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BRIDGING AGENT-BASED MODELING AND LEARNING DESIGN[1]

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Abstract. Agent-Based Modeling (ABM) has emerged as a powerful tool for simulating complex systems across various disciplines, particularly in educational contexts. This paper explores the intrinsic connection between ABM and learning design thinking, highlighting how both approaches converge to foster modeling thinking among learners. Recognizing the growing importance of computational thinking in education, the research investigates how ABM can serve as a powerful tool for simulating complex adaptive systems and enhancing students' engagement in learning processes. Utilizing Semantic MediaWiki the research employed a structured approach to facilitate the design and implementation of ABM within teacher education programs, allowing for dynamic interaction and the development of competencies in modeling thinking. Findings indicate that engaging with ABM not only enhances students' understanding of complex concepts but also equips them with essential computational thinking skills. The framework demonstrated that students' roles as model designers foster creativity and leading to deeper comprehension of classroom dynamics as complex systems. As students assume the role of model designers, they cultivate creativity and problem-solving abilities that are essential for navigating both classroom dynamics and broader learning design challenges. The research concludes that bridging the gap in computational thinking education across disciplines is crucial for preparing future educators.

Keywords: agent-based modeling, learning design, complex adaptive systems

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СВЯЗЬ АГЕНТНОГО МОДЕЛИРОВАНИЯ И ДИЗАЙНА ОБРАЗОВАТЕЛЬНЫХ ПРАКТИК

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Аннотация. Многоагентное моделирование является мощным инструментом для изучения сложных систем в различных дисциплинах. В статье исследуется связь между дизайном многоагентных моделей и дизайном образовательных практик. При этом мы используем оба подхода для развития у учащихся вычислительного и модельного мышления. Учитывая растущее значение вычислительного мышления в образовании, мы используем многоагентное моделирование как мощный инструмент для имитации сложных адаптивных систем и повышения вовлеченности студентов в процессы обучения. Мы использовали среду Semantic MediaWik для структурированного подхода и облегчения разработки и реализации моделей в программах подготовки учителей. Это позволило обеспечить динамическое взаимодействие учащихся с учебными материалами и развитие умений моделирования. Результаты показывают, что работа с моделями не только улучшает понимание учащимися концепции сложных адаптивных систем, но и помогает им освоить навыки моделирования применительно к образовательным практикам. Роль студентов как разработчиков многоагентных моделей приводит к более глубокому пониманию ими учебной деятельности как сложной адаптивной системы. Исследование показывает, что формирование вычислительного и модельного мышления на материалах различных дисциплин имеет решающее значение для подготовки будущих педагогов.

Ключевые слова: многоагентное моделирование, педагогический дизайн, сложные адаптивные системы

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Introduction

The ABM has emerged as a powerful tool for simulating complex systems across various disciplines. This paper explores the intrinsic link between ABM and learning design thinking, emphasizing how both methodologies converge within educational contexts. We draw on existing literature to illustrate that ABM functions not only as a modeling technique but also as a means of fostering computational thinking skills among learners. The significance of computational thinking (CT) has gained considerable recognition in educational frameworks worldwide. Among the various methodologies exemplifying CT, ABM is notable for its capacity to simulate interactions among autonomous agents within complex environments. This approach enables researchers and practitioners to create detailed simulations that reflect real-world phenomena by modeling individual agents with specific behaviors and interactions. Such modeling aligns closely with the principles of computational thinking, which advocate for breaking down complex problems into manageable components. As Page notes in "The Model Thinker" (Page, 2018) understanding how to manipulate models is essential for effective data utilization. Several researchers have examined the relationship between ABM and computational thinking in the context of complex adaptive systems. Basawapatna et al. (Basawapatna et al., 2019) present a framework for designing educational interventions that integrate computational thinking through ABM, demonstrating how these methodologies can enhance student engagement and comprehension of complex concepts. Musaeus and Musaeus (Musaeus, & Musaeus, 2019) discuss high school students' engagement with coding and modeling using NetLogo, illustrating the integration of CT into the learning process. Their findings suggest that students develop both content knowledge and computational skills through hands-on experiences with ABM.

The theme of fostering computational thinking among students has significantly evolved over the past 50 years, beginning with foundational contributions from Papert and Solomon (Papert, & Solomon, 1971). During this period, various educational environments have emerged, including AgentSheets, Scratch, Snap!, StarLogo Nova, NetLogo, and GAMA, each designed to enhance students' computational thinking skills while teaching them to model effectively and think like agent-based modelers. A key aspect shared by these platforms is the emphasis on students as designers of agent-based models, which allows learners to engage deeply with the principles of computational thinking through hands-on experiences that promote creativity and problem-solving. For instance, Snap! has been effectively utilized to teach design principles, as highlighted by Huisman and Monti (Huisman, & Monti, 2022), who explore its application in teaching design by contract. Similarly, Greybosh (Greybosh, 2024) discusses how StarLogo Nova facilitates computational modeling in classrooms. Furthermore, Dasgupta (Dasgupta, 2016) emphasizes Scratch's role in empowering children as data scientists, enabling them to create, think critically, and learn with data.

Collectively, these platforms demonstrate the potential of ABM in fostering computational thinking and enhancing learning design across diverse educational contexts. ABM has also become essential for analyzing and understanding complex systems, particularly within network structures. Gammack (Gammack, 2015) emphasizes the versatility of NetLogo as a platform for modeling such systems. By employing NetLogo, educators can guide students in exploring scientific concepts through agent-based simulations, which enhance their understanding of intricate network dynamics and promote interdisciplinary scientific thinking. Wilensky and Rand (Wilensky, & Rand, 2015) provide a comprehensive resource on using NetLogo for ABM, offering numerous examples that capture the complexities of various networks and facilitating deeper analysis and understanding of these intricate systems.

Fontana and Terna (Fontana, & Terna, 2015) discuss the application of ABM in analyzing complex networks within policy-making contexts, illustrating how agent-based models enable the exploration of agent interactions and provide insights into the dynamics of network structures and their policy implications. Sayama (Sayama, 2015) offers foundational insights into modeling complex systems using ABM, emphasizing how agent-based approaches can effectively capture network dynamics and analyze emergent phenomena.

The ODD Protocol paper by Grimm et al. (Grimm et al., 2017) outlines a standardized framework for describing agent-based and other simulation models, underscoring the importance of clarity and replicability in modeling complex adaptive systems. Researchers increasingly view classroom practices and student activities as manifestations of complex adaptive systems, recognizing the intricate interactions and emergent behaviors that characterize these environments. Blikstein, Abrahamson, and Wilensky (Blikstein et al., 2008) present a framework in their study “The Classroom As a Complex Adaptive System”, which investigates students’ emergent collective behaviors through an agent-based approach, highlighting how individual actions can lead to unexpected group dynamics. Knight (Knight, 2021) further explores the classroom as a complex adaptive system, discussing how learning arises from the dynamic interactions among students, teachers, and learning materials.

Laghari and Niazi (Laghari, & Niazi, 2016) contribute to this discourse with their article on modeling complex adaptive communication networks. Although their focus is on the Internet of Things, the cognitive agent-based computing approach they propose can be applied to educational settings. By modeling communication patterns among students as agents within a network, educators can gain insights into information flow and collaborative learning dynamics in classrooms. ABM serves as a powerful framework for understanding and analyzing complex systems, particularly in educational contexts. The importance of viewing education through the lens of complexity is further underscored by Vulic (Vulic et al., 2024) in the paper highlights the intricate dynamics within educational environments and proposes a multi-level ABM framework that captures interactions at micro, meso, and macro levels.

This modeling approach shares notable similarities with the principles of Learning Design, as articulated by Conole (Conole, 2018; Conole, 2007). Both ABM and Learning Design emphasize dynamic interactions among various components whether agents in a model or learners and educators in a classroom. Conole critiques the limitations of a content-focused approach, advocating for a comprehensive understanding of the teaching and learning processes necessary to achieve desired outcomes. This aligns closely with the design of ABM, where individual agents interact within a defined environment to produce emergent behaviors that can be analyzed for collective dynamics. Conole outlines the components of a learning activity, including context, intended learning outcomes, and specific tasks for learners. Similarly, ABM involves defining the context in which agents operate, their roles, and the interactions leading to specific outcomes.

Just as Learning Design maps learning outcomes to frameworks like Bloom's taxonomy, ABM allows researchers to analyze how agent interactions contribute to achieving specific goals within a modeled system. At the heart of both ABM and Learning Design is the recognition that effective outcomes emerge from a series of interconnected tasks or interactions, suggesting that students' learning experiences are shaped not just by content delivery but by their engagement in collaborative activities and problem-solving tasks.

We utilize ABM languages such as Scratch, Snap!, StarLogo Nova, and NetLogo in our efforts to prepare future computer science teachers. However, we contend that all contemporary educators, regardless of their subject area, should possess skills in computer modeling thinking and experience in designing agent-based models. The challenge is that teachers outside of computer science disciplines typically lack requirements for model design experience, resulting in limited opportunities to engage with and take pride in such skills. This gap in teacher training is significant; without a foundational understanding of computer modeling thinking and its applications in agent-based modeling, educators may struggle to implement innovative pedagogical strategies that reflect the complexities of modern classrooms as adaptive systems. Bridging this divide by integrating computer modeling thinking into teacher education programs across all disciplines is essential, ensuring all educators are equipped to cultivate these critical skills in their students. While not all graduate students have practical experience in creating agent-based models, most have engaged in learning design through qualification projects, where they plan experiments and collect data. This presents a unique opportunity to transfer skills from agent-based model design to learning design, enabling graduate students to leverage their existing knowledge of learning design to approach agent-based modeling with a fresh perspective. By equipping future educators with both computer modeling thinking and learning design skills, we can better prepare them to create dynamic and adaptive learning environments, enhancing their teaching practices and empowering them to instill similar skills in their students, thereby fostering a culture of inquiry and creativity in educational settings.

In light of the challenges and opportunities associated with integrating agent-based modeling into educational practices, a key research question arises: How can we effectively equip future educators with the skills and experiences in agent-based modeling that enable them to integrate these competencies into learning design and educational research?

Materials and research methods

The design of this research was structured around the capabilities of Semantic MediaWiki, a powerful extension of the traditional MediaWiki platform that enhances collaborative content management through semantic annotations. This research utilized the Digida platform, operated by Moscow City University, as a comprehensive environment for educational initiatives focused on digital didactics and computational thinking. Semantic MediaWiki serves as an integrated system for managing both content and metadata, allowing for the creation of a flexible and extensible knowledge representation. The research methodology involved utilizing Semantic MediaWiki's features to facilitate the design and implementation of ABM within teacher education programs. This approach allowed for dynamic interaction with educational content and supported the development of competencies in computational thinking among future educators. A significant emphasis of Digida is on computational didactics, which investigates how computational thinking, simulations, and educational technologies can be effectively incorporated into pedagogical practices. This includes ongoing research and experimentation with Logo-like programming languages and multi-agent modeling approaches.

Furthermore, the content on the Digida platform is meticulously organized into various categories such as Book, Person, Language, Concepts, Model, Dataset, and others. Each category is represented using a template that encompasses multiple properties, facilitating easy navigation and access to relevant information. This structured approach not only enhances the usability of the platform but also supports educators and researchers in their exploration of digital education resources.

An example of course construction is illustrated in Figure 1, which showcases how various digital elements can be combined to create a structured learning path. By utilizing existing digital objects, educators can design courses that are not only informative but also interactive and engaging.

The diagram presented in PlantUML outlines the structure of a course designed on the Digida platform, emphasizing the interconnected components that facilitate the development of competencies in agent-based modeling (ABM) and learning design. Each element within the diagram is accessible on the platform and can be incorporated into articles through queries to Semantic MediaWiki.

The course begins with Learning Outcomes, which focus on two primary competencies: Thinking with ABM models and Making ABM models. These

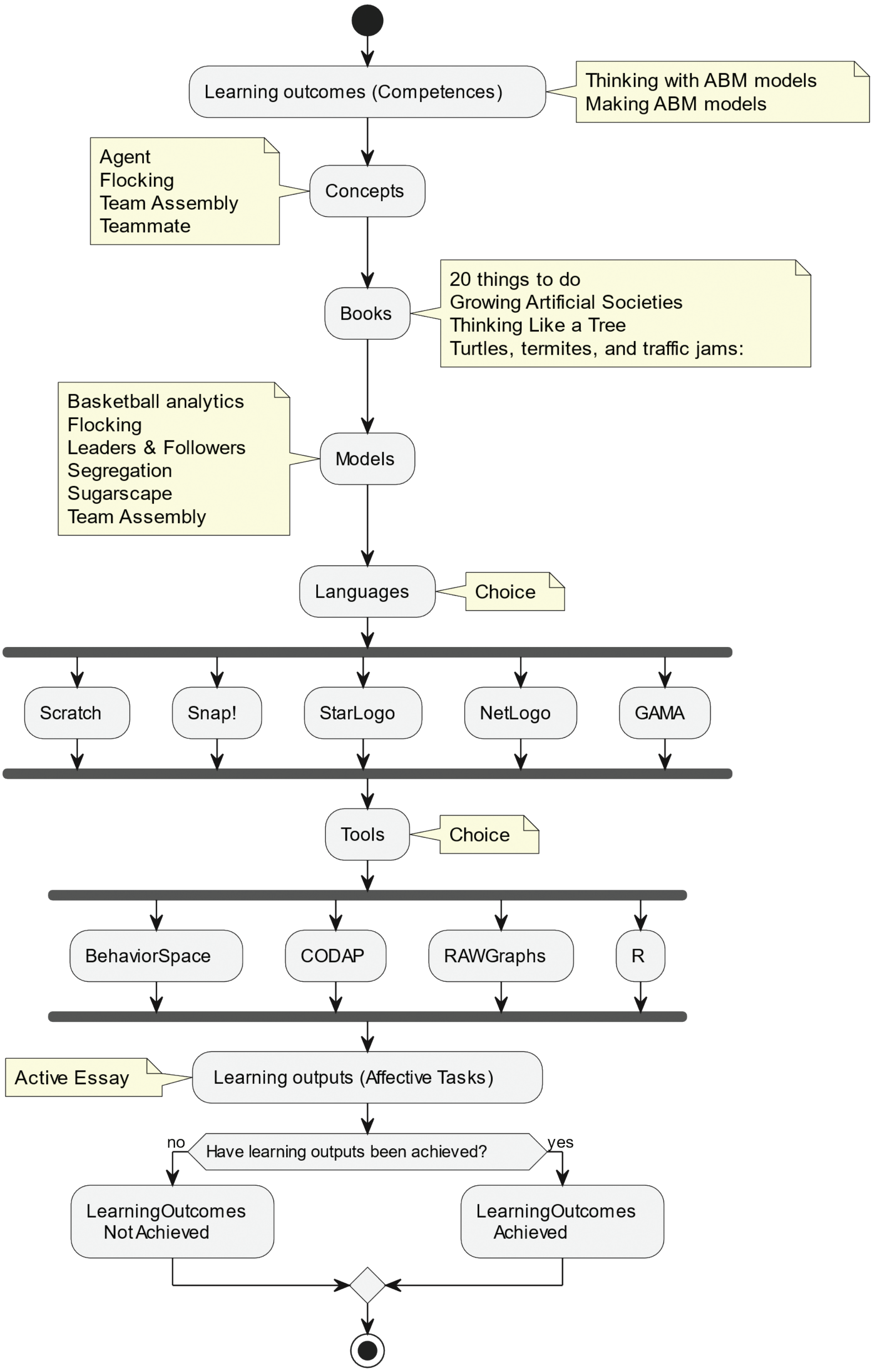

Fig. 1. Diagram of learning course

Рис. 1. Диаграмма учебного курса

outcomes set the foundation for what students are expected to achieve by the end of the course. Next, the diagram includes a section on Concepts, highlighting key terms related to agent-based modeling, such as Agent, Flocking, Team Assembly, and Teammate. These concepts are crucial for understanding the theoretical underpinnings of ABM. The course also references various Books that provide foundational knowledge and context for students. In addition to theoretical resources, the diagram lists several Models that students will engage with throughout the course. These include practical applications like Basketball Analytics, Flocking, Leaders & Followers, Segregation, Sugarscape, and Team Assembly. Each model serves as a case study for students to apply their learning in real-world scenarios. The section on Languages indicates that students will have options for programming languages, with a specific mention of Choice, allowing flexibility in how they approach their modeling tasks. The diagram illustrates a variety of programming environments available for students, including: Scratch, Snap!, StarLogo, NetLogo, GAMA. These environments provide diverse tools for creating agent-based models, catering to different learning styles and preferences. Moreover, the course incorporates various Tools that support data analysis and visualization. The choices include: BehaviorSpace, CODAP, RAWGraphs, R. These tools enhance students' ability to analyze their models and visualize outcomes effectively. Finally, the diagram concludes with Learning Outputs, specifically focusing on an activity called Active Essay (Yamamiya et al., 2009).

This component assesses whether learning outcomes have been achieved. If not, it indicates that learning outcomes remain "Not Achieved"; if yes, they are marked as "Achieved." Overall, this comprehensive course structure on the Digida platform illustrates how all components are integrated to foster a robust understanding of agent-based modeling and its application in educational contexts. The use of Semantic MediaWiki allows for dynamic updates and retrieval of information, ensuring that content remains relevant and accessible for both educators and students. The ability to construct learning courses from existing digital objects on Digida enhances educational practices by promoting active engagement, collaboration, and exploration of complex systems through simulations and agent-based modeling.

Results

The findings indicate that engaging with ABM not only enhances students' understanding of complex concepts but also equips them with essential computer modeling thinking skills. During the 2024 academic year, 17 educational courses were launched on the Digida platform (http://digida.mgpu.ru), all employing a consistent course structure that integrated the previously outlined ABM methodologies. This structured approach significantly increased student engagement, particularly in utilizing the features of Semantic MediaWiki for collaborative learning. Evidence of this enhanced engagement is reflected in the total number of pages utilizing queries of the form {{#ask ...}}. The overall count of such pages can be assessed using the query

{{#ask: [[Has query::+]] | format=count }}.

Furthermore, we observed an increase in the number of students employing queries on their user pages, as indicated by the query

{{#ask: [[Has query::+]] [[Category:UserMGPU]] | format=count }}.

These metrics suggest a meaningful rise in student interaction with the platform's capabilities, illustrating their growing proficiency in applying computer modeling thinking within their learning processes.

The framework demonstrated that students' roles as model designers foster creativity, leading to a deeper comprehension of classroom dynamics as complex systems. As students assumed the role of model designers, they developed critical problem-solving abilities essential for navigating both classroom dynamics and broader learning design challenges. This not only underscores the effectiveness of ABM in educational settings but also highlights its potential to transform how future educators engage with and understand complex adaptive systems in their teaching practices.

The Active Essay is a key component of the learning outputs within the Digida platform, designed to enhance students' understanding and application of agent-based modeling. This activity provides pedagogical students with the opportunity to gain practical experience in creating and utilizing ABM models, while also engaging with the Semantic MediaWiki framework. The Active Essay encourages students to think critically about how ABM can be used to analyze complex systems and phenomena, thereby deepening their computational thinking skills. As students engage in this process, they are guided to assess whether their learning outcomes have been achieved. If they successfully integrate ABM into their essays and demonstrate a clear understanding of the concepts, their outcomes are marked as "Achieved". This reflective practice fosters a deeper engagement with the material and encourages continuous improvement. Through this approach, students not only develop their writing skills but also enhance their ability to apply computational concepts in real-world contexts. The integration of ABM into the Active Essay serves as a powerful tool for bridging theory and practice, ultimately preparing future educators to implement innovative teaching strategies in their classrooms. In the context of various educational courses, students are introduced to the use of pre-existing agent-based models (ABMs) and encouraged to create their own models on the Digida platform. These student-created models can be accessed upon request using the query

{{#ask: [[Category:Model]] [[Student-created::Yes]] | ?Environment}}.

While the quality of these models may vary, they consistently exhibit interactions among multiple agent types, enabling data generation and experimentation with different modeling scenarios.

Within the framework of the educational courses, future teachers from various disciplines engaged in the development of agent-based models, demonstrating their understanding and application of complex adaptive systems. Notably, projects created by female students in the English language program exemplified a strong focus on storytelling and thematic content, adhering to essential design principles of agent-based modeling.

In one project https://www.slnova.org/AgishevaVA684/projects/928766/, the model explores the dynamics between ordinary individuals and vampires. In this simulation, ordinary people possess a probability of becoming infected upon colliding with vampires. The model features an exorcist character capable of curing individuals bitten by vampires; once cured, these individuals cannot be transformed into vampires again. The simulation begins with five original vampires who remain immune to the exorcist's powers. Throughout the course of the simulation, the narrative unfolds as the exorcist endeavors to save all the ordinary people, culminating in a scenario where only one exorcist ultimately prevails, successfully rescuing everyone. This project not only illustrates the mechanics of infection and healing but also invites discussions about the implications of societal dynamics and individual agency within a fictional context.

Another project https://www.slnova.org/APhobia/projects/924636/ depicts a predator-prey relationship in which cats hunt dogs, with the added complexity that cats can consume dogs. The model incorporates a "kindness index," which regulates the probability of a cat eating a dog. Additionally, environmental factors such as stones can lead to the death of cats upon collision. The project introduces a fascinating interplay where cats increase their kindness level when encountering flowers, while dogs simultaneously gain energy. An energy indicator for cats reflects their energy levels, which are replenished when they consume dogs. The model also includes an age parameter for all animals; if an animal's energy depletes or its age reaches 100, it dies. This project engages with themes of survival and ecological balance, challenging students to consider the consequences of interactions between different species within a modeled environment. Both projects adhered to the foundational rules of agent-based modeling, including the incorporation of multiple agent types, adjustable variables, and data visualization through graphs representing agent properties and interactions. By focusing on the narrative and thematic content of their models, these students not only enhanced their understanding of complex systems but also cultivated their creativity and problem-solving skills. Their work illustrates the potential of agent-based modeling as a versatile educational tool that bridges theoretical knowledge with practical application.

The ability to design a model of an artificial society that can be utilized for experimentation by varying its parameters is a crucial skill that we believe should be emphasized within teacher education programs. This skill not only fosters a deeper understanding of complex adaptive systems but also equips future educators with tools to facilitate dynamic learning environments. As we discuss the transfer of skills in designing agent-based models to the design of educational processes and pedagogical research, it is essential to recognize that both ABM and Learning Design focus on the dynamic interactions among various components whether they are agents within a model or learners and educators within a classroom setting. This perspective aligns closely with the principles of ABM, where individual agents interact within a defined environment to produce emergent behaviors that can be analyzed to understand collective dynamics. By applying these insights from ABM to educational design, we can create more responsive and adaptive learning experiences that mirror the complexities of real-world interactions.

Discussion

In this section, we aim to align the sequences of agent-based modeling (ABM) design, learning design, and pedagogical research design. We believe that the influence of ABM experiences on the design of pedagogical research is particularly significant. Through engaging with ABM, students develop a heightened awareness of the complexities involved in modeling dynamic systems, which translates into their approach to educational research.

Engaging students in the world of ABM can be a rewarding yet challenging task, especially for those without programming experience. The goal is to maintain a balance between introducing fundamental concepts and avoiding overwhelming them with complex coding. Here, we outline seven essential steps of ABM, using the Segregation model as an example in Snap!, StarLogo Nova, and NetLogo. This approach aims to make the process accessible and engaging for students from various disciplines.

Step 1: Overview of the Situation. Objective: Understand the problem you want to model. In our case, we want to explore social segregation, where individuals of different types (e. g., happy and unhappy agents) prefer to be near others like themselves. This step involves discussing real-world implications of segregation and why it's important to study.

Step 2: Identify the Agents Objective: Define the agents that will inhabit your model. In the Segregation model

– Agents: Represent individuals in a community.

– Attributes: Each agent has an attribute called "happy", which indicates whether they are satisfied with their neighbors.

Example in Snap!: Create "happy" as a boolean variable for each clone.

Step 3: Define the Environment. Objective: Establish the space where agents interact. The environment can be a grid or a continuous space where agents can move around and interact with each other. Examples in Snap!, StarLogo Nova or NetLogo — Set up a grid environment where agents can occupy cells. Each cell (patch in NetLogo) can hold one agent at a time.

Step 4: Specify Rules for Agent Behavior. Objective: Determine how agents interact with their environment and each other. In our model, agents will move to a new location if they are unhappy (i. e., if they have too many neighbors of a different type).

Step 5: Implement the Model. Objective: Build your model using your chosen platform. This involves coding the behaviors and rules defined in previous steps. Example in NetLogo: ask turtles with [not happy?] [find-new-spot] Example in Snap!: Use blocks to create logic for agent movement based on their happiness status — Figure 2.

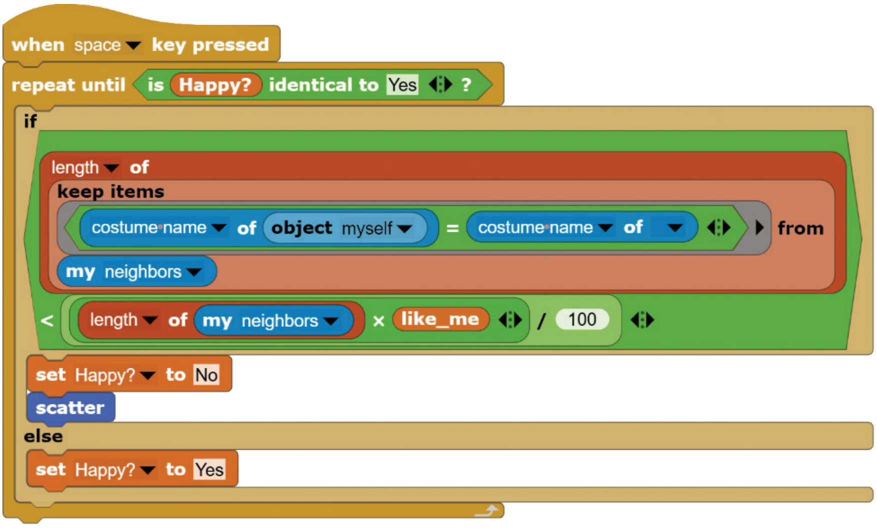

Fig. 2. Example of scattering in Snap!

Рис. 2. Пример расселения в Snap!

Step 6: Run Simulations Objective: Execute your model to observe behaviors and outcomes. After implementing the model, run simulations to see how segregation evolves over time.

Example in StarLogo Nova: Start the simulation and watch how agents move based on their happiness levels. You can adjust parameters like #be_like_me and #vision — Figure 3.

Step 7: Analyze Results and Iterate Objective: Reflect on what you observed and refine your model accordingly. Discuss the outcomes of your simulations. In Snap!, you can collect data in list of lists. In NetLogo, you can use BehaviorSpace to systematically vary parameters and analyze results — Figure 4.

The outlined sequence of presenting educational materials through the seven essential steps of ABM serves as a structured approach for educators. By guiding students through each step ranging from understanding the problem and defining agents to implementing models and analyzing results teachers can foster a deeper comprehension of complex phenomena related to group behavior. This pedagogical method not only enhances students' engagement with agent-based modeling but also facilitates the integration of these models into collaborative learning environments,

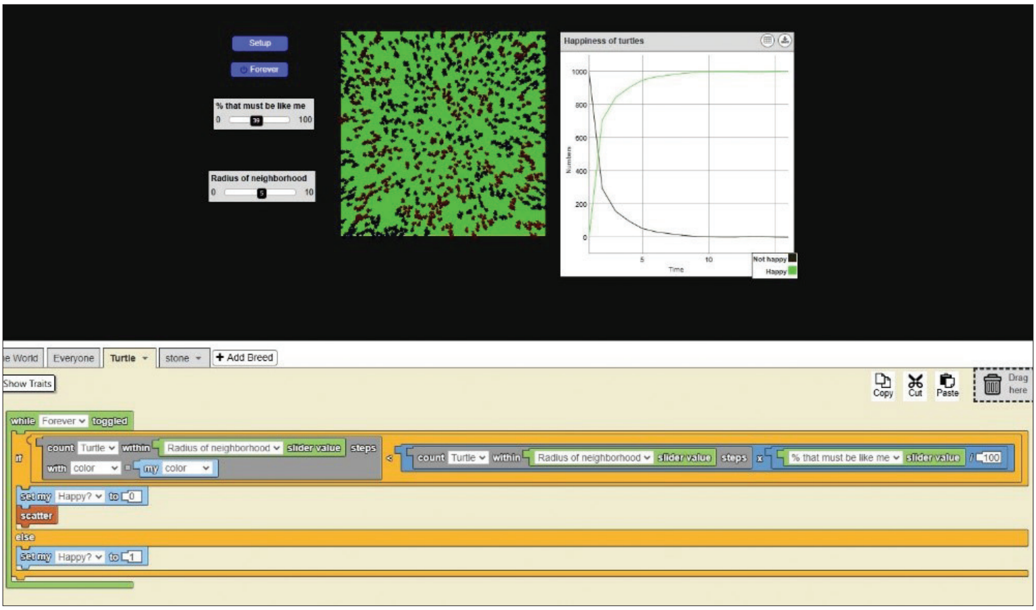

Fig. 3. StarLogo Nova Model

Рис. 3. Модель StarLogo Nova

such as wiki pages created by students. Ultimately, when students embed their models within these pages and present their findings in the form of Active Essays, they not only demonstrate their understanding of the concepts but also contribute to a dynamic learning community.

The mapping between the steps of agent-based modeling and educational research reveals several parallels that can enhance pedagogical practices, particularly for future educators who may lack programming experience (see table). By mapping these steps between agent-based modeling and educational research, we can cultivate a more dynamic approach to teacher training that embraces iteration and adaptability skills that are essential for effective teaching in today's rapidly changing educational landscape.

Table / Таблица

Mapping Table: Steps of Agent-Based Modeling vs. Steps of Educational Research

Сравнительная таблица: последовательность многоагентного моделирования и педагогического исследования

Agent-Based Modeling	Educational Research
Overview of the Situation	Identify Research Problem
Identify the Agents and Environment	Define Participants and Context
Formulate the Model	Develop Research Design
Implement the Model	Conduct Data Collection
Test the Model	Pilot Study / Preliminary Analysis
Collect Data	Gather Data through Surveys
Analyse Results and Iterate	Analyse Data and Reflect on Findings

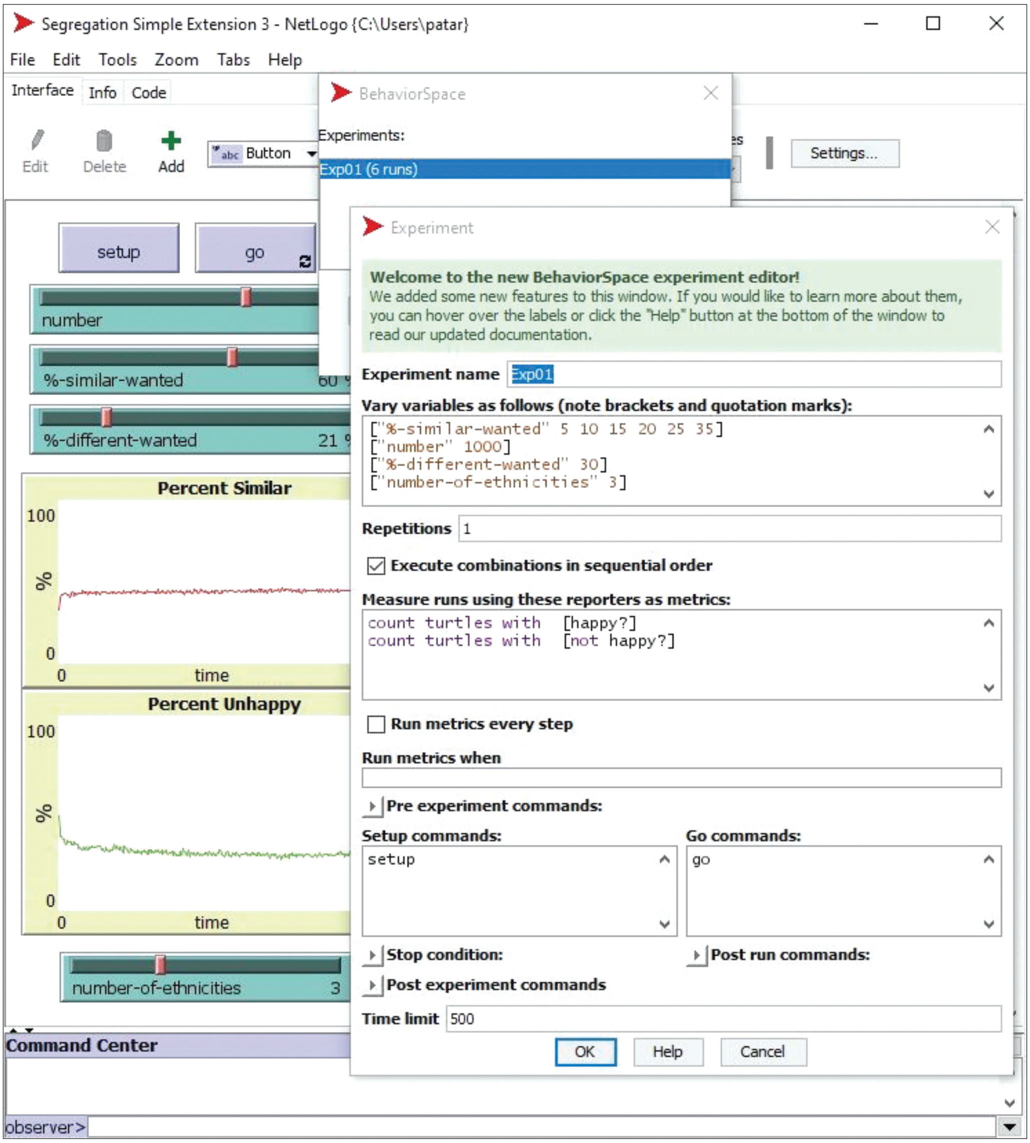

Fig. 4. BehaviorSpace NetLogo

Рис. 4. Инструмент BehaviorSpace NetLogo

The mapping between the steps of agent-based modeling and educational research reveals several parallels that can enhance pedagogical practices, particularly for future educators who may lack programming experience. The mapping between the steps of agent-based modeling and educational research reveals several parallels that can enhance pedagogical practices, particularly for future educators who may lack programming experience.

Both processes begin with a clear understanding of what needs to be addressed whether it's a specific educational challenge or a broader systemic issue. This foundational step is crucial for guiding subsequent actions. In ABM, identifying agents involves understanding their roles within a system, while educational research focuses on participants' characteristics within a learning environment. This alignment emphasizes the importance of context in both fields. Creating a conceptual model in ABM parallels designing a research methodology in education. Both require careful planning to ensure that variables are appropriately defined and interactions are understood. While implementing an ABM involves coding, conducting data collection in educational research can also be seen as a systematic approach to gathering information, albeit without programming.

Testing an ABM ensures its validity, similar to how pilot studies help refine research methods in education before full-scale implementation. Data collection step is crucial in both domains as it directly influences analysis outcomes. In ABM, data collection informs about agent behaviors; in education, it provides insights into student learning experiences. The iterative nature of ABM is particularly noteworthy for educational researchers, as iteration is often underutilized in pedagogical studies. Emphasizing this step could foster a culture of continuous improvement among educators, encouraging them to refine their teaching strategies based on evidence gathered from their practices.

Conclusion

In conclusion, the integration of agent-based modeling (ABM) into teacher education through the Digida platform has demonstrated significant practical value. By uniting various environments for creating and utilizing ABM models, we have established a comprehensive framework that enhances the pedagogical training of future educators. This approach not only enriches their understanding of complex adaptive systems but also equips them with essential skills for effective learning design. The transfer of competencies from ABM design to pedagogical research and learning design is particularly noteworthy. Students learn to apply their modeling skills in diverse contexts, whether it be through crafting educational research designs or refining learning processes. This versatility ensures that they are well-prepared to address the multifaceted challenges of contemporary education. Moreover, we note that our students are developing the ability to utilize the concept of "Ask" across various platforms. In agent-based modeling environments like Snap! and NetLogo, they can query groups of agents to gather information about themselves and their interactions with others. Similarly, in Semantic MediaWiki, they can by {{#ask: }} access categories and retrieve summarized information, enhancing their research capabilities. This skill extends further into pedagogical research, where they can solicit insights from respondents, and into learning design, where they can refine and adapt educational processes based on feedback. This multifaceted approach not only cultivates a robust skill set among future educators but also fosters an innovative mindset that embraces inquiry and adaptability. As we continue to explore the integration of ABM within teacher education, we anticipate its profound impact on shaping educators who are equipped to thrive in an ever-evolving educational landscape.

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