An experimental study of segregation mechanisms

SUPPORTING APPENDIX

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1. Simulation

Our simulation to a large extent replicates the model studied by [*7*]. Agents in the model are situated on a two-dimensional 6x6 grid. At every time period, an agent is selected uniformly at random from the population and given the opportunity to relocate if it is unsatisfied. The agents have local information and evaluate the nearest four available locations in the up, down, left and right directions, as well as their current location. If agents identify a single strictly best available location among these, they move to (or stay at) it; if they identify multiple best locations, they randomly choose to relocate to one of them. Thus, as in [*7*], we assume that agents use a myopic best response, while we also restrict the agents' information and movement to more accurately reflect our experimental design.

To generate predictions for the experiments, we ran 1000 simulations for each utility function in Figure 1A-D and each population size in the range 13-25. We ran each simulation for 100,000 time periods and recorded the outcome in the last period, regardless of whether a stable equilibrium was reached.

Our results largely replicate the results in [*7*]. We find that segregation obtains even in the presence of a preference for diversity (segregation is similar for the Same and the Same and Diverse utility function) and that integration is possible only when there is no homophily (i.e. for the Diverse utility function; Figure S1A). In other words, segregation results from the asymmetry of preferences for similar and different neighbors. Segregation obtains for the Same and Diverse utility function because the best-response dynamics eliminate ideal locations quickly and leave only less satisfactory ones. Thus, the dynamics pose a coordination problem – agents need to collectively coordinate on more optimal outcomes, which also happen to be the less segregated equilibria.

Generally, the equilibria for the Same and Diverse utility function are characterized by low average scores (Figure S1B). Compared to the Same utility function, adding diversity only slightly lowers segregation but at the cost of a large drop in collective happiness. In contrast, preference for diversity without homophily (the Diverse utility function) achieves ideal integration at only slightly lower efficiency than just homophily (the Same utility function).

The Diverse utility function also produces the outcomes with highest clustering (Figure S1C). While pure homophily (Same) results in a segregated world with clusters with clear boundaries, pure preference for diversity (Diverse) produces tightly knit and well-integrated communities.

The results are largely robust to alternative information and moving rules, as long as the myopic best-response assumption remains. The results hold if we assume global information and global movement, as in [*7*]. They also hold if we assume that agents pick the best location on the whole grid but can only move to the nearest empty spot toward it in one of the four major directions, that is, if we assume global information and local movement. These analyses are not reported here but are available from the authors upon request.

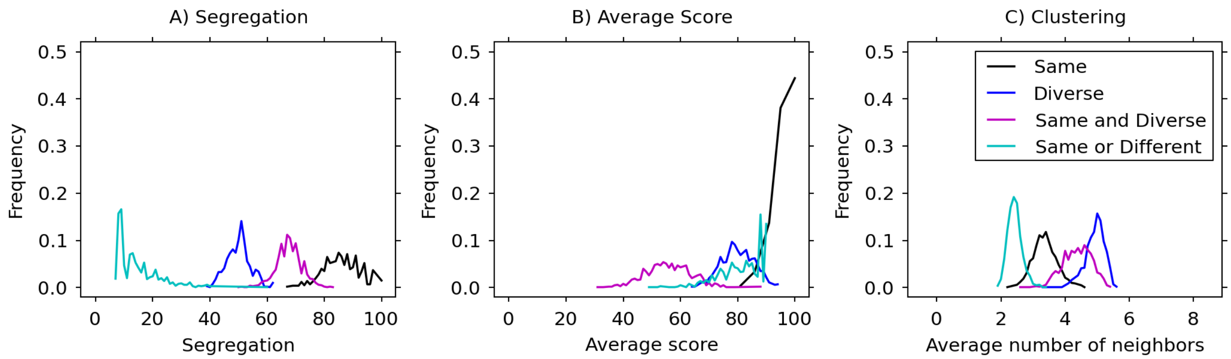


Figure S1. The predictions from the simulations for group size 20. Results are shown for (**A**) average percent of same-color neighbors, (**B**) average score, and (**C**) average number of neighbors.

2. Experiment Design

The experiments were conducted as part of an interactive demonstration on mathematical modeling that we presented to high school students in Sweden. The demonstrations aimed to combine disseminating scientific ideas to the general public with collecting data for research. We conducted the sessions in November 2014, December 2014 and March 2015.

Using this population group had a number of advantages and disadvantages. In Sweden, minors in schools do not require parental permission to participate in research conducted during regular class sessions. This age group has almost universal familiarity with computer games and digital devices. This meant that the participants would not only understand the game rules and the game interface more readily but would also be more engaged in playing the game. The latter was particularly important since we were not allowed to use monetary incentives in the school context.

We recruited classes from schools in the Uppland, Väster-götland and Dalarna provinces, which are in the east, the west, and the center of Sweden, respectively. The sample included both urban and rural, and both public and privately managed schools. The schools also largely varied in size. The classes we selected were from non-vocational specializations only, since they tend to have more extensive training in Mathematics. The contacted teachers were instructed not to inform the students what the session would involve, rather to say that researchers from Uppsala and Cornell University would allow them to participate in an experimental game on "modeling social processes."

The games were designed to be as simple and intuitive to play as possible. We restricted movement to a grid, rather than a torus, and to the four main directions, instead of including diagonal movement. We used numbers for the avatars to make them easy to track during the fast game dynamics. We presented the utility function in the form of a score bar, which is a common element in computer games (Figure S2). Most importantly, we allowed decisions to happen in real time, rather than in periods (Figure S3). On the one hand, this made the games stimulating and engaging. On the other hand, it helped us avoid forcing the model dynamics on the interactions in the experiment and consequently, prevented us from "cooking in" the theoretical predictions.

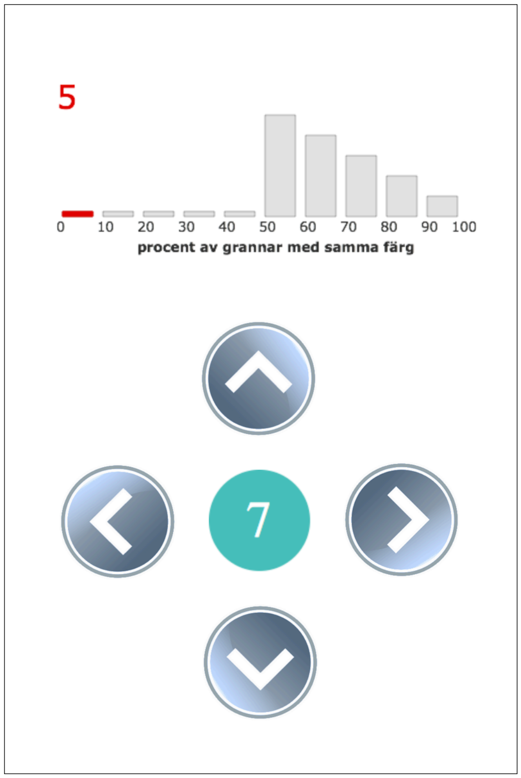


Figure S2. A screenshot of the game control as it was seen on a surf tablet.

We allowed communication during the games as students were in close proximity and full visibility of each other. The play caused a lot of excitement and loud comments, including exclamations of joy for obtaining high score, as well as curses about neighbors who misbehaved. Almost always, there were also students who suggested coordinating strategies to mutually solve the game. For example, in the Same game, someone would yell something similar to "blues to the left, yellows to the right." Surprisingly, this opportunity to coordinate strategies was not always successful. The fact that only three groups managed to coordinate on a checkerboard pattern and zero on a segregated pattern in the Same or Different Game demonstrates this.

At the beginning of the experiment, students' ID numbers were placed face down on their desk or chair. However, due to students being in close physical proximity to each other in the classroom, it was impossible to prevent them from sharing their ID with their neighbors. Further, the ID numbers were in order, as we needed to record the exact seating arrangement both for the demonstrations and for research, and hence students could potentially extrapolate the numbers for everyone else. Nevertheless, there is no evidence that this "weak anonymity" systematically biased participants' behavior (Figure S4). The games were so fast-paced (3.8 moves per second on average) that it was impossible to keep in mind other players' IDs and colors.

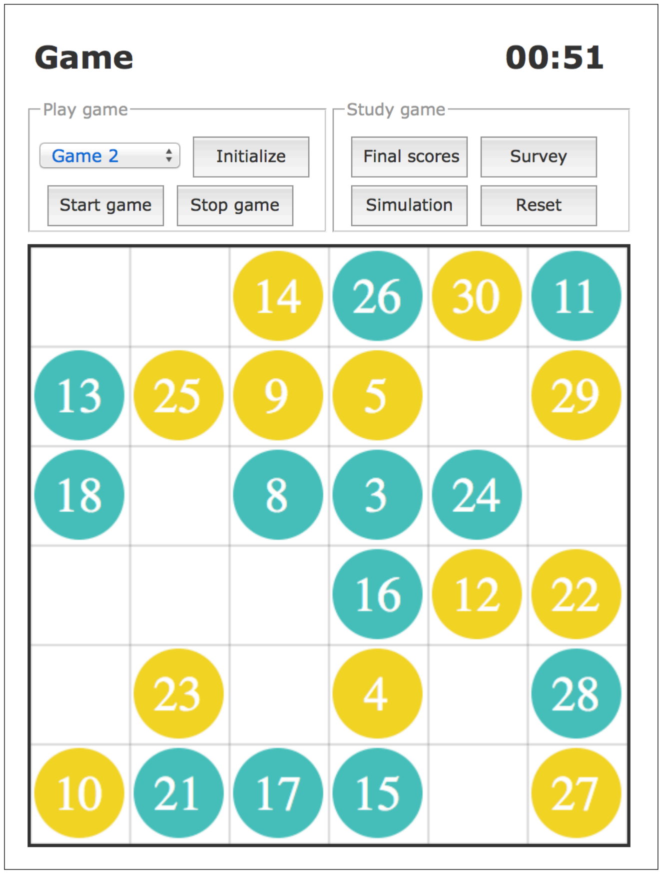


Figure S3. A screenshot of the game, which was projected on a screen at the front of the classroom.

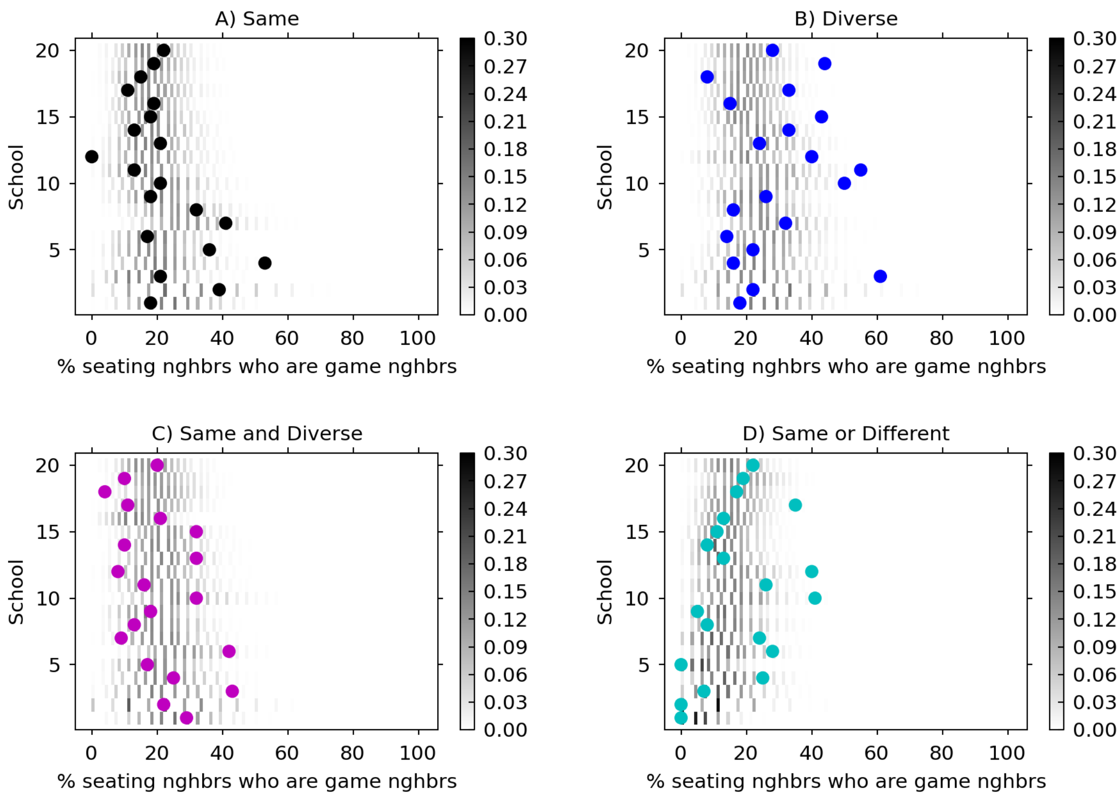


Figure S4. The average percent of participants' two immediate neighbors in the classroom (to the left and right) who were also neighbors at the end of each game. The solid circles show the percent observed in the experiment and the gray areas show the expected percent if individuals were randomly assigned to classroom seats.

3. Experiment Software

The game platform was developed as a Node.js application, entirely written in JavaScript and HTML 5. The application uses the WebSocket protocol to allow for an ongoing two-way communication between the server and the browser. Data are saved in a MongoDB database, which is a NoSQL database using JSON-like documents with dynamic schemas. All used software is free and open-source and the scripts and communication protocol are compatible with the vast majority of commercial web browsers. The source code for the game platform is available from the authors upon request.

4. Experiment Protocol

Students in the classes knew that they would be given an interactive demonstration on modeling a social phenomenon but were not informed what that social phenomenon was. At the beginning of the demonstration, they were informed that their decisions and answers would be recorded for research but kept confidential. The demonstration started with a brief description of the game setup. Then, students logged in the tablets with their assigned ID number, provided their first name, and answered a four-question survey. The survey asked them to indicate their gender (female or male), preferred pet (cat or dog), preferred school subject (Math or Swedish), and preferred leisure activity (computer games or outdoors). This information was used for the demonstration and the data collection process only. Specifically, we deleted the names from the database once we collected all data.

Students then played a trial run and after that, the four games in randomized order. Each time, they were given brief instructions about the score rules in the particular game and then allowed two minutes to play. The score rules were projected on the screen and thus, participants knew that they were all playing the same game. After the games, students were asked to complete a short survey on their national origin, academic aspirations, family socioeconomic status, and social network. Then, their final scores were revealed in a list on the screen.

At that moment, we revealed that the games were based on a mathematical model of segregation. We then gave a lecture on the problem of segregation and the Schelling model. In the lecture, we used the students' answers from the first four-question survey and the final configurations in the games to demonstrate the problem of segregation and the model. Additionally, the demonstration included a ten-minute segment in which students were asked to run simulations of the model (using a web application we had developed) in order to answer a few questions about the model behavior. The introduction and the games were lead in Swedish, while the lecture was given in English.

The following is the original English version of the demonstration protocol. This version was translated into Swedish for the experiments:

Segregation in Minutes

"Segregation in Minutes" is an educational demonstration and behavioral study that uses a web-based platform and an online real-time multi-player game. The session is introduced to students as an interactive lesson on mathematical modelling. To prevent behavioral and response bias, it is important not to reveal the topic of segregation to students before all data have been collected (see below).

The goal of the session is twofold:

1) to demonstrate basic concepts of segregation to students according to the Schelling model;
2) to collect data on individual and collective behavior for research.

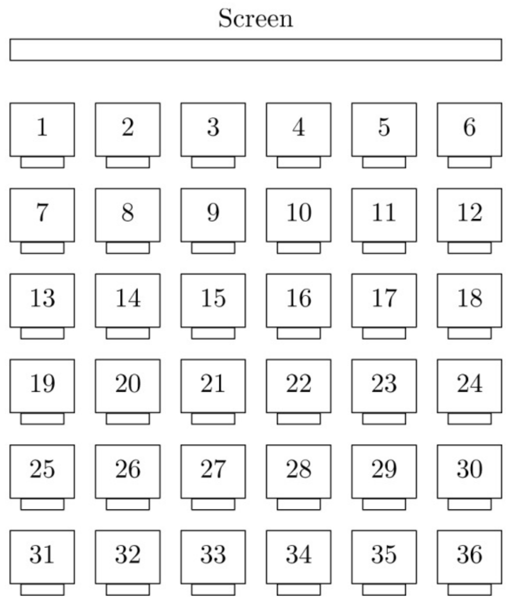
Required Equipment

- 25 surf tablets with a browser with capability for web sockets to serve as game "consoles" for each student
- Instructor's laptop
- 36 ID cards, numbered from 1 to 36 (the login ID)
- Overhead projector and screen

Method

1) Setup

- Arrange the seats in the classroom on a 6x6 square grid. On each seat, place one of the ID cards facing down. Arrange the cards so that the numbering increases consecutively from left to right and then from top to bottom:



- Choose (uniquely) one of the orders in which Game 1, Game 2, Game 3, and Game 4 will be played in the session.

1, 2, 3, 4	
1, 2, 4, 3	
1, 3, 2, 4	
1, 3, 4, 2	
1, 4, 2, 3	
1, 4, 3, 2	
2, 1, 3, 4	
2, 1, 4, 3	
2, 3, 1, 4	
2, 3, 4, 1	
2, 4, 1, 3	
2, 4, 3, 1	

3, 1, 2, 4	
3, 1, 4, 2	
3, 2, 1, 4	
3, 2, 4, 1	
3, 4, 1, 2	
3, 4, 2, 1	
4, 1, 2, 3	
4, 1, 3, 2	
4, 2, 1, 3	
4, 2, 3, 1	
4, 3, 1, 2	
4, 3, 2, 1	

- Log in to the site as admin and set up the session.

2) Students enter

- *Welcome. Please take a seat. You can sit wherever you would like.*

3) (3 min) Introduction

- *I will start by reading you the instructions for this session.*
- *You are about to participate in an interactive demonstration on mathematical modeling. (Mathematical modeling is about describing events with the help of mathematics.) First, you will play 4 different games. The tablets will serve as game controls; the game itself will be projected on the screen. Then, you will be asked to fill out a short survey. Finally, you will explore an interactive simulation model on which the games are based.*
- *At the beginning, we will ask you for your name but we will need it only for the demonstration. Eventually, we will anonymize all information and your name will be deleted. Your answers and decisions will be saved for research on mathematical modeling.*

4) (7 min) General game instructions

- *As I mentioned, we will start by playing 4 games. The games have different scoring rules but in each game, your goal is to score the highest number of points at the end of the game.*
- *In each game, your avatar is shown by a colored circle with a number. Your avatar will be one of two colors: either yellow or blue. All avatars are situated on a grid.*
- *On the grid, you can move your avatar left, right, up, or down to the next empty spot in the specified direction, if such a spot exists. If the spot immediately next to you is occupied by another avatar, you will jump to the next empty spot. If you are at the edge of the grid and there are no more spots in the direction you want to move, you will not move.*
- *In each game, your score depends on the color of your neighbors. A neighbor is anyone who occupies one of the 8 cells surrounding you. Thus, you can have at most 8 neighbors. However, if there are empty spots around you, you will have fewer than 8 neighbors.*
- *You can use your game control to move your avatar and track your score. The heights of the score bars show how many points you get for different percent of same-color neighbors. The red bar and the red text show your current score.*
- *The games have different scoring rules but in each game, your goal is to score the highest number of points at the end of the game. Each game will end once everyone is satisfied with their location and all movement has stopped, or after 2 minutes of play at most.*
- *After we are done with all 4 games, we will display each person's total score on the screen.*

- *Are there any questions?*

- Distribute tablets to all students. Describe how to handle the device.
- *To turn the tablet on, press the button on the corner of one of the long sides. To go to the desktop, press the arrow in the center at the very bottom of the screen. Please try not to press any other buttons or icons because that will interrupt your game. Feel free to rotate the tablet if you cannot view all of the information on the screen.*

- *To log in, please click on the Play icon on the tablet screen. Please log in to the site with the ID written on the card on your desk. Then, please submit the additional login information. You will then reach the game control. However, we need to wait for everyone to be done before you can use the game control.*

5) (4 min) Trial Run

- Wait for all students to complete the survey.
- *Before you play the games, we will do a trial run so that you can practice how to use the game control and how to follow your avatar on the screen. Your score from the trial run will not be used for calculating your final score. The trial run is intended for practice only.*
- *Your score will be between 5 and 100 depending on the percent of same-color neighbors you have and the particular game you are playing. Each score bar corresponds to different percent of same-color neighbors: between 0 and 9 percent, between 10 and 19 percent, and so on up to 100 percent. The height of each score bar shows how many points you get if you have that percent of same-color neighbors. The red bar corresponds to your current neighborhood and the red text shows your current score.*
- Select [Trial Run ▾] from the drop-down menu and [Initialize]. Read the Trial Run instructions. [Start game].

6) (4 x 3 min) Games

- *Now, we will play the 4 games. We will go over the scoring rules before each game. Remember, the score you obtain at the end of each game will be used to calculate your total score. At the end, we will display each person's total score on the screen.*
- For each of the four games: Select the game ([Game 1 ▾], [Game 2 ▾], etc.) according to the predetermined random order. [Initialize]. Read the game instructions. [Start game].

7) (5 min) Survey

- *Before we show you your final score, we would like to ask you to answer a short survey that we need for research. Your answers will be kept confidential and not shared with anyone who is not a researcher in our study. When you have completed the survey, please leave the tablet in front of you on your desk.*

8) (1 min) Final Scores

- Click on [Final scores] to show student scores.

9) (10 min) Lecture: Modeling Segregation

- *These games were designed to demonstrate to you the social phenomenon of* **segregation.**
- Show lecture slides 1–19.
- Use simulation model to demonstrate segregation outcome in mathematical model. [Display] results for [Game 1 Start] compared to [Game 1 End].
- Show lecture slides 20–21.
- [Display] results for [Game 1 End] compared to segregation in current seating arrangement as per the [Survey]. Use [Previous] and [Next] to cycle through the different survey answers.
- Show lecture slide 22.

10) (12 min) Simulation model

- Distribute task sheets to students.
- Show lecture slide 23.
- *You now have 10 min to use the simulation model and study what happens if people prefer both similarity and diversity. You can work in pairs or in groups of 3.*
- *To go to the simulation, please click on the Simulation icon on the tablet screen.*

11) (5 min) Lecture: Segregation and Integration

- *What did you find out?*
- [Display] results for [Game 1 End] compared to [Game 2 End].
- [Display] results for [Game 1 End] compared to [Game 3 End].
- Show lecture slides 24–26.

Legend

- To do
- To say
- To show from lecture slides

5. Additional Analyses

5.1. Time Series

Our analysis of the game dynamics suggests that most of the experimental groups converged to a dynamic equilibrium within the allowed two minutes of play. The convergence was remarkably fast in the Same game (Figure S5A and S5E) and relatively gradual in the Diverse game (Figure S5F). There was very little change in the levels of segregation and the average scores in the Same and Diverse game (Figure S5C and S5G), while the change in the levels of segregation in the Same or Different game shows a shift in strategies: an initial attempt at the "Same" strategy followed by the "Different" strategy. The latter game also exhibits the largest variation in dynamics and outcomes, similarly to the simulation predictions.

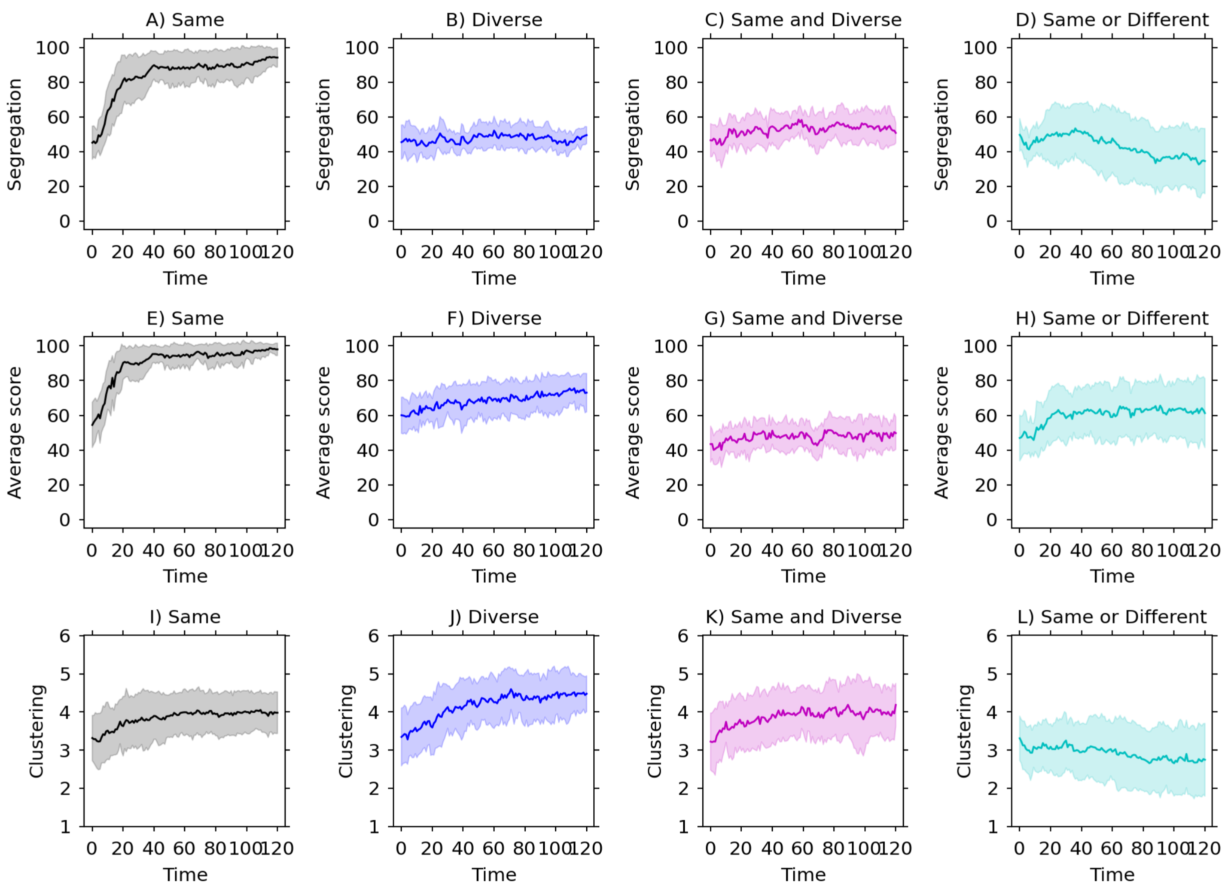


Figure S5. Time series of the level of segregation, the average score, and the average number of neighbors in the experiment. The figures show the mean and one standard deviation from the mean. The four columns correspond to the Same game, the Diverse game, the Same and Diverse game, and the Same or Different game.

5.2. Clustering

Overall, the experimental groups achieved clustering that is similar to the clustering predicted by the simulations. There was only a slight tendency for the Same game to end more clustered than predicted and the Diverse game to be less clustered than predicted (Figure S6).

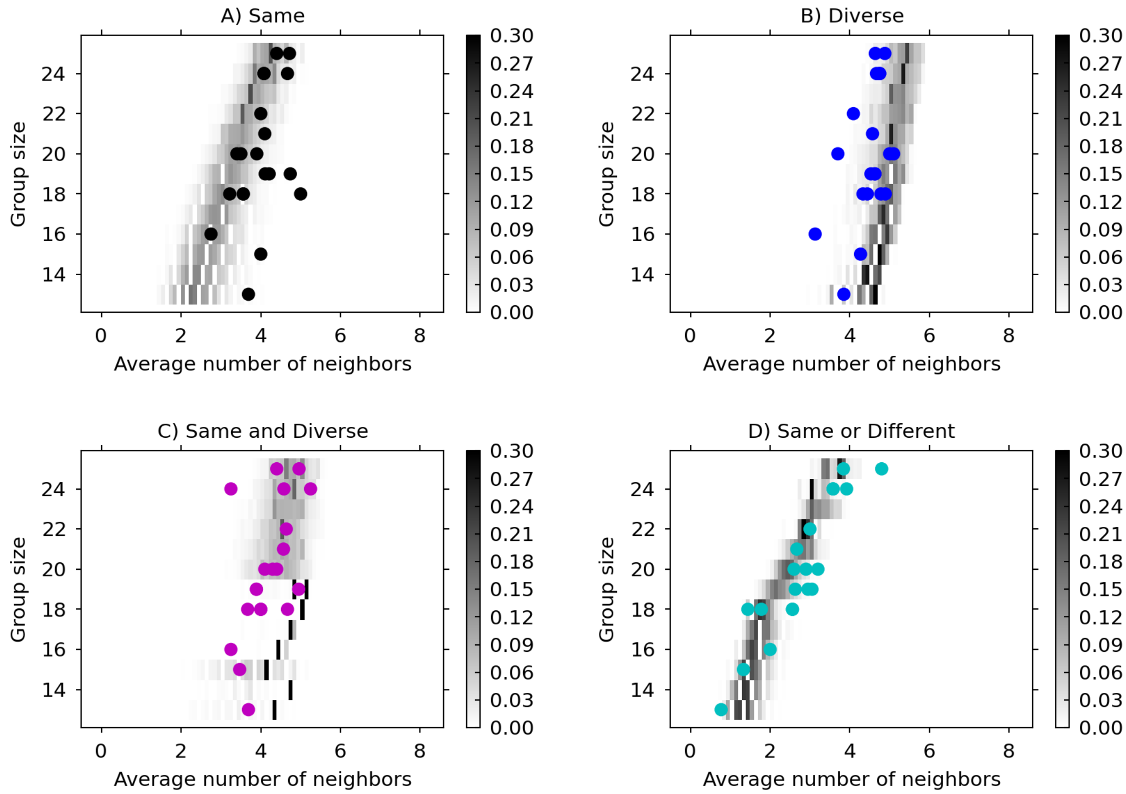


Figure S6. The average number of neighbors at the end of each game. The solid circles show the average number of neighbors in the experiment and the gray areas show the proportion of the simulation replications that predicted that particular average number of neighbors for each group size.

5.3 Movement Strategies

We investigated whether the moves were score-maximizing by plotting the percent of moves that originated in a certain score that resulted in another score. If participants moved mainly to locations that increased their scores, we would expect a higher number of moves in the right half of the plots on Figure S7. Except for the Same game, this is clearly not the case. It appears that participants chose a random direction when they decided to move. There is no evidence that they preferred the nearest empty spot that increased their scores.

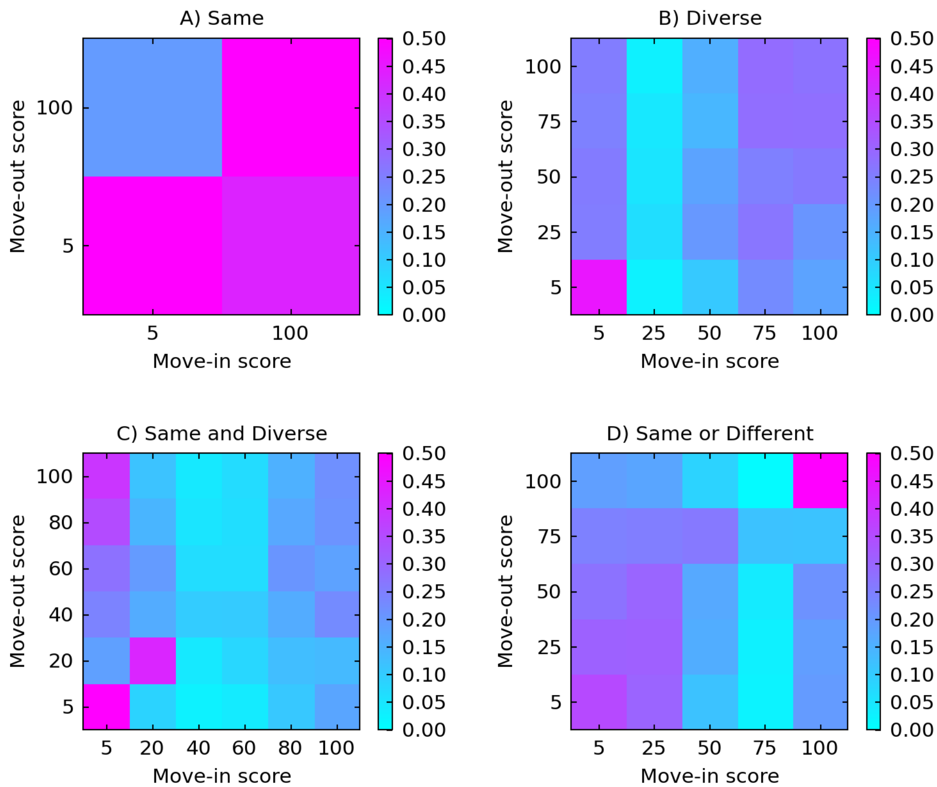


Figure S7. The frequency of score changes as a result of a move. The frequencies are normalized along each row. Each cell shows the proportion of moves away from a particular score (move-out score) that result in the move-in score.