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The Use of Board Games in Teaching Biodiversity for Sustainable Development: A Quasi-Experimental Method

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Abstract

This research aimed to develop and evaluate learning media for sustainable development, specifically through a board game entitled "Board Game Maju Indonesiaku". The game is designed around the dilemma between biodiversity conservation and economic development, covering four core systems concepts: economics, policy, society, and ecology. The study involved 61 middle school students who played the game for 360 minutes (180 minutes per week). Data was collected through post-test assessments and game performance. An independent t-test was used to analyze the post-test scores. The results showed a significant improvement in students' understanding, with a moderate effect size overall. Notably, there were large effects on the biodiversity concept dimension and moderate effects on the biological conservation concept dimension. The game performance analysis indicated that secondary school students faced challenges in achieving the four sustainable economic development goals. This research highlights the potential of game-based learning as an effective strategy for teaching complex concepts related to sustainable development. It also underscores the need for further refinement of educational tools better to support student understanding and application of these concepts.

Keywords: Board Game, Teaching, Sustainable Development, Quasi-Experimental Method

INTRODUCTION

The world's population has reached 7 billion in 2014 (Mochtar *et al*., 2014). By 2019, there were more than 7.7 billion people on the planet (Dasgupta *et al*., 2023) while the ecological footprint of the global population does not correspond proportionally with the availability of natural resources, energy, clean water, and food, all of which are increasingly diminishing. Smail (2017) pays attention to the widening gap between realistic scientific estimates of the Earth's capacity and reasonably accurate demographic projections of future global population growth, which is predicted to become more than 9 billion by the mid-twentieth century. United Nations predicts that the world population would reach 9.22 billion in 2075.

Global poverty and food shortages are worsening by the destruction of tropical forests. Between 1990 and 2020, deforestation destroyed about 420 million hectares of forest, with over 90% of that loss occurring in tropical regions (Ometto *et al*., 2022). Local populations' access to resources for food and income declines as forest ecosystems are destroyed (Pišl *et*

al., 2024). Human activities, such as burning fossil fuels and deforestation, have increased global greenhouse gas concentrations; atmospheric carbon dioxide levels have risen from 280 parts per million (ppm) in the late 1700s to today's level of about 400 ppm (Brown *et al*., 2015). This increase leading to extreme climate change, a stark manifestation of intertwined poverty and human rights violations, and poverty, with approximately 850 million people worldwide experiencing food shortages (FAO, 2023).

The United Nations Conference on the Human Environment held in Stockholm in 1972 and the Earth Summit's Declaration on Environment and Development in Rio de Janeiro in 1992 agreed on the principle that development must consider environmental and human dimensions. Effective resource use, biodiversity preservation, and intergenerational justice should all be included in sustainable development plans. In order to ensure that human needs and environmental integrity are addressed fairly, they must confront climate change, advance environmental education, and adopt waste-reduction technologies (Mahanayak, 2024). This agreement aligns with the World Summit on Sustainable Development in Johannesburg in 2002, which discussed ways to address environmental degradation.

The United Nations introduced the 2030 Agenda for Sustainable Development in September 2015, highlighting quality education as a primary objective (SDG4). Education is crucial in tackling sustainable development challenges (Tsai *et al*., 2021). It empowers learners to make informed decisions and take responsible actions for environmental integrity, economic viability, and a just society while respecting cultural diversity (Giangrande *et al*., 2019).

Science education aims to cultivate students into future citizens who can address global issues by employing problem-solving skills, collaboration, and informed decision-making (Choi *et al*., 2011). Runco (2007) stated that teachers should encourage creativity in the classroom and create an environment where students actively learn and develop their creative skills to create an environment that fosters creative solutions to the challenges societies encounter.

Game-based instruction has been implemented as a strategy to enhance student performance in terms of knowledge and skills in engaging students in the learning process (Carberry *et al*., 2023; Divjak & Tomić, 2011; Van Eck, 2006; Martí-Centelles & Rubio-Magnieto, 2014; Young *et al*., 2012). Compared to traditional teaching methods, game-based instruction significantly improves academic performance due to its interactive learning experiences, increased student motivation and engagement, and improved comprehension of

factual, conceptual, procedural, and metacognitive knowledge (Chen & Li, 2024). Therefore, many researches try to use games to teach many subjects in class. Games can be used to teach various subjects, from specialized knowledge to complex comprehension (Scurati *et al*., 2023). One of the interesting games applied in classrooms is the traditional board game. Tsai *et al*. (2021) use the board game Be Blessed Taiwan, designed to simulate the balance between economic development and biological conservation. The pre-game and post-game data collected from 34 high school students come from two schools. The result shows a significant increase in students' understanding of biodiversity concepts and a medium effect on biological conservation concepts. Shimabukuro *et al*. (2022) applied *Sui Maru*, a board game to teach water resources management by simulating conflict and cooperation. The board game test was conducted in Tarama Island, Japan, involving 5th grade elementary school students. Increased understanding was found. The findings show that the students realized the importance of cooperation in conserving water resources. The Sui-Māru board game is effective as an educational tool to increase environmental literacy, encourage discussion about water issues, and instill values of cooperation in resource management. Yusa & Hamada, (2023) developed the board game simulates the complexities of energy production and resource management from a Japanese perspective. Their study involved 50 undergraduate and graduate students who evaluated the game through a questionnaire after gameplay. The findings revealed that the game was highly enjoyable and effective in teaching the characteristics of various power sources.

The engaging aspect of game-based learning boosts students' motivation to participate in gameplay and tackle problems or decisions within the game's context. As active learners, students are expected to develop creative and critical thinking skills, which will aid them in solving complex and contentious issues (Franco Mariscal *et al*., 2012)

The focus should shift from teacher-centered to student-centered approaches to prevent teaching from becoming merely the transmission of knowledge to passive recipients and enabling students to gather learning materials independently. Courses should include simulation scenarios so that students can actively participate in the learning process, apply ideas, and make decisions.

To demonstrate conflict and competition between different points of view, instructional activities may include role-playing. It also allows students to communicate and work together in these challenging situations. Overall, courses of this type should provide students with opportunities to consider problems, make value judgments, and make decisions about what

they should do (Tsai *et al*., 2021). Maju Indonesiaku, a board game that teaches sustainable concepts, is the subject of this research. It is hoped that this board game can increase student participation by giving them the opportunity to learn independently through play activities.

"Board Game Maju Indonesiaku" is an educational game that aims to increase students' understanding of economic development and is intended for six players. This study utilizes the board game Maju Indonesiaku to introduce sustainable development concepts during gameplay.

The game's impact is assessed across four dimensions—social development, economic growth, environmental protection, and animal survival—reflecting sustainable development indicators. The game's design encourages students to communicate and interact freely, exploring the game world in a student-centered learning environment. Students independently strategize, make value judgments, and decide on their actions. This section will detail the thematic context, conceptual structure, rules, steps, and board game implementation.

Board games are widely applicable and can be used to teach various subjects. Teachers can create their own board games to meet specific educational objectives. The themes of board games are diverse and adaptable, covering topics related to scientific, environmental, and social issues. Typically, the most effective board games are designed by the teachers who use them (Tsai *et al*., 2021).

Roles

Farmers and fishermen specializing in agriculture and fishery focus primarily on grain production. Bisnisman and Hunters, emphasizing industry and commerce, can generate significant revenue to boost economic growth. Environmentalists advocate for a self-sustainable development model. In the game, players engage in discussions and strategic thinking to choose from seven economic facilities: farmland, fisheries, business districts, hunting huts, factories, ports, and roads.

Thematic Context

The board game "Maju Indonesiaku" simulates Indonesia's economic development process. Its educational aim is to encourage students to consider balancing economic growth with biological conservation and how to sustain the way of life in Indonesia while achieving sustainable development goals. The game's setting is DKI Jakarta, and students assume six roles: farmers, fishermen, Bisnisman, hunters, environmentalists, and government officers. Each role has distinct capabilities, with farmers & fishermen and Bisnisman & hunters on opposing sides. Students alternate as the government officer, who starts the game. Each role

has specific missions categorized into economic development and environmental conservation, leading to both conflicts and collaborative opportunities. Here is a summary of each role's duties that can be seen in Figure 1.

1. Farmers and fishermen: Produce food and fish to meet basic living needs.
2. Businessman and hunters: Hunt animals, trade fur, and build business districts or factories.
3. Environmentalists: Protect native species and prevent the introduction of exotic species.
4. Government officers: Develop policies and construct public infrastructure.

Figure 1. Role's Duties

The Ecological System

The ecological system is central to the game, focusing on biodiversity and integrating other core systems. It encompasses three concepts: species diversity, genetic diversity, and ecosystem diversity. The game highlights species diversity, including native and invasive species. Animal cards detail species' habitats, habits, characteristics, conservation status, and risks, helping students learn about animals while playing. in this game there are two endemic animals (bulus and bondol eagles) and two invasive animals (broomstick fish and arapaiman fish) that can be seen in Figure 2.

Figure 2. Endemic and Invasive Animals

The Social System

The social system reflects human cultural impacts, categorized into natural events, man-made events, and infectious disease events. Human culture shapes the game's atmosphere and interactions. Events such as climate disasters (e.g., hurricanes, droughts), human-induced disasters (e.g., habitat destruction, ocean pollution, economic crises), and infectious diseases (caused by fungi, bacteria, viruses, parasites, prions) influence students' thinking, judgment, and decisions. Genetic diversity affects species' immunity to diseases, teaching students that species with limited gene pools face higher extinction risks.

The Economic System

Besides unique missions and challenges, all roles share the goal of sustaining life in DKI Jakarta. As the game progresses, population growth pressures players to ensure livelihood. They must hunt animals, build business districts and factories to earn money, and invest in development or purchase food to maintain basic living standards and health.

The Policy System

The policy system features five neutral topics where students choose between economic development and environmentally friendly policies. Examples include farming vs. housing development and nuclear vs. offshore wind power. Students' policy votes influence economic performance and mission completion. Students must discuss policy choices within their groups and collaborate with others to succeed.

Rules and Steps of the Board Game

Players are divided into groups of six, each assigned two missions: economic development (50 points) and environmental goals (50 points). The group with the highest score out of 100 wins. Each group must sustain its population, with points deducted for deaths due to accidents or insufficient food. Extra points are awarded for maintaining a large population. The game has four phases: events, actions, policy decision-making, and settlement, briefly described below.

METHOD

For this study, both qualitative and quantitative data were collected. Two board game teams from senior high schools participated: Team A (Boys) and Team B (Girls). The board game-based teaching sessions lasted 180 minutes (90 minutes per week). Each team, comprising five groups, played three rounds in total.

Comprehensive post-game data were collected from the participating senior high school students. This data included their responses to a biological conservation concepts test,

interviews, and the game-playing outcomes. The biological conservation concepts test consisted of 10 items to evaluate the students' understanding of biodiversity and biological conservation. The researchers created the questions and reviewed by two experts in science education and a school teacher to ensure content validity. The test duration was 25 minutes. During the game sessions, the teacher recorded the results of each group for each round.

For quantitative analysis, the study used an independent samples t-test to evaluate the post-game scores on the biological conservation concepts test. Trend charts were utilized to analyze the gameplay process and outcomes. The game results were evaluated based on four indicators: economic development, social development, animal survival, and environment. Formulas, derived from relevant Organisation for Economic Cooperation and Development (OECD) literature were simplified to match the board game's parameters. The data recorded by the teacher during the game were input into Excel and converted into grade levels for each of the four indicators.

RESULTS AND DISCUSSION

The results of this study are divided into three categories: the effect on students' conceptual learning, the game-playing performance, and the results. The following section presents an interpretation and discussion of each of these categories.

Effect on Students' Cognitive Learning

The results in Table 1 show a difference in the average learning outcomes between male and female students for several tested concepts. For the concept of biodiversity, the average score for male students was 4.069, while for female students it was 3.5625. The t-test produced a t-value of -2.349 with a p-value of 0.022, indicating a significant difference. The effect size (Cohen's d) of 0.84100 indicates a large effect, suggesting a practically significant difference in learning outcomes between male and female students for this concept.

Table 1. Assessment of Scientific Concepts Related to Biodiversity Boys and Girls Classes

Assessment Dimensions (# of item)	Mean		SD		t-Value	Effect Size (Cohen's d)	Levene's Test for Equality of Variances	t-test for Equality of means
	Boys	Girls	Boys	Girls			Sig.	sig. (2-tailed)
Concepts of biodiversity (5)	4.07	3.56	0.80	0.88	-2.35	0.84	0.35	0.02
Concepts of biological conservation (5)	3.90	3.78	0.67	1.21	-0.45	0.99	0.00	0.65
Total (10)	7,97	7,34	1,47	2,09	-2,80	1,83	0,35	0,67

For the concept of biological conservation, the average score for male students was 3.8966, while for female students, it was 3.7813. Although the effect size (Cohen's d) of 0.99284 indicates a very large effect, the t-value of -0.453 with a p-value of 0.652 indicates that this difference is not statistically significant. Additionally, the data variance between the two groups was not homogeneous (Levene's Test p-value = 0.00), so the interpretation of these results should be cautiously approached.

Overall, this analysis shows a significant and practically important difference in learning outcomes for biodiversity between male and female students. The significant difference in learning outcomes for the concept of biodiversity suggests a potential disparity in how male and female students engage with or understand this topic. This result highlights a need to explore gender-related factors in teaching and learning, such as differences in interest, prior knowledge, or instructional methods. It is essential that students of all genders actively participate in class activities (Atanasova *et al*., 2024).

However, the difference in the concept of biological conservation is not statistically significant despite the large effect size. This indicates the need to carefully interpret results that show non-homogeneous data variance. In contrast, the results for the concept of biological conservation demonstrate the importance of considering both statistical significance and practical effect size. The effect estimate's statistical significance is not the issue but is practically inconsequential (Mcshane & Gelman, 2022). While the large effect size suggests a notable difference in outcomes, the lack of statistical significance and non-homogeneous variance advises caution. These results could indicate group variability or other external factors influencing the scores. This analysis emphasizes that different interpretations of educational data are needed, especially when differences in effect sizes or variances are found. To ensure equitable learning opportunities, researchers and educators must consider these things when evaluating teaching strategies and creating interventions.

The Results of Gameplay

Figures 3 and 4 look at how students played during the game based on the cumulative points they earned from each group each round. Each group has different missions and challenges, and each group can collect up to 60 points. In the first half, The Boy 1, The Boy 2, The Boy 3, The Boy 4, and The Boy 5 groups each obtained 10, 30, 20, 10, and 20 points. Performance improved drastically in the second half, where Groups The Boy 1, The Boy 2, and The Boy 4 maintained or increased their points, while Groups The Boy 3 and The Boy 5

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gained 20 and 30. Most groups improved their points by the third round, showing that understanding the rules of the game helped students find better solutions to their missions.

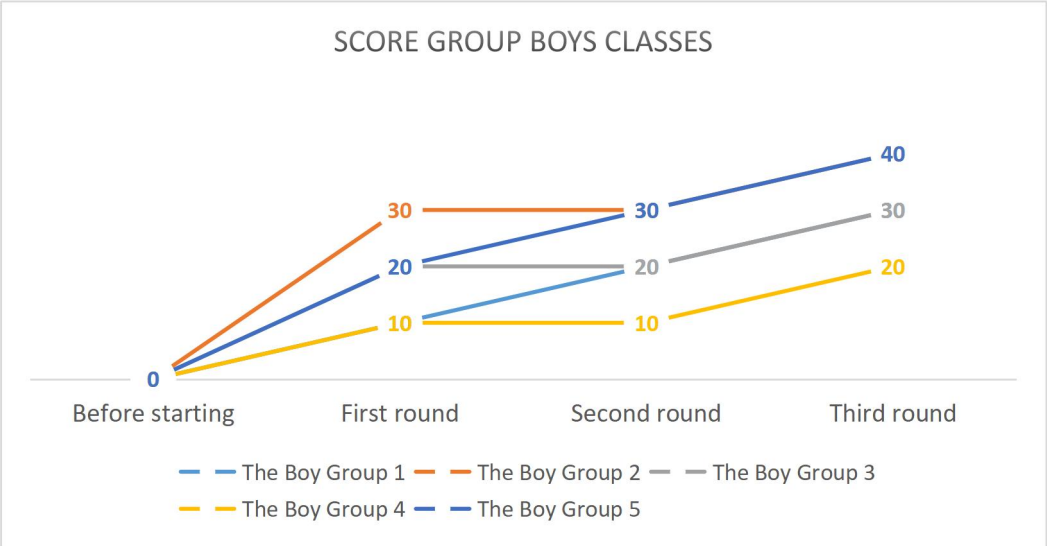

Figure 3. Group Score Boys Classes

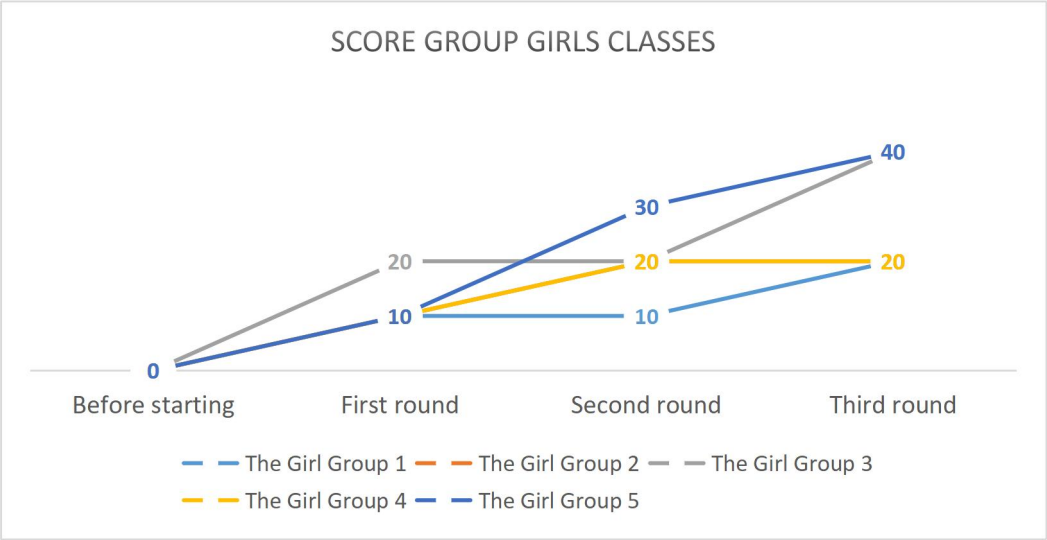

Figure 4. Group Score Girls Classes

Competition between groups increases during the game. The groups become more competitive during the game and create new strategies that allow offensive moves against other groups. These dynamics create new challenges, requiring groups to achieve their missions by balancing defensive and offensive strategies. The conditions in which groups compete encourage them to change their plans quickly. For example, due to direct interference from other teams, some groups stagnate or lose points. Due to interference by other groups, points sometimes drop. For example, The Boy Group 4 earned 20 points in the

third round, after only 10 points in the second round. From 20 points in the first half to 40 points in the third round, The Boy 5 Group experienced significant improvement. Strong internal communication and collaborative problem-solving skills are often demonstrated by superior groups. These groups can work well together to adjust strategies, optimize resource use, and overcome challenges, resulting in better scores. It is proven that increasing points depends on the group's ability to communicate and collaborate effectively, as well as their ability to develop an ideal strategy. Conversely, when there is too much competition, groups must change their plans regularly to avoid challenges and attacks, which can reduce points for both parties.

Consistent improvement over rounds shows that repeated gameplay helps improve strategic thinking and understanding complex rules. The need to respond to interference from other groups shows how important it is to think flexibly and change strategies in pressure situations. This skill is especially important in real-world situations where situations and factors can change unexpectedly.

Performance Evaluation Based on Production and Conservation

In addition, Figures 5, 6, 7, and 8 show the group's ability to maintain ecosystem balance and manage resources. The group's efforts to achieve sustainable economic development goals are shown in graphs of food production and the number of native and non-native species. For example, additional points are usually awarded to groups that successfully maintain populations of native species and prevent the introduction of alien species. It explains how the final outcome of the game can be influenced by strategic environmental conservation decisions.

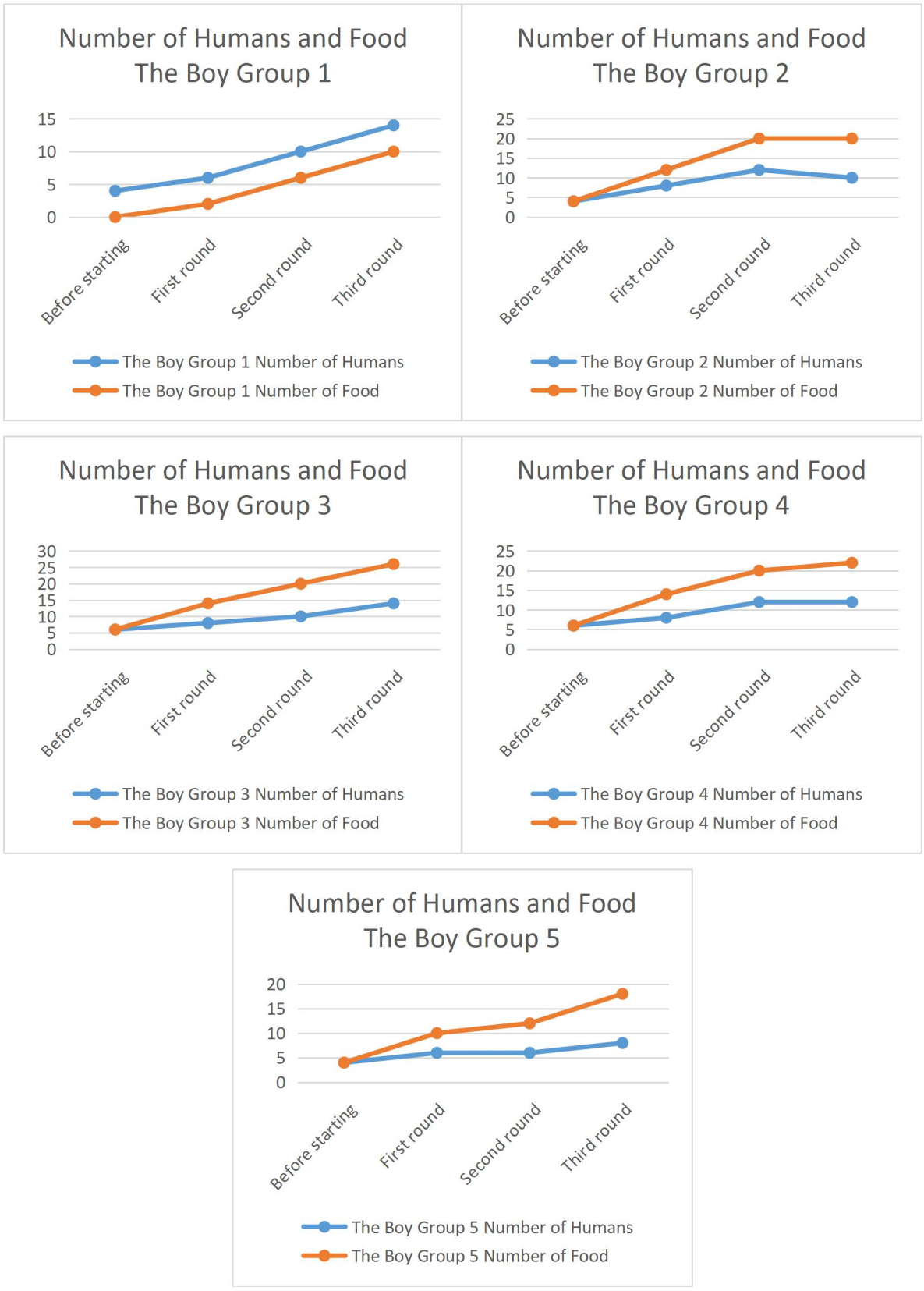

Figure 5. Number of Human and Food The Boys Classes

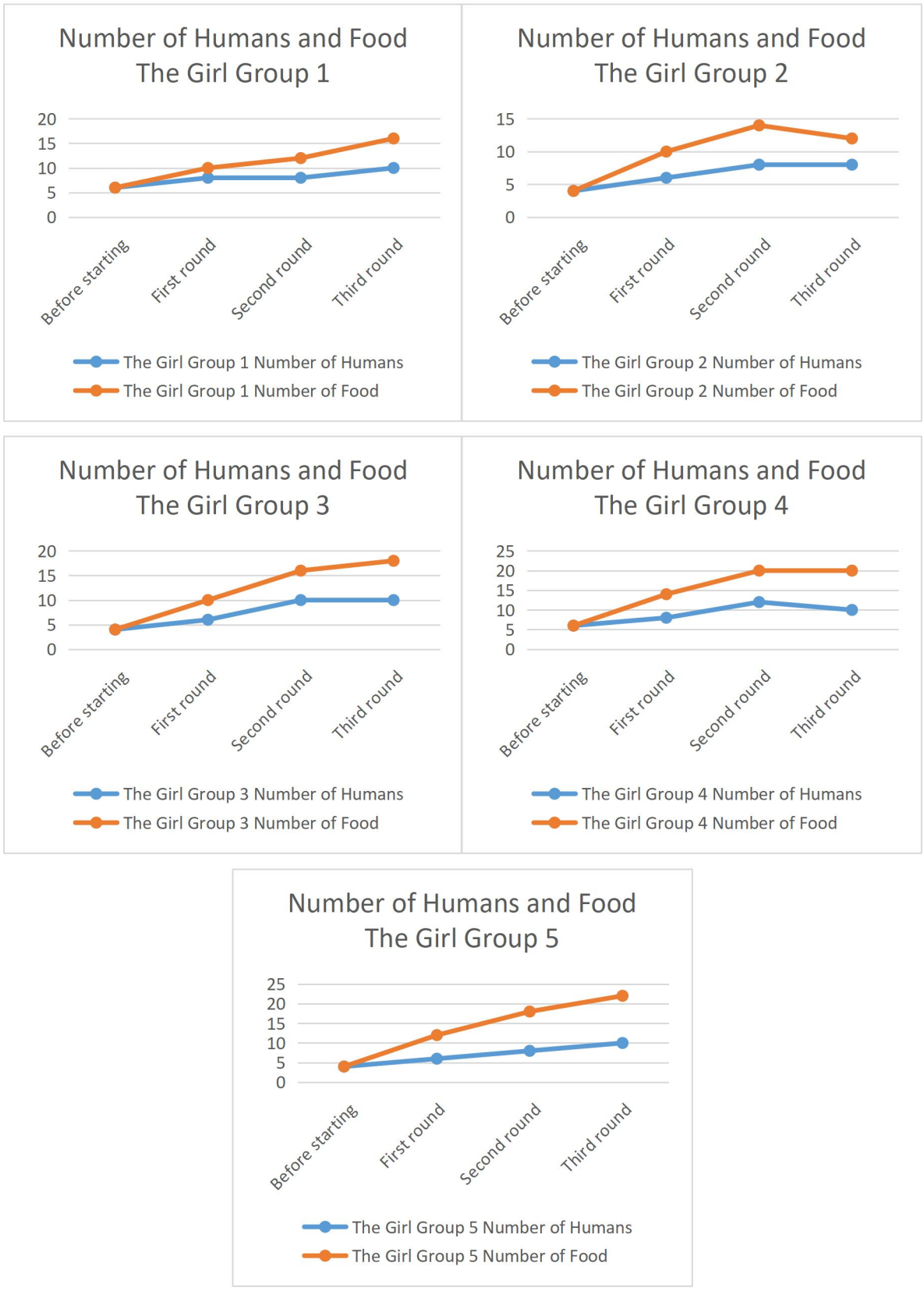

Figure 6. Number of Human and Food The Girls Classes

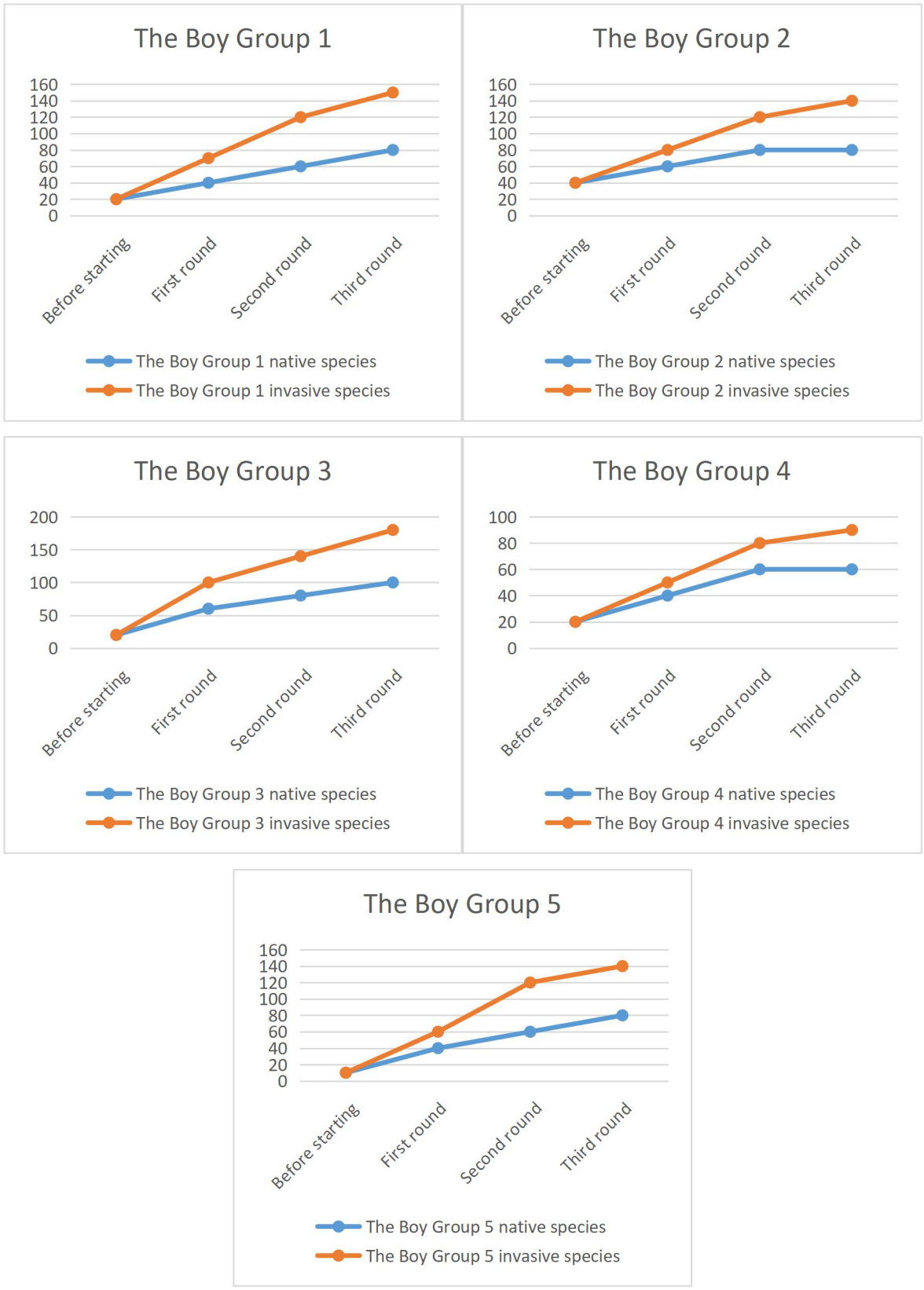

Figure 7. Trend of Native Species and Invasive Species The Boys Classes

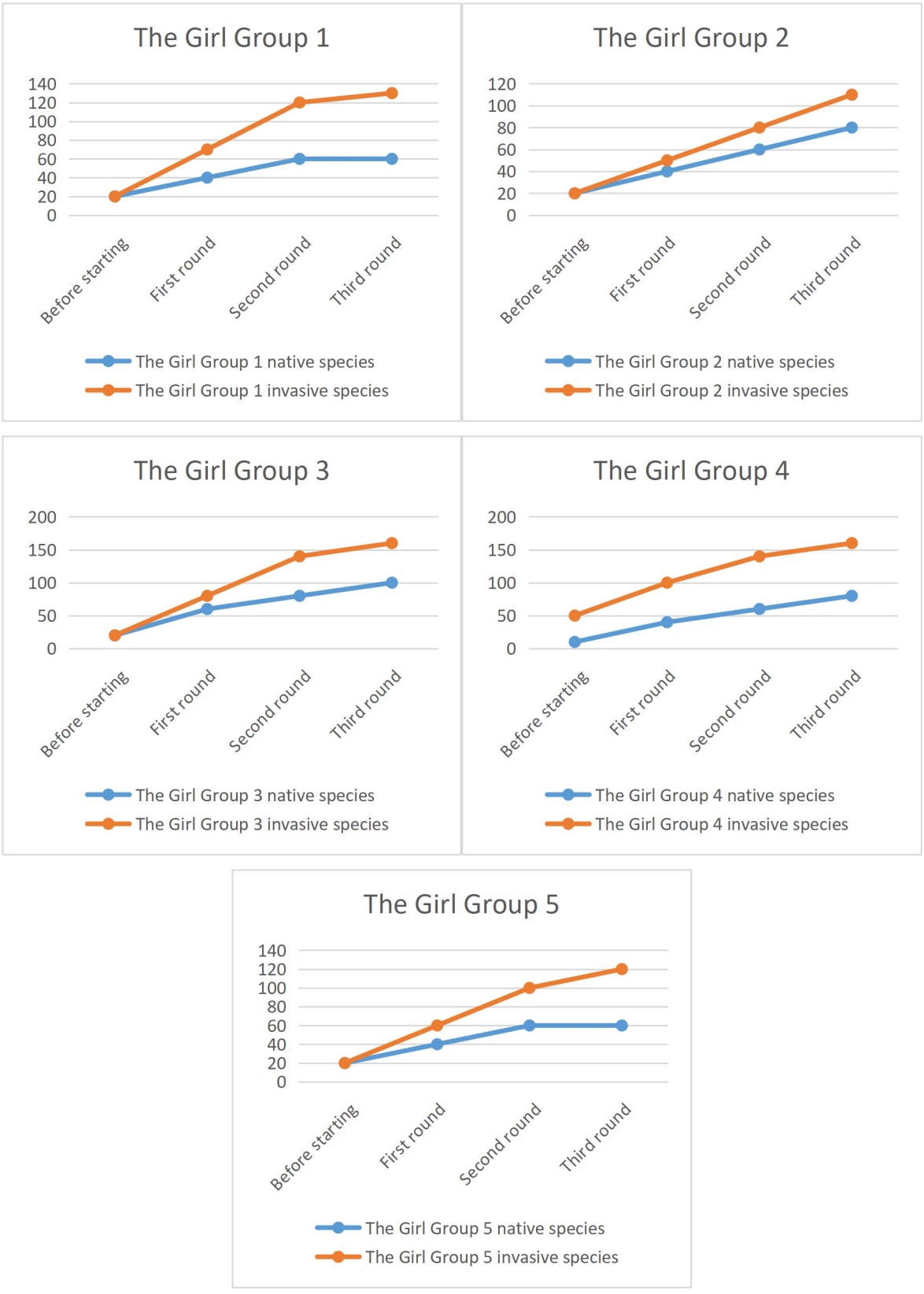

Figure 8. Trend of Native Species and Invasive Species The Girls Classes

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Economic Development of Groups

The economic development indicators of each group are shown in Figures 9 and 10. How the policies adopted by each group affect their economic results is depicted in these graphs. In most cases, groups that achieve stable economic growth can incorporate economic, social, and environmental elements into their strategies. For example, The Boy Group 2 focuses on teamwork and environmentally friendly technology development, which increases their financial points significantly each round of the game.

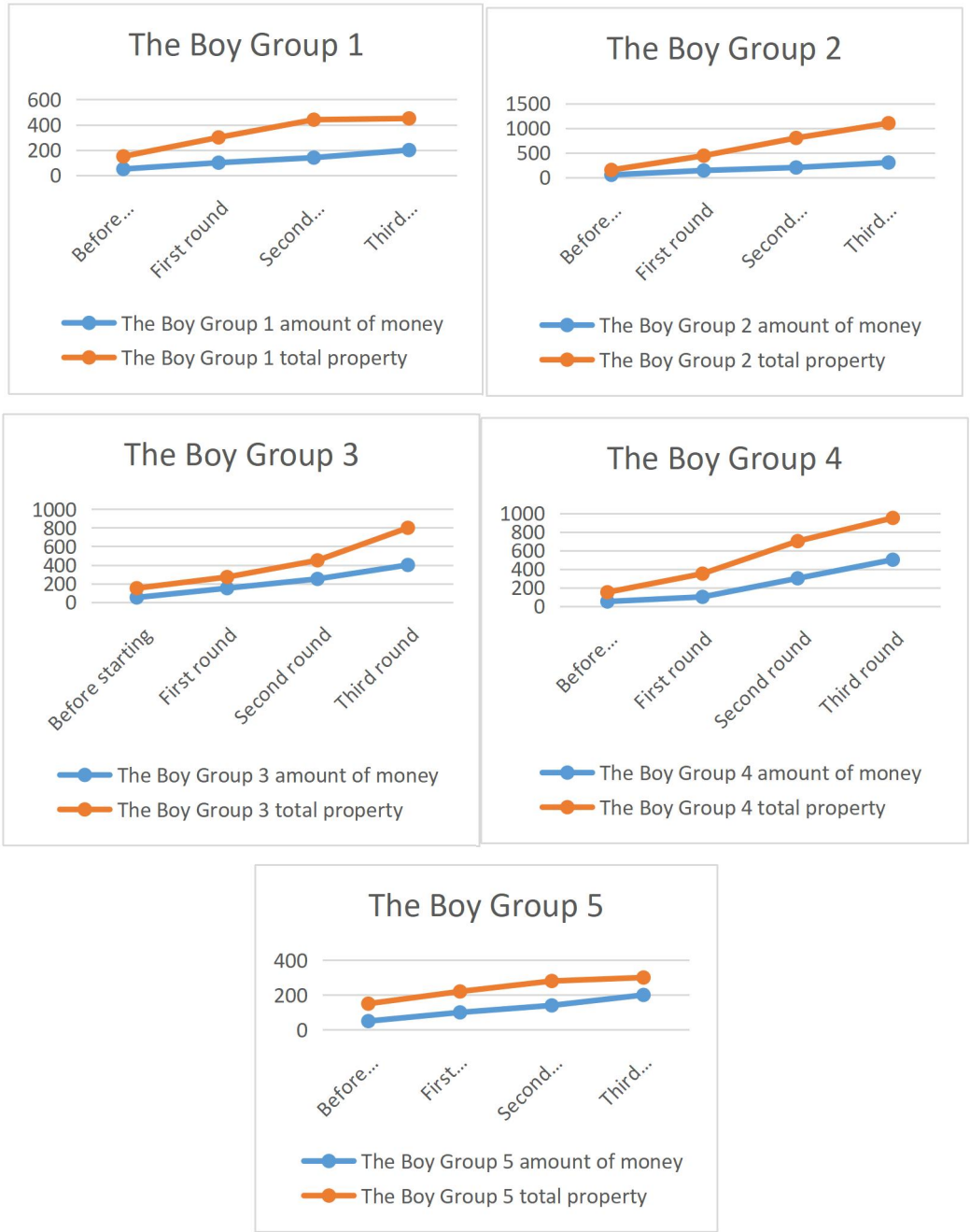

Figure 9. Economic Development Trend The Boys Classes

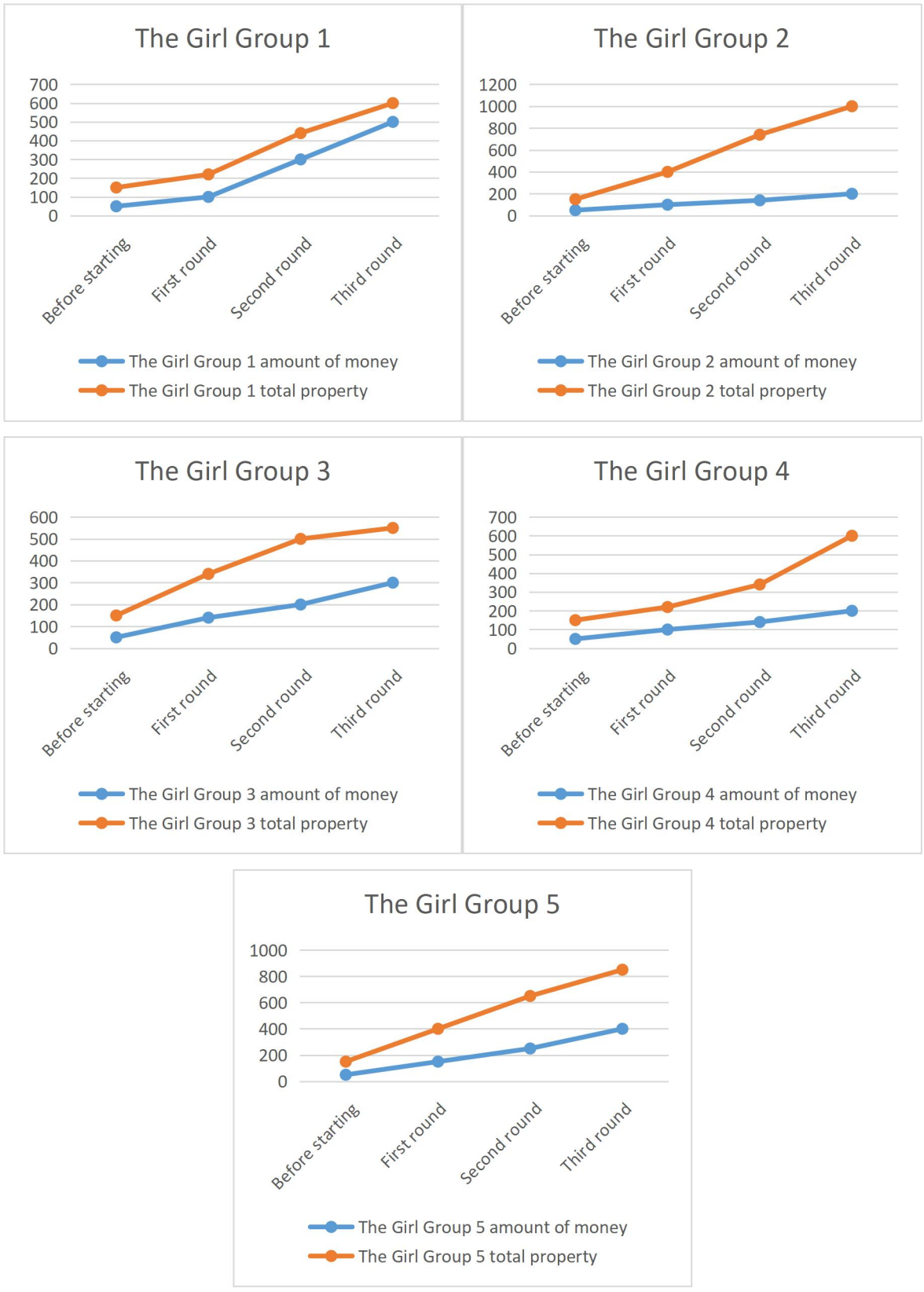

Figure 10. Economic Development Trend The Girls Classes

Collaboration and Conflict Between Groups

According to data analysis, group conflict and collaboration are crucial to the final outcome of the game. The Boy 1 and The Boy 5 consistently increase points. In contrast, groups that are too competitive or poor at communication often result in significant point changes. In situations of excessive competition, groups are forced to change their tactics continuously to avoid challenges from other groups, which sometimes results in a drop in points.

CONCLUSION

This study shows that board games help students understand sustainable economic development. The results show that game-based learning encourages students to participate actively in learning activities, think critically, and work together in problem solving. Successfully combining economic, social and environmental strategies demonstrates stable economic growth and better resource management. To achieve better performance scores, it is also important to maintain native species populations and stop invasive species from entering. These findings suggest that future research should look at a variety of game-based approaches in various educational contexts to address global sustainability challenges. They also support the incorporation of interactive and experiential learning approaches in education.

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