Urban Planning Simulation Game and the Development of Spatial Competence

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Abstract. The use of simulation has proven to be helpful for many academics from various disciplines in the last decade. In the field of pedagogy, not only does simulation help in learning something new, but it also can be utilized as a learning tool for students. Today, there have been a lot of academic discourse of what kind of competence that can be harvested from the use of simulation. On the other hand, spatial intelligence is one type of intelligence whose existence is foreshadowed by the two more popular intelligence today; verbal and mathematical intelligence. To this day, only a few studies have thoroughly explored how to develop spatial intelligence, but only for children. This lack of dedicated framework and research has produced a consequential impediment for the uptake of simulation use in university-level education, particularly in spatial-oriented subjects. This paper addresses this shortcoming by reintroducing several key information regarding simulation, model, gamification, and its connection to spatial intelligence. This literature review will then be applied to an urban planning simulation game case study of SimCity. The result of this paper shows that there are several types of simulation that can train specific spatial competencies, which will further students’ spatial competence.

Keywords. Architecture, Urban planning, Simulation, Model, Education

1. Introduction

This paper tries to elaborate on the impact of urban planning simulation game in developing spatial competencies of its users. According to the previous statement, we generate two questions that we will attempt to answer with this paper, (1) What components does an urban planning simulation game has that could develop spatial competencies, and (2) how these components manage to develop spatial competence.

Simulation is commonly used in many disciplines, especially in science, technology, engineering, and mathematics (often abbreviated as STEM). Simulation is heavily used in those disciplines due to its capability to simulate a system or potential problem and allows scientist to actually test on them so that they don’t have to make a real test. With this advantage, scientists can test their new answers or strategies within a simulation, without the constraint of finance, labor, and time. One field that has implemented simulation heavily is education. A physics teacher can manage to explain a difficult concept to its students within the reach of his computer. Various educational simulations have been implemented in order to solve various problems in education, such as the now-computerized National Examination (Ujian Nasional) to educational software that help students in rural areas that lack human resources.

This paper will then attempt to find the possibility of simulation in developing one’s spatial competence. Both spatial intelligence and competence are rarely addressed in the list competencies of
Spatial intelligence consists of understanding and the development of spatial intelligence are only made possible with the use of technology. The SAMR model progression highlighted the progress through (1) substitution, (2) augmentation, and (3) simulation knowledge integration. This model is called the SAMR model that stands for Substitution, Augmentation, Modification, and Redefinition [7]. The use of simulations in education can be modelled based on degrees of classroom technology integration. This model is called the SAMR model that stands for Substitution, Augmentation, Modification, and Redefinition [7]. The SAMR model was created to generate a language that can be used to describe the system and its application in the real world. A system is described as a collection of organized components [11] including (1) entity, (2) condition, and (3) events [8]. An entity is the subject of the system, and it can be tangible or intangible. Researchers use a set of condition to differentiate between one entity and another. A condition can be further defined into an attribute (quality or characteristic that an entity may have) and activity (activity an entity may do). An entity is then put into a series of events that can trigger a change of its attribute and activity.

The use of simulation may provide several types of knowledge for its users, including; (1) contextual knowledge, (2) scientific knowledge, and (3) simulation knowledge [10]. These three knowledges can serve as answers to the original goal of the use of simulation; as a basis for individuals to be able to formulate answers, or as feedback to develop better simulations.

Contextual knowledge is the knowledge, which is gained from the use of simulations, that can be used to describe the system and its application in the real world. Scientific knowledge is contextual knowledge that is connected to each other in order to explain a bigger cause within a bigger framework. Simulation knowledge is knowledge of how to develop simulation designs, which ultimately enriches the information that can be received by simulation users. This three knowledge is obtained in stages. Contextual knowledge is obtained from the individual's understanding of the simulation as a set of models that have their own context. Scientific knowledge is derived from an individual's understanding of simulation as a set of interrelated models. Finally, simulation knowledge is obtained from the individual's understanding of the simulation as a set of interrelated models in explaining a system [10].

2. Literature review

We conducted literature reviews that can be grouped into three stages; SimCity, spatial competence, and how specifically SimCity helped to develop spatial competence. We looked at how a system of simulation (SimCity) works and its constituent components [4], types of knowledge obtained from the use of simulation [2], what are the things to identify in spatial environments [5], spatial competences [1,6], and the application of technology in pedagogy [7].

Simulation is defined as the process of imitating something tangible, together with its surroundings [8], or as a collection of artificial models that represents parts of a real system so it can be used a replacement of the real system in an experiment [9]. A system is described as a collection of organized components [11] including (1) entity, (2) condition, and (3) events. An entity is the subject of the system, and it can be tangible or intangible. Researchers use a set of condition to differentiate between one entity and another. A condition can be further defined into an attribute (quality or characteristic that an entity may have) and activity (activity an entity may do). An entity is then put into a series of events that can trigger a change of its attribute and activity.

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The use of simulations in education can be modelled based on degrees of classroom technology integration. This model is called the SAMR model that stands for Substitution, Augmentation, Modification, and Redefinition [7]. The SAMR model was created to generate a language that can be used to model classroom technology integration. Regardless of the variety of subjects, they all share the common SAMR language. The SAMR model progression highlighted the progress through teaching with technology. The higher the model level, the more profound the effect it may have on students.

Substitution is the first level in the SAMR model, where technology only acts as a replacement of the same task, without any functional changes. Augmentation is where technology augments the same task and stands out as a better tool to use. Modification is where not only technology increases the ability of conventional education derivatives but can also modify the original learning objectives. Redefinition is where technology allows students to redefine tasks that were previously impossible to do without technology and it also produces new learning objectives [7].

Spatial intelligence is the intelligence used in imagining and processing a space [11]. Even though not all intelligence is made equal, spatial intelligence ranks second in education (compared to verbal intelligence and logic-mathematical intelligence which ranks first as the most tested intelligence at school) [1]. Currently, no computer simulations are associated with the development of spatial intelligence as one of the benefits of its use, and the development of spatial intelligence are only addressed almost exclusively for children only [12–15]. This research seeks to find out how urban planning simulations (with the SimCity case study) can affect a person's spatial intelligence. Spatial intelligence consists of competencies that can be used to measure whether someone is spatially intellect or not.

Spatial competence includes the ability to position two tangible or three-dimensional objects in the context of Euclidean space (x, y, and z axes). Spatial thinking competencies consists of several abilities
to imagine and interpret six visual attributes, including (1) location, (2) position, (3) distance, (4) direction, (5) relationship, and (6) movement [5]. Spatial thinking skills are not only useful to architects, artists, or other visual professions but also to ordinary individuals in their daily activities, starting from reading maps to finding an address or even to read chart tables in newspapers.

Spatial competence is composed of (1) the selection of strategy in solving spatial problems and (2) the ability to choose and use spatial representation [6]. It can then be concluded that not only does one have to be able to imagine and analyze a three-dimensional object, but he also needs to be able to choose and use the appropriate representation. Due to the advancement of technology, representation tools have then progressed to be more sophisticated, which then triggered the emergence of new spatial competencies.

Those two competencies eventually developed into four subcategories beyond Hegarty’s two spatial competence categories. These sub-categories are; (1) spatial, (2) mental rotation, (3) spatial visualization, and (4) spatiotemporal [1]. Spatial perception is the ability to be able to position an object and ignore irrelevant information. Mental rotation is the ability to visualize objects with provisions rotated, folded, or reflected. Spatial visualization competence is the ability to see and think analytically in the form of three-dimensional space. Spatiotemporal competence is the ability to read patterns and draw conclusions about the movement of a two-dimensional or three-dimensional object that moves over time.

3. SimCity Components

SimCity provides two types of views that can be utilized in accordance with its users’ needs; regional view and city view. The regional view provides an overview of the micro of a city, whereas city view provides an overview of the micro of a city. Both views are available for SimCity users to generate a comprehensive picture of what a city looks like. It will enable them to get a clear picture of how a city works and constructed and to observe the impact of their every command to the city development.

In the city view tab, there are several systems that can be identified, including; zoning, electricity, water, sewage treatment, roads, public transportation, garbage disposal, government, parks, health, fire, education, and the police. We then categorized these systems into three major systems that are crucial in urban planning namely; zoning system, utility system, and public facilities system. The zoning system consists of residential, commercial and industrial zone. Utility systems consist of electricity, water, and waste treatment systems. Finally, the system of public facilities consists of road systems, public transportation, waste disposal, government, parks, health, fire, education, and police. These systems (Table 1) have their own entities that act as their building blocks, which will be identified later.

| Zoning          | Utility  | Public Facilities |
|-----------------|----------|-------------------|
| Residential zone| Electricity | Road               |
| Commercial zone | Water     | Public transportation |
| Industrial zone | Waste treatment | Waste disposal     |
|                 |           | Government         |
|                 |           | Park               |
|                 |           | Health             |
|                 |           | Fire               |
|                 |           | Education          |
|                 |           | Police             |

Table 1. Identified systems on SimCity 5

Every system represented in SimCity 5 has their own respective entities, attributes, and activities. In this paper, we selected residential zone as the chosen system for further analysis.

3.1. Simulation components

Residential zone has several identified entities, namely (1) location (zoning), (2) object (house), and (3) subject (resident). Based on these entities, we conclude that SimCity has two (2) types of entities; playable and non-playable entities. Playable entities, such as zoning and house, are entities the users can locate, position, and measure accordingly. Whereas non-playable entities such as residents are non-
An entity has attributes and activities that can be used to distinguish one entity from the others. Residential zoning doesn’t have any attributes except for its location. House has attributes that include its density level (that determines whether the house is a single, landed house or a skyscraper apartment) and its land value (that determines whether the residence falls into which economy level). Activities that occur at residential zone – as well as the rest of the system in SimCity 5 – includes the (1) construction, (2) upgrade, (3) operation, and (4) destruction when needed.

3.2. SAMR model

The simulation model is a model that directly replaces the real form of the system and the entities involved in building a city. It only substitutes the real form with a digital form that can be used in the game. But then again, this simulation model cannot provide more features than the actual system. Based on Figure 1, SimCity modeled the exact actual system and translated it into a digitalized version.

![Figure 1](image1.png)

**Figure 1.** The real residential system (left) and the simulated residential system (right) on SimCity 5. Note how the simulated (right) doesn’t have any added features other than depicting the real entities.

Source: Maximillan Conacher of Unsplash (a) and illustrated by author (b).

The augmentation model is a model that directly replaces the real form of a system to simulation and adds features that don’t exist in the real world. As a result, SimCity users can learn about entities, attributes, and activities that are owned by a system by directly clicking the simulation, an action that cannot be done easily in the real life. Based on Figure 2, SimCity modeled the entity and added augmentation such as information of the entity and its condition with graphs and visual cues.

![Figure 2](image2.png)

**Figure 2.** The augmentation model in SimCity 5 that provides information regarding land value and density of an apartment building (a) and giving visual cues regarding the condition of the apartment building that is abandoned (b).

Source: Illustrated by author.

The modification model is a model that can change the shape of an old model into a new one, thus enabling the users to obtain new information that previously could not be seen. This model is useful for describing complex things that are impossible to be displayed by one model. Based on Figure 3, SimCity modeled the entity and managed to modify the entity into other forms of communication (bar chart, pie chart, spectrum) to generate a more comprehensive condition to the users.
The modification model provides information regarding the total population in SimCity 5. The model provides (a) distribution of the population in a part of the city, (b) population growth in a city per time, and (c) number of needs for residential zoning per economic level.

Source: Illustrated by author.

The redefinition model is a model that can reshape an old model into a new one and associate the simulation with other simulations, therefore making it easier to observe the relationship between simulations. This model is useful for describing things that previously could not be represented with only one simulation. Based on Figure 4, SimCity modeled the entity and provided augmented maps to explain the current condition.

Figure 4. The redefinition model in SimCity 5 that describes the land value of a residential zone (a), that are influenced by (b) water availability (noted in blue), (c) availability of schools (marked green), and (d) the level of air pollution (polluting agents marked red).

Source: Illustrated by author.

4. SimCity and the Development of Spatial Competence

4.1. Visual perception

This competence requires users to be able to distinguish between one entity and another entity by comparing their attributes and activities. SimCity trains users' visual perception competencies with simulation models and augmentation models. The simulation model (Table 2) will give a clear idea of an entity to the users. If the users can recognize the entity by its attributes and activities, it will be easier for them to determine what kind of entity it is. The augmentation model will provide a more in-depth picture of entities that are not visible to the naked eye when observing the real system (Figure 5).

Table 2. SimCity 5 simulation type, identified components, and how it develops visual perception.

| Model Type   | Model Description                                           | Components Observed                  | Objective                                  |
|--------------|-------------------------------------------------------------|--------------------------------------|--------------------------------------------|
| Simulation (S) | An aerial view of several residential zones with houses of various designs and sizes | Entity (house, street, park, power plant) | perceive what a city consists of          |
|              |                                                             | Attribute (size, location, and position of house) | perceive how city constituents distinguish from each other |
| Augmentation (A) | A zoom in view of an apartment building, with a pop-out consists of spectrums that depicts the apartment building's land value and density level | Entity (apartment building) | perceive what an apartment building looks like |
|              |                                                             | Attribute (size of apartment building) |                                             |
|              |                                                             | Augmentation (spectrum of land value and density level of an apartment) | perceive the land value and density level of an apartment building |
4.2. Mental rotation

This competence requires the users to understand every part of an entity so they can determine the size of said entity before they put it on its designated place (Figure 6). SimCity trains mental rotation competencies with simulation models and augmentation models. The simulation model will give an idea of the shape of an entity that will be mentally rotated. In order to be rotated, users need to be familiar with every angle of the entity, so that they can still recognize the entity even when they see it from different perspective or point of view. SimCity also facilitates mental rotation by its augmentation model. SimCity is able to display the consequences of the wrong placement so the users might reconsider their choice and start planning their next move. SimCity is also able to help its users to tell whether the entity is proportional enough for the lot to be placed (Table 3).

| Model Type   | Model Description                                                                 | Components Observed                                   | Objective                                                                 |
|--------------|-----------------------------------------------------------------------------------|--------------------------------------------------------|---------------------------------------------------------------------------|
| Simulation (S) | A zoom in view of a coal power plant in operation, emitting air pollution in the  | Entity (coal power plant)                              | perceive what a coal power plant looks like                                |
|              | process                                                                          | Attribute (size, location, and position of power      | silence how a coal power plant operates (generates power and pollution)  |
|              |                                                                                  | plant)                                                 |                                                                           |
|              |                                                                                  | Activity (generating power)                            |                                                                           |
| Augmentation (A) | An aerial view of a coal power plant placed amidst residential housing. Residential housing is highlighted green to distinguish between houses and the rest of the entities captured in the view | Entity (power plant, residential area)                 | perceive what a coal power plant looks like and how it operates           |
|              |                                                                                  | Attribute                                              |                                                                           |
|              |                                                                                  | Activity (generating power)                            |                                                                           |
|              |                                                                                  | Augmentation (green = residential area)                | highlighted the position of coal plant (which generates pollution) among residential areas |
| Modification (M) | The same aerial view as previous, but with the colors muted. The simulation can be switched interchangeably (zonation map, wind map, etc). The simulation depicts each and every map differently - in the case of wind maps, blue moving arrows were used. | Entity (city components)                                | generate what an overview of a city looks like                            |
|              |                                                                                  | Augmentation (blue arrow = wind direction)            | highlighted the direction of the wind                                     |
Figure 6. With information generated by the model, it allows the user to simulate the consequences of placing the power plant in certain parts of the city in their mind. Users must mentally rotate the power plant (highlighted) in different scenarios (A, B, C, or D) to decide which position is the best. SimCity deems the best position is when it has the least exposure to the residential areas.

4.3. Spatial visualization

This competence requires the users’ imagination to picture how an entity looks like if a change occurred to its attributes or activities. SimCity trains users’ spatial visualization competency by showing the attributes in the form of data (Table 4). It will help the users to predict the outcome if they change the attributes or activities of an entity. SimCity trains the spatial visualization competency of its users using modification models and redefinition models. The modification model will show how the entity changes when the change occurs. If the users have a good understanding of the entity, they will have no difficulty to identify which entities will change in the new conditions. The redefinition model will provide information about how the changes will affect other entities. If the user is able to read the pattern of changes from the entity, then the users can predict the next results without needing further simulation. With the use of these two simulations, the users can visualize an entity and its attributes in under any circumstances and at any time (Figure 7).

| Table 4. SimCity 5 simulation type, identified components, and how it develops spatial visualization |
|----------------|-----------------------------------------------|
| Model Type     | Model Description                             | Components Observed                  | Objective                                           |
| Simulation (S) | An aerial view of several residential zones with houses of various designs and sizes | Entity (house, street, park, power plant) | perceive what a city consists of                    |
|                |                                               | Attribute (size, location, and position of house) | perceive how city constituents distinguish from each other |
| Augmentation (A) | A zoom in view of the houses with a yellow house figure blinking on top of several houses, indicating that the house is abandoned | Entity (houses) | perceive what housing zone in a city consists of |
|                |                                               | Attribute (size, location, and position of house) | perceive that the house indicated is abandoned |
|                | The same zoom in view but with the colors muted except parks (tinted green) and coal power plant (tinted red), indicating its effects on the residential areas | Entity (house, street, park (in green), power plant (in red)) | perceive what a city consists of |
|                |                                               | Augmentation (yellow indicator = house is abandoned) | perceive that parks raises land value, whereas power plant lowers land value |
| Modification (M) | Bar graph of the city population, showing a significant drop from February to March. | identify sudden drop of population happening in some part of the city |
| Model Type       | Model Description                                                                 | Components Observed                                                                 | Objective                                                                 |
|------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Observed         | The information is also supported by pie charts indicating population source (locals, visitors) and wealth (low, medium, high) | Bar chart indicating population growth in a city per month                           |                                                                           |
| Objective        | The same aerial view in simulation but with the colors muted except for the bar graph mapped in every residential entity, indicating the number of populations living in a particular house | Mapping of distribution of population in the city                                   | perceive and identify which part of the city has higher / lower population than the others |
| Redefinition (R) | The same aerial view in simulation but with designated maps that highlights level of land value, utilities (water, electricity, sewage) and public facilities location (e.g. parks) | Mapping of distribution of land value (a), water (b), education (c), and pollutants (d) | perceive what causes the sudden population to drop (power plant), which will affect land value (a), water (b), education (c), and pollutants (d) |

**Figure 7.** With every information modified into different models, allow the population drop issue to be addressed by the user (a), locate where the population drop happens (b), and identify what city entities that causes the population drop (c). From the figure it can be deducted that the cause of the population drop is the current placement of power plant (indicated red in c1) that causes the water to be polluted (highlighted brown in c2).

### 4.4. Spatiotemporal

This competency requires the users to be able to read the visual pattern of a changing spatial entity in a certain duration of time. SimCity trains its users’ spatial-temporal competency with both simulation and augmentation models (Table 5). The simulation model will provide information about how SimCity depicted the pattern over time. The users then can inspect the visual changes that are taking place and the pattern of changes. If the users understand the pattern of changes and their reasons, they can determine how these changes can occur. With the use of a simulation model, the users can read and translate patterns that occur in an entity that goes along with time in under any conditions (Figure 8).
Table 5. SimCity 5 simulation type, identified components, and how it develops spatiotemporal

| Model Type    | Model Description                                                                 | Components Observed                                                                 | Objective                                                                 |
|---------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Simulation (S)| A zoom in view of a commercial entity (a store) with a garbage truck picking up the store's trash | Entity (shop, garbage truck)                                                        | perceive what a city consists of                                           |
|               |                                                                                    | Attribute (size, location, and position of the garbage truck)                       | perceive the capacity and the attribute of a garbage truck                |
| Augmentation (A)| An aerial view of the city with muted colors except for brown bar graphs mapped in every entity, indicating the volume of trash they have | Entity (city components)                                                            | perceive how trash collecting system works inside a city                 |
|               | The same aerial view as the previous description, but as the time goes by, the brown bar graphs has started to decrease, indicating the trash were picked up by the garbage trucks, providing information on garbage trucks' movement pattern throughout the city (it started in small circles, picking up from the blocks around the landfill before moving to a bigger circle) | Volume of trash per entity (highlighted brown)                                      |                                                                            |

Figure 8. Information generated by models (a) allows the users to read the garbage truck movement pattern when operating in the city (b). This information will be useful once they decide to put another garbage dump, as the garbage truck movement determines the placement of the next garbage dump. Based on (a1) through (a3), we can see that the garbage truck works in a circular motion and will deduce the movement of garbage trucks with (b). Source: Screenshot of SimCity by author.

5. Conclusion

Based on the evaluation study, we find that the simulation components that directly addresses and exercises spatial competencies are simulation, augmentation, modification, and redefinition. Each model requires and exercises specific spatial competencies. Every type of model trains different spatial competencies. All perception, mental rotation, and spatiotemporal competencies are trained with simulation and augmentation model, whereas spatial visualization requires all four of the models. We
conclude that in order to train every spatial competence, the users must be able to utilize all four of the specified models.

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