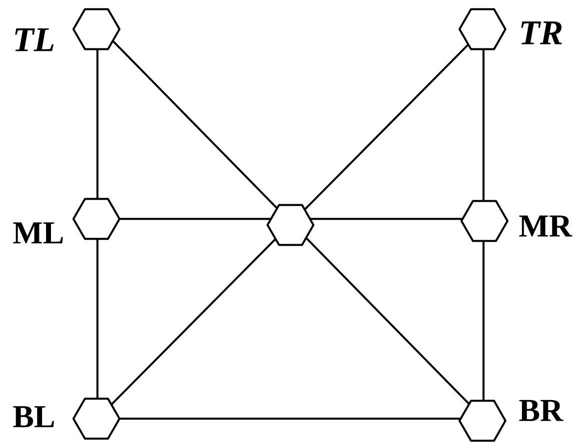


Figure 3

SciGame Gamma

Given below is the playing board and the moves for four games of Gamma.



Round	Black	White	Black	White	Black	White	Black	White
1	BL	MR	M	BR	M	BR	TL	M
2	BR	M	ML	BL	TL	ML	MR	BR
3	ML	TL	TL	MR	MR	BL	BL	ML
4	***WHITE WINS***		M-TR	BR-M	MR-TR	BR-MR	MR-TR	M-MR
5			***WHITE WINS***		M-BR	MR-M	TL-M	ML-TL
6					TR-MR	M-TR	BL-ML	BR-BL
7					BR-M	BL-BR	M-BR	TL-M
8					M-BL	BR-M	ML-TL	BL-ML
9					MR-BR	TR-MR	BR-BL	M-BR
10					***WHITE WINS***		TR-M	MR-TR
11							M-MR	TR-M
12							MR-TR	M-MR
13							***DRAW***	

Figure 4

Scigame Psi Board

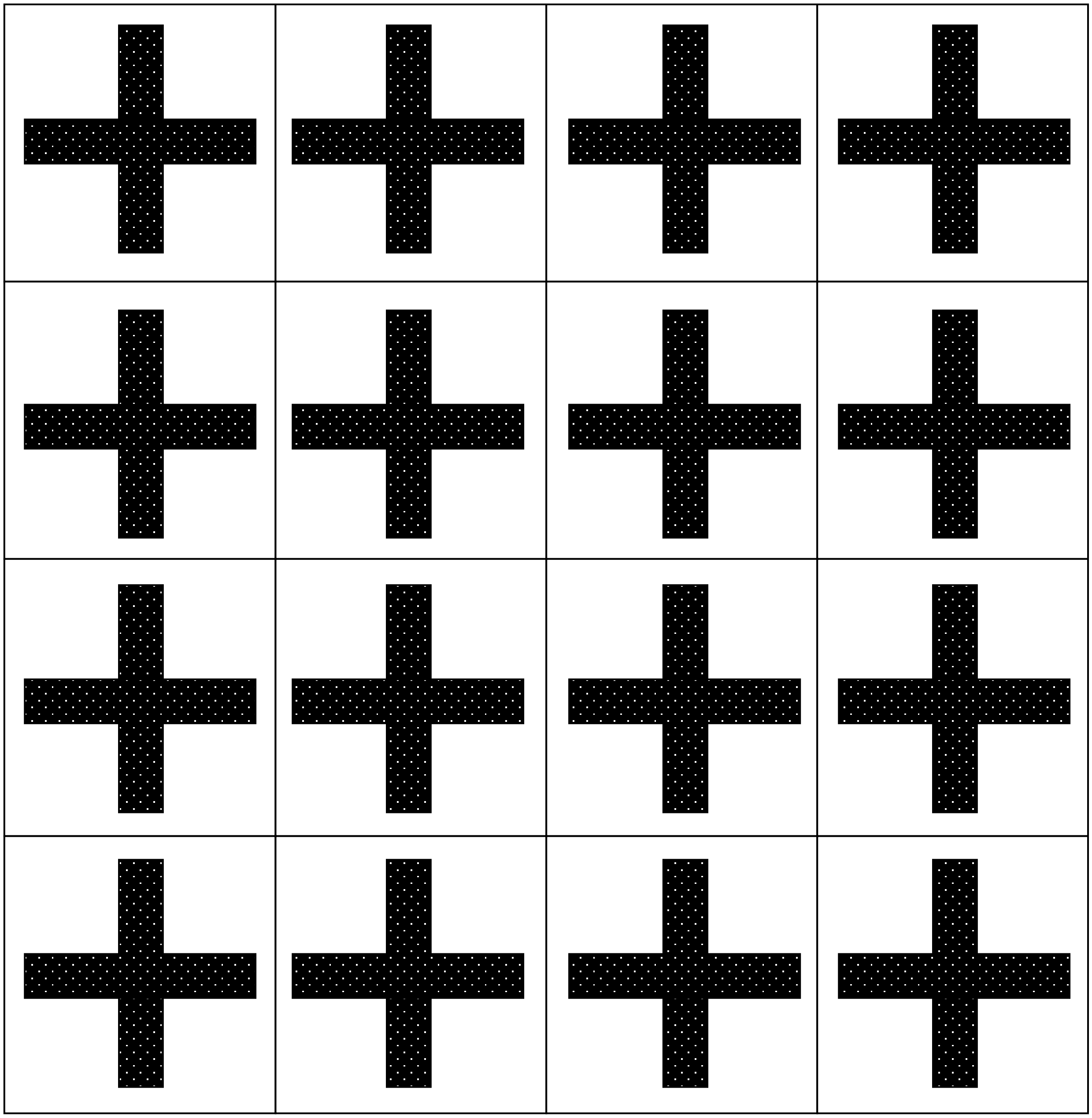


Figure 5