

Distinguishing Emergent and Sequential Processes by Learning Emergent Second-Order  
Features

by

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## ABSTRACT

Emergent processes can roughly be defined as processes that self-arise from interactions without a centralized control. People have many robust misconceptions in explaining emergent process concepts such as natural selection and diffusion. This is because they lack a proper categorical representation of *emergent processes* and often misclassify these processes into the *sequential processes* category that they are more familiar with. The two kinds of processes can be distinguished by their second-order features that describe how one interaction relates to another interaction. This study investigated if teaching emergent second-order features can help people more correctly categorize new processes, it also compared different instructional methods in teaching emergent second-order features. The prediction was that learning emergent features should help more than learning sequential features because what most people lack is the representation of emergent processes. Results confirmed this by showing participants who generated emergent features and got correct features as feedback were better at distinguishing two kinds of processes compared to participants who rewrote second-order sequential features. Another finding was that participants who generated emergent features followed by reading correct features as feedback did better in distinguishing the processes than participants who only attempted to generate the emergent features without feedback. Finally, switching the order of instruction by teaching emergent features and then asking participants to explain the difference between emergent and sequential features resulted in equivalent learning gain as the experimental group that received feedback. These results proved teaching emergent second-order features helps people categorize processes and demonstrated the most efficient way to teach them.

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## CHAPTER 1

### INTRODUCTION

#### **Misconceptions with Processes**

We encounter processes of all kinds in our daily lives. When we see a flock of birds fly across the sky, get stuck in a traffic jam, or watch the news about all kinds of things that goes on around the world, we are experiencing or witnessing various processes occurring at different scales. The definition of a process includes three components: 1) the agents involved in the processes and what do they do, 2) the change of events over time, and 3) the causal relationship between different events in a process (Van de Ven, 1992). Chi, Roscoe, Slotta, Roy and Chase (2012) provided elaboration by breaking a process down into three levels: 1) the micro level referring to the agents and their interactions, 2) the macro level referring to the observable pattern that changes over time, and 3) the inter level referring to the causal connection between the micro and macro levels.

Due to the multiple levels that exist in a process, there is the potential for misconceptions about processes that resemble each other at the macro level. For example, we could understand a macro level pattern of a process, but misunderstand how agents interact at the micro level to cause the pattern to happen. Consider the two processes of planes flying in a V-shape during a big ceremony and migratory birds, such as geese flying in a V-shape. At the macro level, we can see a similar pattern between the two processes since both involve agents flying in a V-shape. This similar pattern at the macro level may lead to the misconception that agents at the micro level involved in both processes interact and behave in a similar manner. For example, people may believe a

leader bird gives orders and others take orders from it to coordinate their flight formation (Resnick, 1996). This example illustrates how similarities at the macro level can lead to misconception about micro-level interactions.

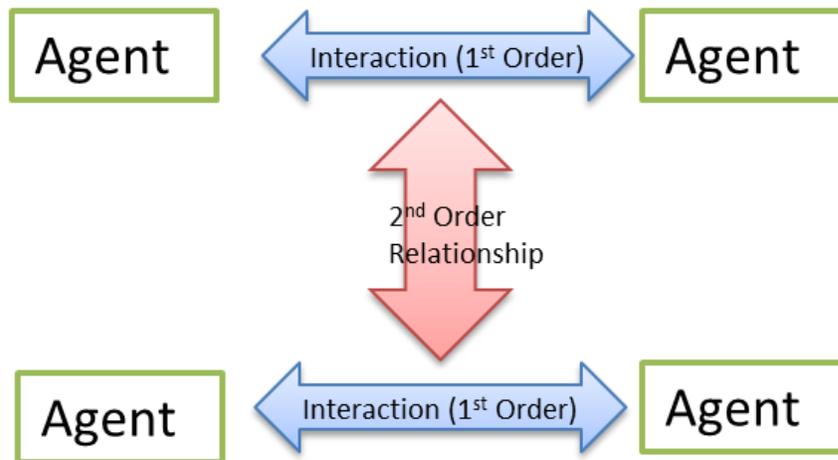
### **Two Kinds of Processes and How They Differ**

The birds flying in a V-shape and planes flying in a V-shape are two very distinct processes with regard to the micro-level interactions; next, we will analyze their differences in more detail, and discuss how those differences make them two distinct kinds of processes. When planes are flying in a V-shape, every pilot plays a distinct role that differs from each other depending on their position. The pilot in the leading position should coordinate the flight plan with other pilots, he would give an order and other pilots would follow the order and perform certain actions. This process is very well planned out and coordinated by communication among pilots. The process of how birds fly in V-shape may appear similar; however, it is qualitatively different from the process of planes flying in V-shape. Birds in the group do not have distinct roles that make their interaction differ from each other. For example, even the leading position is not always fixed to one particular bird; members rotate to take that position. Birds do not need orders to tell them where to fly or to stay together and form a V-shape. In fact, birds achieve their pattern by simply following the same rule -- stay behind another bird at a slightly angled location during flight (Duman, Uysal & Alkaya, 2012).

In summary, processes such as planes flying in a V-shape have various distinct types of interactions. Each type is restricted to certain agents of the process, and the different types of interactions occur in a sequential order because some interactions depend on others. We call them **sequential processes** in this study. In contrast, processes such as

birds flying in a V-shape have similar interactions throughout. The interactions involve many random agents in the process; they happen simultaneously with each other, and they are independent of each other. Such processes are called **emergent processes** (Chi, et al., 2012).

We have discussed differences regarding how agents interact with each other in the two processes and identified them as emergent and sequential processes. Next, we detail the true nature of these differences by pinpointing where they can be located in a process. Basically at the micro-level of processes there are agents and their interactions with each other make up the first-order relationships; beyond that, how the interactions relate to one another make up the second-order relationships (see Figure 1). The relationships among interactions are termed “second-order” because they are one level above first-order relationships of agents. Emergent and sequential processes are systematically distinguishable by the second-order relationships (Chi, et al, 2012).



*Figure 1.* Illustration of Second-order Relationship

Chi, et al. (2012) proposed five pairs of features that summarized second-order relationships of emergent and sequential processes. Next we will illustrate how these

second-order features differentiate emergent and sequential processes, still with the same two examples. First, interactions in an emergent process such as birds flying in a V-shape are **similar** to each other because all birds possess the same instinct to follow each other at a distance. In a sequential process such as planes flying in a V-shape, many interactions are **distinct** (e.g. giving orders vs. following orders). Second, when birds fly in a V-shape, each member takes up a position in the group randomly, thus leading to **random** interactions. In contrast, when planes fly in a V-shape, the placement of each plane is predetermined, leading to **restricted** interactions. Third, interactions between birds can happen **simultaneously** within the entire flock. For example, some birds may be switching positions, at the same time others keep flying close to their neighbors. When planes fly in a V-shape, pilots of each plane communicate with each other before they take actions. This process follows a **sequential** order of interactions. Fourth, interactions between birds flying in a V-shape are determined by each bird's own instincts resulting in independent interactions. In contrast, interactions between planes flying in a V-shape are **dependent** on one another since interactions, such as communication between pilots, determine how they interact. Finally, birds will **continue** to interact by keeping an angled position to the bird in front even when the V formation is broken. In contrast, planes will **terminate** interactions with each other when the overall V formation is over, such as when they land. The five pairs of second-order features distinguish emergent and sequential processes (see Table 1).

Table 1

*Five Pairs of Second-order Features of Emergent and Sequential Processes Proposed by*

*Chi, et al. in 2012*

Features for Sequential Processes	Features for Emergent Processes
Sequential: Agents interact <b>distinctively</b> .	Emergent: Agents interact <b>similarly</b> .
Sequential: Agents only interact with <b>restricted</b> other agents.	Emergent: Agents interact with <b>random</b> other agents.
Sequential: Agents interact <b>sequentially</b> .	Emergent: Agents interact <b>simultaneously</b> .
Sequential: One interaction is logically <b>dependent</b> on another interaction.	Emergent: Interactions are <b>independent</b> from one another.
Sequential: Interactions <b>terminate</b> as the pattern terminates.	Emergent: Interactions <b>continue</b> even when pattern is over or disrupted.

### **Importance of Distinguishing Two Kinds of Processes**

Emergent processes occur in both social and natural sciences, examples include supply chain networks, evolution, neural activities in the brain and how information spread via internet (Levin, 1998; Mitchell, 2006; Surana, Kumara, Greaves & Raghavan, 2005). Misconceptions about emergent processes suggest that people often mistake an emergent process as sequential process (Chi, 2005; Chi, 2008; Chi, et al., 2012; Ferrari & Chi, 1998). For example, one common misconception about evolution is that mutation only happens to enable a species adapt to a new environment (Gregory, 2009). This misconception implies a sequential view in that mutation is dependent on the environment; when mutation actually occurs randomly. Similarly, when people think about diffusion, they often believe that molecules only move around to achieve equilibrium when they are mixed with another kind of molecule, and they stop moving once equilibrium is achieved (Odom, 1995). This misconception also occurs because

students mistake an emergent process for a sequential process. In fact, molecules are constantly moving around regardless of whether equilibrium is achieved. In both of these examples, people adopt sequential thinking (e.g. dependent interactions, termination of interactions once pattern is achieved) and mistakenly apply it to emergent processes. Misconceptions like these are categorical mistakes because people are misplacing emergent processes into the sequential process category. These misconceptions hinder their understanding of many important emergent concepts in social and natural sciences.

Such misconceptions are often very resilient to change because people have a strong affinity to treat processes in a sequential way. For example, Brewer (1984) stated that many English-speaking readers possess a narrative schema, which biases episodic memories to be encoded in a linear manner, potentially distorting accuracy. Past studies have found that both adults and children were more inclined to agree with explanations for natural phenomenon that assume events occur to achieve a goal, as opposed to being random (e.g., believing that the sun *intentionally* radiates heat to nurture life) (Kelemen, 1999; Kelemen & Rosset, 2009). In short, these studies suggest that people have an underlying theory that most processes happen for a reason, and they happen in a series of events.

Gelman and Coley (1991) argued that people are much more likely to assume all members in a category share properties if the category is constructed based on a coherent theory. A later finding also indicated that people have a stronger commitment to membership in theory-based categories than convenience-based categories (Rhodes & Gelman, 2009). Therefore, since most people's category for processes is driven by a theory based on sequential thinking, people are prone to apply sequential schemata to all

processes they encounter. People's commitment to conceptualizing all processes as sequential is very difficult to change.

In order to address these misconceptions, we need to help people learn the new emergent category and construct an emergent schema. Before we do that however, people need to be able to properly distinguish emergent and sequential processes so they do not make more mistakes by misplacing processes into the wrong category. So in this study, we focus on teaching people how to correctly categorize the two kinds of processes.

### **Proposed Approach: Teaching Second-Order Features**

We have discussed in the previous sections why it is important to teach people to distinguish emergent from sequential processes. We also explained that these two kinds of processes are distinguished by second-order features. The second-order features are diagnostic of each category because they are exclusive properties that cannot exist in the other category (Chin-Parker & Ross, 2004). Furthermore, discrimination requires an understanding of both emergent and sequential features. Because people already have prior knowledge about sequential features, we postulate that successful discrimination depends on gaining sufficient knowledge of emergent features. A main goal of this study is to test this assumption.

This main interest of teaching emergent second-order features to distinguish two kinds of processes is different from many other studies which also targeted at teaching emergent topics. Other studies often chose a few specific emergent processes such as natural selection and traffic jam, and they focused on students' understanding of these selected processes rather than distinguishable features between emergent and sequential processes (Resnick, 1996; Levy & Wilensky, 2008; Dickes & Sengupta, 2013).

Studying categorization of processes in itself is a relatively new direction, as few studies have examined this aspect in human category learning. Category learning research typically focuses on perceptual categories, which are made up of artificial objects or models (Ashby & Maddox, 2005; Markman & Ross, 2003). Using artificial objects to study human category learning has two advantages: 1) the artificial category is unfamiliar to most people and novel; 2) features of an artificial category are easy to manipulate. With our focus, while we also want people to learn an unfamiliar category which is emergent processes, we cannot manipulate the features of this category and most processes belonging to this category have already been incorrectly classified in another category. Therefore, our current study shall shed light on category learning of real life processes and perhaps mostly importantly how to overcome people's prior mistakes in categorization.

### **How to Effectively Teach Emergent Second-Order Features**

If we want to examine the effect of learning emergent second-order features on people's categorization of processes, we must first ensure students can correctly learn second-order features. Therefore, the next main question is how to effectively teach second-order features of emergent processes? In the following section, we shall attempt to answer this question with three considerations: 1) how to prepare people to learn emergent features; 2) how to address the learning paradox of learning emergent features when people don't have any prior emergent knowledge; and 3) which teaching method should we choose to teach emergent features?

**Introducing levels of processes.** We need to prepare people to learn about second-order features because people rarely think about processes in this level. For most people,

it is easier to focus on properties of individual agents than their interactions (Gentner & Kurtz, 2005). Second-order features that describe relationships of these interactions are even harder to reason since they must consider multiple interactions at the same time (Viskontas, Morrison, Holyoak, Hummel & Knowlton, 2004). Therefore, before introducing concepts of emergent second-order features, we need to provide people with general concepts about the multi-level structure of the processes (such as pattern, agents, and interactions). Basically, we want people to be first aware there are levels in the process, then at the micro level agents interact with each other, and there are relationships between these interactions. With a hierarchical structure of process in mind, their attention can be directed at the second-level.

**Use contrast cases of emergent and sequential processes.** We must also consider the learning paradox, namely how can people generate new knowledge about emergent processes when they lack prior knowledge for emergence (Bereiter, 1985; Smith, diSessa, & Roschelle, 1994). To overcome this barrier, we need to develop method that allows people to generate emergent features based on their existing knowledge on sequential features.

The solution to address the learning paradox employed by Chi, et al. in 2012 is to have learners contrast cases of emergent and sequential processes. By displaying the two kinds of processes side by side; the discrepancies between them create cognitive conflicts that need to be resolved. Because emergent processes have features that are consistently opposite to sequential features, we can have people generate emergent features based on sequential features. In essence, the use of contrast cases in this study was different from the traditional application of contrast cases for analogical transfer. In analogical transfer,

people compare the cases to induce the common abstract structure the cases share (Gentner, Loewenstein & Thompson, 2003; Gick & Holyoak, 1983). In short, we want people to contrast two cases with opposite underlying structure to induce novel features.

**Generation of emergent features followed by direct telling.** The next consideration concerns with the instructional design where knowledge differentiation is important. Schwartz and Bransford (1998) argued that people need to be properly prepared before such concepts can be taught. Schwartz and Bransford's method involved having people analyze different cases in order to generate a pattern. After analyzing cases, participants received a lecture corresponding to the concepts they analyzed. Their experiments had two important implications regarding this method of preparation. First, analysis of different cases was better than simple elaboration or summarization of text, indicating analyzing provided people with better insight into differentiated knowledge structure beyond the task of generating something on their own. Second, analysis followed by a lecture was better than analyzing different cases twice, indicating that direct telling was important to help people organize and make sense of their analysis and additional analysis cannot replace telling (Schwartz & Bransford, 1998).

Schwartz's and Bransford's study (1998) is highly relevant to teaching emergent second-order features since the general principle of preparing people to learn differentiated knowledge can be applied here. In our case, we also want to draw people's attention to the differences in second-order features between emergent and sequential processes. A differentiated knowledge structure at that level should facilitate learning of emergent second-order features. However, our interest is also different from Schwartz's and Bransford's study (1998) in that the concepts we want to teach are directly opposite

to some pre-established ideas and we want people to focus only on second-order differences, compared to just noticing some pattern or agent level differences. Therefore, instead of pattern generation analysis of contrasting cases, we would like our participants to focus on thinking about the opposite properties between emergent and sequential processes at second-order level. In order to achieve that, we shall first have participants read through one pair of emergent and sequential processes, then show them the second-order features of sequential processes instantiated with the case they just read, and finally have them think about the opposite features based on what they have read and try to instantiate them with the emergent case. After each attempt to generate the opposite emergent feature based on a sequential one, the correctly instantiated emergent second-order feature would be shown to people. This step serves as the direct telling step to help people make sense of the features they just generated.

***Importance of feedback:*** We believe giving direct feedback is of vital with emergent concepts when most people are novices with them. The lack of any prior knowledge in emergence would make the task of generating emergent features very difficult and cognitively demanding (Paas, Renkl & Sweller, 2003). Without any form of feedback, learners can become frustrated and lost during the task. Past research has found that providing feedback is better than no feedback (Shute, 2008); and with novice learners, elaborative feedback is better than simply telling them they are right or wrong (Hanna, 1976; Moreno, 2004). These finding suggest that feedback is most effective when it is used to explain rather than simply verify answers. It is consistent with the notion that they should serve the function of direct telling in a learning activity.

***Doing generation before direct telling:*** On the other hand, generation before directly giving out the concept is also important; because it can potentially induce deeper understanding of the target concepts and can promote transfer. Past research has shown that when generation was coupled with direct instruction afterwards, students were more likely to apply what they learned to a new situation compared to students who received direct instruction first (Schwartz, Chase, Opezzo & Chin, 2011). The similar result can be observed even when students did not successfully generate the target concepts (Kapur, 2012). Even failures at generation can still be helpful because it allows students to pay more attention to correct answers in direct instruction later on (Chi, Leeuw, Chiu & LaVancher, 1994).

**Summary.** In short, generation followed by direct feedback may have two benefits: 1) inducing deeper understanding of the concepts and 2) reducing confusion by giving elaboration of correct answers. And this kind of instructional design should be applied to teaching emergent second-order features when most of the learners are novices and we want them to understand the features well enough to transfer. Only then can we expect to see a successful learning outcome in distinguishing new processes.

### **Two Main Research Questions and Proposed Research Design**

All the above discussions about pedagogical concerns serve one purpose: to come up with a design that can teach emergent second-order feature effectively. We want to identify the most effective method to teach these features, and this leads to our first research question: *“Are both generation and direct telling necessary to facilitate effective learning of emergent second-order features?”* Answering this research question may

demonstrate that “generate before direct telling” can be effective in teaching complex concepts like emergence where most people lack any prior schema.

We want to teach emergent second-order features effectively, so we can answer our main research question raised earlier: *“Does learning emergent second-order features provide people with a better ability to distinguish between emergent and sequential processes?”* Investigation into this question can provide evidence that second-order features serve the diagnostic purpose based on Chi’s theory (Chi, et al., 2012); it may also shed light into how people naturally categorize various processes and what reasoning they provide when they categorize processes.

In order to investigate the two main research questions raised above, we developed an experimental design that included four different conditions facilitating three different types of comparisons. 1) In our first comparison, the “generate with feedback” condition is compared to the “generate without feedback” condition to test the importance of direct telling in teaching emergent features. 2) In the second comparison, the “generate with feedback” condition is compared to “read and explain difference” condition to test the importance of generating features first before directly telling them. The “read and explain” difference condition will let participants read emergent features first and then explain difference between emergent and sequential features. 3) In the last comparison, the “generate with feedback” condition is compared to the “sequential only” condition to test the importance of teaching emergent features. The “sequential only” condition focuses on teaching sequential features and not emergent features.

## **Hypotheses**

We make three hypotheses based on the research question and design discussed above:

- 1) Participants in the “generate with feedback” condition can distinguish the two kinds of processes better than participants in the “sequential only” condition, as emergent and sequential processes differ by second-order features and most people only lack any emergent knowledge.
- 2) Participants in the “generate with feedback” condition can distinguish the two kinds of processes better than participants in the “generate without feedback” condition. This will occur because direct feedback can clarify and complete the emergent features, improving participants’ ability to learn them.
- 3) Participants in the “generate with feedback” condition can distinguish the two kinds of processes better than participants in the “read and explain difference” condition. This will occur because generation of features sets up differentiated knowledge structure that facilitates the effect of direct telling.

## CHAPTER 2

### MATERIALS AND METHODS

#### **Participants**

Participants were undergraduate students from a public university in the southwest US who participated in the study fulfilling their introductory psychology class requirements. There were 132 participants (58 male and 74 female) with 33 for each condition. Their average age was 19.152 (SD = 1.536).

#### **Materials**

**Introduction to Processes.** The introduction to processes was mainly verbal text with a few supplementary images. The text was 509 words long and it provided the basic structure of all processes by defining the following terms: process, macro level, micro level and interactions. After each definition, the term was also instantiated with the example “holding a concert”. The supplementary images were generic images relating to concerts (concert hall, playlist, performers) to help depict the terms defined in the text. At the end of this section, we provided another generic image depicting interactions (with three circles and arrows between them); we also described another process “spreading of disease” to reiterate concepts covered in this section. All verbal text in this section was original and written by the author. All images were found online.

**Cases of Emergent and Sequential Processes.** Cases are essential for this experiment because they were used in both assessment and learning activities. All cases included both a verbal part and a video part to supplement each other. They were constructed with existing material collected from the internet (National Geographic, USAtoday, encyclopedia Britannica, etc. for verbal materials; youtube for video materials)

or a science textbook (i.e. college level introductory biology and chemistry textbooks for processes like diffusion and evolution). These verbal sources usually focus on describing first-order relationships (interactions). For example, regarding birds flying in a V-shape, the case from USAtoday focused on the aerodynamics of how one bird's wing stroke uplifts another bird behind it. Regarding planes flying in a V-shape, the case from encyclopedia Britannica focused on how pilots and especially lead pilots use various methods to communicate and coordinate with others during the flight. These existing materials talked about interactions but did not give away second-order relationships.

For each verbal case, we selected three parts from the original source: the general background of the processes, description of agents and description of the interactions. Transition sentences may be added to link the texts together in certain cases. But most text selected from the original source was kept intact. Each case was approximately 200 words long. The supplementing video counterpart for each verbal case varied between 30 to 120 seconds in length; they were selected based on two criteria: 1) the video must contain a clear view of micro-level interactions of the system; 2) the video must also demonstrate multiple interactions occurring at the same time. These two criteria allow the second-order relationship to be derived from videos. All videos were muted during the experiment so they did not provide any additional information beyond the visual representation.

Example verbal parts of cases were given in Appendix A.

**Second-order features of process cases.** Verbal texts describing second-order features were constructed for each sequential or emergent process used during the learning activities. A text first described some interactions of a concrete process, then

described the second-order features by specifying how these interactions are related to each other in certain ways. We avoided using technical terms (e.g. restricted, random, dependent) in these texts of second-order features to reduce confusion.

Example features were given in Appendix B.

**Prompts.** Three generic prompts were used to elicit responses from participants in all conditions when they were learning the processes. Seven to ten prompts were delivered when participants were learning the second-order features. Prompts about second-order features differed across conditions as a part of the manipulation, which will be described in the Manipulation section.

In all these prompts, we avoided using technical terms (e.g. sequential, emergent, second-order) to reduce confusion.

## **Measures**

In this experiment, pre-test and post-test served the purpose of assessing participants' ability to categorize emergent and sequential processes before and after the experiment. These assessments are composed of cases of processes that needed to be sorted into two unlabeled categories. Both pre-test and post-test also contained open-ended responses for participants to explain their categorization.

**Pre-test.** There were two isomorphic versions of the pre-test (A and B, see Table 2). Each version contained four sequential processes and four emergent processes. In both versions, the processes included human activities, scientific phenomena and natural processes. Following the eight cases, the categorization task asked participants to sort them into two unlabeled categories. In the next part, several open-ended questions were given for each category. The first question asked for definition of the category; the

second question asked for three common features of the category; the third question asked which processes were hard/easy to categorize and why they were hard/easy. These questions were repeated for the second category.

**Post-test.** The post-test also had two isomorphic versions (Table 2). Each version contained 12 cases: eight cases were identical from the different version of pre-test; four additional cases were added to serve as transfer items. The four additional cases were identical between the two versions of post-test. The post-test had similar categorization task and open-ended questions compared to the pre-test.

Table 2  
*Sequential and Emergent Processes Used in Two Versions of Assessments*

		<b>Version A</b>		<b>Version B</b>	
		<b>Sequential</b>	<b>Emergent</b>	<b>Sequential</b>	<b>Emergent</b>
<b>Pre-Test</b>		Controlled Burning	Forming Snowflake	Lion Hunting	Sand Dune Forming
		Bee Dancing	Fish Schooling	Building Skyscraper	Building Termite Mound
		Elephant Family Migration	Stock Market Exchange	Military Parade	Wikipedia Page Editing
		Using Barometer	Gas Pressure	DNA Replication	Natural Selection
<b>Post-Test</b>		Lion Hunting	Sand Dune Forming	Controlled Burning	Forming Snowflake
		Building Skyscraper	Building Termite Mound	Bee Dancing	Fish Schooling
		Military Parade	Wikipedia Page Editing	Elephant Family Migration	Stock Market Exchange
		DNA Replication	Natural Selection	Using Barometer	Gas Pressure
		Penguins in Long Winter	Traffic Jam	Penguins in Long Winter	Traffic Jam
		Transcytosis	Diffusion	Transcytosis	Diffusion

*Note.* Blocks with same shading have identical cases.

## **Procedure**

After consenting to participate in the study, participants were randomly assigned to one of the four conditions. At the beginning of the experiment, all participants took the pre-test. After that, all participants read the “introduction to processes”. Then depending on the condition, they went on to learn second-order features with different learning activities (in more detail below). Finally they all took a post-test. All steps in the experiment including pre-test, introduction to processes, learning activities and post-test were carried out via an online learning platform called WISE (web-based inquiry science environment). This platform allowed participants to conduct all required actions in this experiment (such as categorizing processes, answering prompts, reading cases, etc.) from a lab computer and data was automatically collected.

**Manipulation.** Following the “introduction to processes”, participants contrasted two pairs of processes in four different ways (Figure 2). The first three conditions contrasted two pairs of emergent and sequential processes. The two pairs of processes were: birds flying in a V-shape and planes flying in a V-shape; human population growth and ants’ reproduction. For each pair, we chose processes that resemble each other at macro-level because we do not want participants to differentiate processes based on pattern differences.

For the sequential only condition, participants contrasted two pairs of sequential processes. The two pairs of cases chosen for this condition were: planes flying in V-shape and people forming human pyramids; ants’ reproduction and salmon’s reproduction. The two pairs were also chosen because they share some macro-level similarity.

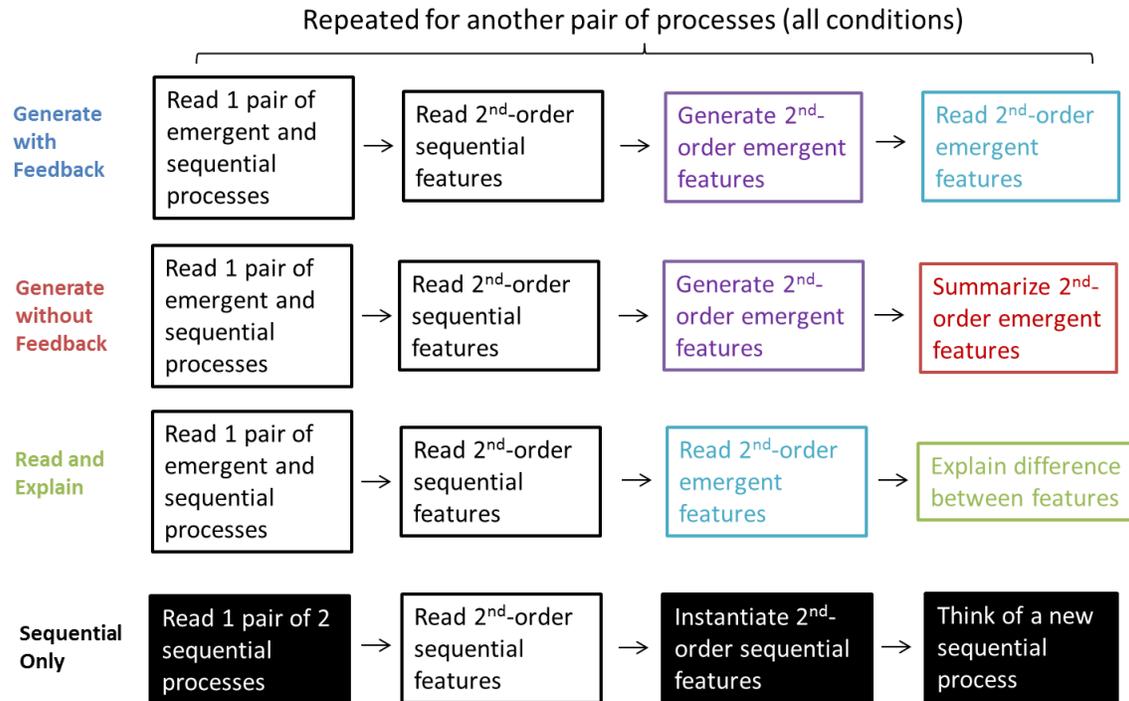


Figure 2. Different Learning Steps of Four Conditions. Same colored boxes represent same activities across conditions at each step.

**Generate with Feedback Condition.** Participants first read the texts and watched the videos of one pair of emergent and sequential process cases. Then they answered three generic questions (What is the pattern? What are the agents? What are the interactions?) to ensure they understand these processes. After that, they read instantiated sequential features. Five feature generation prompts were delivered to ask students to generate the opposite emergent features. A feature generation prompt first explicitly pointed out a sequential second-order feature instantiated in a sequential process case, then asked students to generate the opposite second-order feature that applied to the emergent process case. Examples of feature generation prompts for all five features were given in Appendix B. Finally, they read instantiated emergent features as feedback.

Participants repeated this procedure for a second pair of processes.

***Generate without Feedback Condition.*** Participants first read the texts and watched the videos of one pair of emergent and sequential process cases. They answered the same three generic questions as the “generate with feedback” condition listed above. After that, they also read instantiated sequential features and answered the same feature generation prompts as the “generate with feedback” condition to generate the opposite emergent features. Instead of receiving correct features as feedback, after students generated all five emergent features, they were given a feature summary prompt to summarize the emergent second-order features they generated and use these features to describe the emergent process case.

Participants repeated this procedure for a second pair of processes.

***Read and Explain Difference Condition.*** Participants first read the texts and watched the videos of one pair of emergent and sequential process cases. They answered the same three generic questions as the two conditions listed above. After that, instead of generating emergent second-order features, they read both instantiated sequential second-order features and emergent second-order features of the contrasting process cases. They were given five explaining difference prompts to self-explain the differences of the sequential and emergent second-order features in their own words.

Participants repeated this procedure for a second pair of processes.

***Sequential Only Condition.*** Participants first read the texts and watched the videos of one pair of sequential process cases. They answered the same three generic questions like other conditions. Then they read sequential features instantiated in one of the cases, and were given five feature rewriting prompts. A feature rewriting prompt asked students to explain how the same sequential second-order feature could be applied to the other

case. After they reiterated the five sequential features, students were asked to come up with a new process they have experienced and describe how the five sequential features applied to that process.

Participants repeated this procedure for a second pair of processes.

## CHAPTER 3

### RESULTS

#### **Data Analyses**

Based on our assessments, we were able to collect and analyze two kinds of data. The categorization scores reflected participants' accuracy in their categorization of processes. On the other hand, the open-ended responses reflected participants' reasoning in their categorization. How we calculated the categorization scores and coded the open-ended responses was described below.

**Categorization Scores.** In both the pre- and post-tests, participants sorted processes into two categories. Their accuracy scores of categorization were calculated by finding out the proportion of processes in the appropriate categories. We shall demonstrate how this was done with an example in the post-test: One participant put five emergent processes and three sequential processes in the first category, three sequential processes and one emergent process in the second category. At this point, we would call his first category "emergent" because that category had more emergent processes than sequential processes; and vice versa, we can call his second category "sequential". With the categories defined, this participant had five emergent processes in his emergent category and three sequential processes in his sequential category. His total number of correct cases was then added up to be eight. Since the post-test contained 12 processes, we divided eight by 12 and got a proportion score of .667.

The above procedure can be applied to most situations, except when participants had same amount of emergent and sequential processes in their categories. In that situation,

the participant would receive a score of .5 and this serves as the baseline score for categorization.

**Coding of Open-ended Responses in Pre- and post-tests.** We also coded the open-ended responses given when participants explained their reasoning for their categorization choices. This was done to confirm that participants who differentiated emergent and sequential processes actually understood emergent and sequential concepts, as opposed to reasoning using unrelated logic. For the open-ended questions, participants were asked to define their category, list three features for this category, and then explain if some processes were easy or hard to categorize. Using this format, participants provided six pieces of information for each category: one definition, three features, one easy categorization response, and one hard categorization response. Because participants performed this process twice (once for each category) for the pre-test and twice for the post-test,  $24 (2*6+2*6)$  pieces of information were available for coding to probe at participants' reasoning of their categorizations. Most of these pieces contained a few words or one sentence and we treated each piece of information equally as one unit of analysis.

Based on our theoretical framework, emergent and sequential processes differ in the second-order features and causal mechanisms; they are not distinguishable by agent and pattern properties, or first-order relationships (agent interactions). Therefore, we coded participants' responses based on the levels of the processes they choose to focus their reasoning on. The types of codes for open-ended responses were: 1) pattern/agent, 2) first-order, 3) sequential second-order, 4) emergent second-order and 5) other/none (which stands for reasoning not pertaining to process itself or no content). In this coding

scheme, we decided to group pattern/agent reasoning together because they were often indistinguishable in the participants' responses. For example, one participant defined his category in the pre-test by saying "These processes all involve humans doing the experimenting." In this response, "humans doing the experimenting" focused on both humans as agents as well as doing experimenting as the pattern. A full list of codes and their definitions, coding criteria and examples of the codes are given in Appendix C.

### **Results of Categorization Scores**

**General Results.** The duration of experiment, excluding pre- and post-tests was compared across four conditions using ANOVA; no significant differences were found:  $F(3, 128) = .376, p = .771$ . Mean experimental length was 40 minutes ( $SD = 13$ ). Participants' pre-test categorization scores were compared across four conditions using ANOVA, and no significant differences were found:  $F(3, 128) = .293, p = .830$ .

To compare experimental conditions, we performed an ANCOVA with post-test categorization scores as the dependent variable, conditions as the independent variable and pre-test as the covariate. Results indicated no main effect of experimental condition. We also compared pre-test to post-test scores with paired sample t-test for each condition to examine the difference in categorization accuracy before and after the experiment. These results, as well as descriptive data of categorization scores, are displayed in Table 3 below:

Table 3

*Categorization Scores and T-test Results for All Four Conditions*

Conditions	Pre-test	Post-test	Pre to Post T-Test	
	Mean (SD)	Mean (SD)	<i>t</i>	<i>p</i>
Generate with Feedback	.599(.116)	.647(.106)	1.834	.076
Generate without Feedback	.579(.093)	.593(.065)	.731	.470
Read and Explain Difference	.591(.105)	.619(.130)	.952	.348
Sequential Only	.602(.110)	.593(.083)	-.402	.690

Paired sample T-test results showed that only the “generate with feedback” condition showed trend level improvement in categorization score from pre- to post-test. As indicated in Table 3, categorization scores stayed the same before and after the experiment in the other three conditions.

**Planned Comparisons Between Conditions.** Pairwise comparisons that tested our three hypotheses were carried out using a regression model with contrast codes. The two compared conditions would be coded as +1 (generate with feedback condition) and -1 (the other condition that was compared to) while the two conditions not compared would be coded 0. Pre-test categorization scores were also included as a covariate in the model. Results for planned comparisons are shown in Table 4 below.

Table 4

*Regression Results for Planned Comparisons between Generate with Feedback**Condition and Other Conditions*

Comparisons	<i>B</i>	<i>SE</i>	<i>df</i>	<i>t</i>	<i>p</i>	$R^2_{y(x.x)}$	Tolerance
Generate with Feedback vs. Generate without Feedback*	0.026	0.012	1	2.12	0.036	0.034	0.996
Generate with Feedback vs. Read and Explain Difference	0.014	0.012	1	1.102	0.273	0.0092	0.999
Generate with Feedback vs. Sequential Only*	0.027	0.012	1	2.185	0.031	0.035	1

*Note.*  $R^2_{y(x.x)}$  denotes squared semi-partial correlation. Tolerance indicates % of non-overlapping variance.

Planned comparisons confirmed two of our three hypotheses. The “generate with feedback condition” was significantly better than the “sequential only” condition, as well as the “generate without feedback” condition in facilitating participants’ categorization of emergent and sequential processes. However, our hypothesis, which predicted that the “generate with feedback” condition would outperform the “read and explain difference” condition, was not supported.

### **Open-ended Response Coding Results**

**General Results.** For checking inter-rater reliability, 14 participants’ pre-test and post-test responses (10.6% of total data) were randomly selected from the sample and coded by a second researcher. Inter-rater reliability using Cohen’s kappa was .816,  $p < 0.001$ .

For each participant, the number of responses pertaining to each type of reasoning (i.e., pattern/agent, first-order, emergent, sequential, or other/none) was calculated for both pre- and post-tests. The mean number of each response type and standard deviation are shown in Table 5.

Table 5

*Mean Number of Responses Using Different Reasoning and Their Correlation with Categorization Scores*

Type of Response	Pre-test	Post-test
	Mean Number of Responses (SD)	Mean Number of Responses (SD)
Pattern/Agent	7.962(2.742)	6.758(3.160)
First-order	.773(1.239)	.818(1.138)
Sequential	.796(1.203)	1.167(1.534)
Emergent	.250(.785)	.508(1.195)
Other/None	2.220(2.400)	2.750(2.901)

Results in Table 5 indicate similar trends in participants' reasoning used to justify their categorization choices for both pre- and post-tests. Overall, pattern level reasoning and agent level reasoning were the most common type of reasoning participants utilized when they categorized processes. The second most common type of reasoning used was other/none. First-order reasoning and sequential reasoning was rarer than the two types mentioned above. Emergent reasoning was the rarest type of reasoning among the 5 types.

ANCOVA with Bonferroni correction was conducted for each response type to test for conditional differences. Specifically, we conducted a series of ANCOVAs using the number of responses pertaining to a particular type of reasoning in the post-test as the dependent variable, conditions as the independent variable, and number of responses pertaining to the same type of reasoning in pre-test as the covariate. We adjusted for family-wise error rate by dividing our chosen  $\alpha$  by 5:  $.05 / 5 = .001$ . We found no significant difference across conditions for response types. For pattern/agent reasoning:  $F(3, 127) = .420, p = .739$ ; for first-order reasoning:  $F(3, 127) = 1.525, p = .211$ ; for sequential reasoning:  $F(3, 127) = .863, p = .462$ ; for emergent reasoning:  $F(3, 127) = .617, p = .605$ ; for other/none reasoning:  $F(3, 127) = .280, p = .839$ . Because our hypotheses did not make strong claims regarding the degree to which participants can express their reasoning after the manipulation, planned comparisons were not conducted for any response type.

**Multiple Regression Analyses.** Finally, we conducted two multiple regression analyses with pre-test or post-test categorization scores as dependent variables, and the number of each type of response as predictors. These analyses inform us, out of the 5 types of reasoning, which types of reasoning are the strongest predictors of accurate categorization. Results for multiple regression analyses are shown in Tables 6a and 6b.

Table 6a

*Multiple Regression Analysis Results for Pre-Test*

Types of Reasoning as Predictors	<i>B</i>	<i>SE</i>	<i>df</i>	<i>t</i>	<i>p</i>	$R^2_{y(x.x)}$	Tolerance
First-Order*	-.017	.007	1	-2.381	.019	.037	.969
Sequential	.009	.008	1	1.140	.256	.0085	.785
Emergent*	.041	.012	1	3.310	.001	.076	.816
Other/None	.002	.004	1	.484	.630	.0015	.944

Table 6b

*Multiple Regression Analysis Results for Post-Test*

Types of Reasoning as Predictors	<i>B</i>	<i>SE</i>	<i>df</i>	<i>t</i>	<i>p</i>	$R^2_{y(x.x)}$	Tolerance
First-Order	.006	.007	1	.775	.440	.0037	.956
Sequential	.012	.007	1	1.757	.081	.019	.584
Emergent*	.029	.009	1	3.360	.001	.071	.606
Other/None	.003	.003	1	1.116	.266	.0077	.875

*Note.*  $R^2_{y(x.x)}$  denotes squared semi-partial correlation. Tolerance indicates % of non-overlapping variance. Number of pattern/agent level reasoning was excluded as a predictor due to multicollinearity in both pre-test and post-test analyses.

Results from the multiple regression analyses indicate that for the pre-test, first-order level reasoning and emergent reasoning were both significant predictors of the pre-test categorization score. However, first-order reasoning was negatively correlated with the score while emergent reasoning was positively correlated. For the post-test, only emergent reasoning was a significant predictor of post-test categorization score, also having a positive relationship similar to the first model. These results support the validity

of our pre- and post-test categorization scores. They show that using emergent reasoning was the most significant indicator of higher scores in both pre- and post-tests. This implies that successful categorization in pre-test and post-test requires some level of emergent thinking and participants who got high scores did not categorize processes using other types of reasoning.

## CHAPTER 4

### DISCUSSION

#### **Summary of Findings**

In this study, we wanted to find out whether teaching second-order emergent features could improve recognition of emergent processes. We also wanted to find an efficient way to teach these features. To achieve these two goals, we compared participants' categorization accuracy of processes across four learning conditions. Specifically, we compared one condition that we considered to be optimal in teaching emergent features (generate with feedback condition) to three other conditions: one condition did not inform participants about the correct emergent features after they attempted to generate them (generate without feedback condition), one condition where participants read emergent features and explained their differences from sequential features instead of generating them (read and explain difference condition), and the control "sequential only" condition that taught only sequential features. Our hypotheses predicted that "generate with feedback" condition would lead to better categorization of processes compared to the other three conditions because it incorporated both generation tasks and feedback. We found that "generate with feedback" condition was better than "generate without feedback" condition and "sequential only" condition; it was also the only condition that showed marginal improvement from pre- to post-test. In addition, we coded participants' reasoning behind their categorization and found that emergent reasoning was the strongest predictor of categorization accuracy, even though emergent reasoning was not

expressed very often when participants categorized processes in both the pre- and post-tests.

Learning emergent concepts and using them to recognize new emergent processes is very difficult. In our study, most participants did not improve much in their understanding of emergence since they could not use emergent reasoning to help them categorize processes even after the intervention. Despite this, this study demonstrated that teaching generalizable emergent second-order features is a promising approach to foster understanding of emergence. We achieved some success in improving students' ability in recognizing emergent processes when we taught them emergent second-order features through generation and feedback. There are two implications regarding this finding: 1) Emergent second-order features are crucial for understanding emergent processes, 2) Emergent second-order features are learnable. Although we have only achieved very moderate success at this point, we demonstrated the feasibility in teaching generalizable emergent concepts.

Our findings suggest that directly providing emergent features is an important step when using contrasting cases of emergent and sequential processes to teach emergence. This step is important because participants may not be able to notice discrepancies between the two kinds of processes due to low prior knowledge about emergence and similarities to sequential processes at the pattern level (Chi & Brem, 2009; Chinn & Brewer, 1993). Directly providing emergent features can point participants to the right direction and help them make more meaningful comparisons with the contrasting cases. This step combined with some generative task to compare emergent and sequential processes can be a good strategy in teaching emergence.

## **Limitations of the Study**

One limitation of this study is the quality of the generation prompts in both “generate with feedback” and “generate without feedback” conditions. The description of the prompts might be inadequate to direct students’ attention to second-order relationships, resulting in a high possibility for students to generate random information unrelated to second-order features. For example, one prompt asked participants to notice “how things are carried out in a sequence of actions” for planes flying in V-shape and then “apply the opposite property to birds flying in V-shape”. The intention of this prompt was to have participants notice that interactions happen simultaneously in emergent processes. However, one participant assumed that this prompt was referring to how things are unchangeable in a sequential process and generated a feature saying that “flight commands may changes under the circumstances”. In the future, we should write more specific generation prompts that take into consideration potential ways that people can misunderstand them.

Another limitation of this study was that we did not provide participants an abstraction of the emergent concepts in the learning materials. The features participants read in the “generate with feedback” and “reading and explain difference” conditions were always instantiated in the context of a concrete process (e.g., birds flying in V-shape or human population growth). Kaminski, Sloutsky, and Heckler (2013) used the term “concreteness” to refer to the amount of information given to students through a specific instantiation. They found that students exhibited worse performance on transfer tasks when they learned concepts using highly concrete instantiations. In our study, we used

instantiated features so students can relate these novel emergent concepts with processes they are familiar with; however, without taking that concreteness away, participants could fail to recognize the deep structure underlying emergent processes, hindering subsequent transfer. In the future, after contrasting concrete processes and reading instantiated features, there should be a consolidation phase that introduces the abstracted emergent features to the participants.

Besides methodological issues, the study was very limited in time. Participants only engaged in learning activities for approximately 40 minutes and only learned two pairs of contrasting processes. The aforementioned methodological limitations and short learning time could explain why even our most successful condition (i.e., “generate with feedback”) only marginally improved people’s categorization of emergent and sequential processes. Most of the participants were still novices in terms of understanding emergent processes because they were still unable to transfer emergent features to help them recognize emergent processes. In sum, we believe that there are three ways we can improve our instruction to achieve better learning outcomes: 1) design more specific prompts to help participants focus on the second-order relationships, 2) teach abstracted emergent features as the consolidation phase of our instruction and 3) extend the learning time for the participants.

## CHAPTER 5

### CONCLUSION

We conducted this study to test whether people can distinguish emergent and sequential processes better by learning emergent second-order features. Although a few flaws and the limitation in time may have hindered the results, our study did demonstrate that learning emergent features and using emergent reasoning can lead to better categorization. We also found that participants were not able to generate emergent features on their own and the features should be provided to them. These results are important because they showed that our vision of first teaching people to distinguish the two kinds of processes is feasible and it may serve as a pre-cursor for further instructions on deeper emergent concepts. The results also provided valuable information (i.e. providing correct information for generative task) that can help us improve future instructional designs about emergent processes. This study should be the first of a series of research that would lead to a complete set of instructional materials to help students get rid of their robust misconceptions in science and improve their understanding of those topics.

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APPENDIX A

EXAMPLE VERBAL PARTS OF CASES

<p><b>Birds Flying in a V-shape</b></p>	<p>During a flight, scientists have found that birds position themselves and time their wing beats so perfectly that, according to aerodynamic theory, they minimize their energy use. It's a task that requires each bird to monitor subtle changes in its wing mates' flight and alter its own path and stroke accordingly. Each bird placed itself an average of four feet behind the bird in front of it and at an average angle of 45 degrees. That's just the configuration needed for individual birds to catch the rising air generated by the flapping of the bird in front of it. By capturing this rising air, or "upwash," the bird stays aloft more efficiently.</p> <p>But the birds do more to save their strength than simply choosing the right spot. Measurements of the birds' flaps showed the birds time their wing beats so precisely that they continually catch the upwash left behind by the moving wings of the guy or gal ahead. That means a bird regulates its stroke so its own wingtips trace the same path in the sky as the bird in front. If a bird happens to get a little closer to or farther from the bird it's following, it instantly adjusts its wing beat accordingly.</p>
<p><b>Planes Flying in a V-shape</b></p>	<p>All navigation, radio transmissions, and tactical decisions are made by the flight leader, who is typically the most experienced pilot. The other pilots in a formation are known as wingmen, and it is their responsibility to follow the leader and to maintain a constant position relative to the lead aircraft. This is called "position keeping." Any change in relative position between aircraft is considered movement by the wingmen.</p> <p>In the case of a single wingman, his goal is to keep his distance from the leader constant by choosing two features on the lead aircraft and keeping them aligned in the same way from his viewpoint. Any change in the alignment of these two features indicates that his relative position to the leader has changed. In larger formations the other wingmen either hold position on the plane in front or alongside of them or look through that airplane at the lead aircraft and hold position on the leader.</p> <p>Flights are briefed so that all pilots know what to expect and so that, generally, no one except the leader needs to speak on the radio. Leaders use hand signals, head nods, aircraft movements, or radio calls to alert their wingmen of changes in flight attitude, formation positions, split-ups, rejoins, and radio frequencies.</p>

## APPENDIX B

### EXAMPLE LEARNING MATERIALS FOR THE FIRST CONDITION

<b>Pairs of Second-order Features</b>	<b>Instantiated Second-order Features of Sequential Process</b>	<b>Feature Generation Prompts</b>	<b>Instantiated Second-order Features of Emergent Processes (Provided After Generation)</b>
Distinct vs. Similar	When planes are flying in a V-shape, navigation decisions are made by the leader while wingmen maintain a position by following the leader. The leader and wingmen will behave differently based on different responsibilities.	Read the text above carefully, especially regarding how members interact differently depending on their roles. What would be the opposite property to that? Apply the opposite property to birds flying in V-shape and write it down below.	When birds are flying in a V-shape, however, each bird flaps and adjusts their flapping behavior according to another bird in front of it. Therefore, each bird does more or less the same thing compared to other birds in the group.
Restricted vs. Random	When planes are flying in a V-shape, the role of leader and wingmen at each position is determined before the flight, so most pilots follow the exact same person throughout the process.	Read the text above carefully, especially regarding how members seem stuck with who they can interact with. What would be the opposite property to that? Apply the opposite property to birds flying in V-shape and write it down below.	When birds are flying in a V-shape, there is no plan as which bird should fly where, one bird may end up following any other bird in the group.
Sequential vs. Simultaneous	When planes fly in V-shape, any change in attitude or position is first signaled by the leader either through gesture or radio calls. The leader would give a signal first and then wingmen will carry out the instruction.	Read the text above carefully, especially regarding how things are carried out in a sequence of actions. What would be the opposite property to that? Apply the opposite property to birds flying in V-shape and write it down below.	When birds fly in V-shape, however, since each bird is tracing the path of the bird in front of them at the same time, any change in their behavior can also happen at the roughly same time.
Dependent vs.	When planes fly in	Read the text above	When birds are

Independent	V-shape, the wingmen must watch and follow the leader's signals; they take actions based on these signals, and they cannot take action without them.	carefully, especially regarding some interaction must be based on some other interactions. What would be the opposite property to that? Apply the opposite property to birds flying in V-shape and write it down below.	flying in a V-shape, each bird behaves and adjusts its flying behavior based on its own surrounding conditions; they do not have to worry about other bird's flying behavior except the one in front of it.
Terminate vs. Continue	When the V-shape is dispersed or when the show is over, the leader stops giving commands, and the pilots can stop holding position to another plane.	Read the text above carefully, especially regarding how interactions stopped at a point. What would be the opposite property to that? Apply the opposite property to birds flying in V-shape and write it down below.	Even when the V-shape is sometimes disrupted or broken, birds would still adjust positions based on its local environment behind another bird to get the "upwash".

APPENDIX C  
CODING CRITERIA AND EXAMPLE RESPONSES

Names and Definitions of Codes	Coding Criteria	Example of Codes
<p>Pattern/Agent: Reasoning based on macro-level or micro-level properties of processes</p>	<p>General description of the overall process, this could be describing the visual pattern, the main theme, the main event, etc. Or focus on agent properties such as identity of agents, actions of agents, motivation behind agents, natural property of agents, etc.</p>	<p>“Category one is the formation of a large group”  “Involve formation and growth on something”  “Non-biological events”  “Involved living organisms: animals, humans, insects”  “These processes all involve humans doing the experimenting”  “Actions are for survival”</p>
<p>First-Order: Reasoning based on interactions between agents and how they relate to each other</p>	<p>This one is coded when the description of agent actions link multiple agents together, or describe dependency or relation of any sorts between agents. The most usual key word is “together”, phrases describing agents “working together” “moving together” “have a community” can be coded first-order (unless they infer some sequential or emergent reasoning).</p>	<p>“These animals work in a cohesive manner allowing everyone to depend on each other”  “Activity between things that occur and what is formed”  “Organism working together”</p>
<p>Sequential: Reasoning describing sequential properties at the second-order level or inter-level</p>	<p>Coded when any of the sequential second-order features was mentioned, or when the reasoning infer at the causal relationship of sequential processes: emphasis on leadership, control, planning, goal matching pattern, etc.  Notes:  When coding about “control”, for the most part, it is coded sequential if it is controlled by humans, as this often indicates a central causality from within the process. However, if the controlling factor is external or about nature/environment, it is not considered sequential and should be coded pattern/agent. If what is controlling is not</p>	<p>“Clear leader to follow and clear roles exist”  “the actions of that one individual affect the actions of one or more individuals, or at least contribute to the overall effect”  “Category 1 consisted of premises where the agents involved were consciously and willingly contributing to the process”  “Category two is all processes that are organized, and its members have specific roles to complete a goal or goals”  “The group could control by themselves”  “Individuals coming together for a common goal.”</p>

	<p>specified, code as sequential. When coding about “goals”, it is coded sequential if there’s indication this goal is shared by many agents and matches the pattern, so phrases like “common goal”, “they work together to...” should be coded sequential. However, if they were simply mentioning agents “want to” or “have a goal”, it is unclear if the goal matches the pattern, and therefore should be coded pattern/agent.</p>	
<p>Emergent: Reasoning describing emergent properties at the second-order level or inter-level</p>	<p>Coded when any of the emergent second-order features was mentioned, or when the reasoning inferred at the causal relationship of emergent processes that are often opposite to sequential ones: emphasis on the lack of leader or control (spontaneity), equality of all individual contributions, etc. Regarding spontaneity, if participants simply mention that something happen “naturally” it is not considered emergent because most of these responses refer to the overall pattern that happen in nature, and it should be coded pattern/agent. Regarding equality of all individual contribution, usually the key word is “as a whole”, if they indicate the pattern is driven by the whole thing instead of parts, code as emergent.</p>	<p>“This category are events that happen by themselves”  “They are all similar processes that naturally occur, where roles do not play a big part”  “Fluid motion, each individual can respond in the same way, no leader, no restriction on the individual”  “Something that doesn’t require guidelines to occur”  “Population progressed as a whole as opposed to parts of a whole”</p>
<p>Other / None: Participants did not provide sufficient reasoning in the response that is relevant to any</p>	<p>Mostly coded when participants express confusion, provide description with no reasoning or categorize based on their personal experience: comment on familiarity, difficulty and etc. of the processes to themselves. Also</p>	<p>“This one was a little obscure but it seems to go better in category 2 than 1”  “It is very good and I like it”  “It is simple”</p>

level of the process	coded when participants do not provide a response or copy a response.	
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In addition to the coding scheme mentioned above, it should also be noticed that some codes can potentially overlap with each other: for example, many mentions of first-order relationship also described actions of agents. We decided to not assign multiple codes in these situations because mentioning properties and actions of agents are often required to describe many first-order relationships, or even second-order relationships. To clarify the coding protocol, a hierarchical order of the following is decided:

Pattern/Agent < First-order < Sequential = Emergent

This order basically means when multiple elements are detected in a response, the codes will be assigned to the highest level in this order, so there was a preference to assign emergent and sequential codes over first-order codes, a preference to assign first-order codes over agent codes, and a preference to assign agent codes to pattern codes.