Chapter 12
Syndemic: Using Game-Based Learning to Engage Students in the Human Microbiome

Emma Ruskin and Tal Danino

> An enormous revolution is occurring in our field due to the changes in technology: shortly, there will be no more culture plates but bacterial signatures based on mass spectrometry and minimal manual work because of automation. There will be great need to use the electronic tools to communicate new findings, to teach what the new technology does, and how to transition from the classical to the "new" microbiology. We need to keep our minds, eyes, and ears open, as only the future will tell what we will need to learn and teach new generations and what electronic tools we will use. Jeannette Guarner and Silvia M. Niño, Microbiology Learning and Education Online, 2016

12.1 Introduction

The average adult has over 10 trillion microorganisms located in and on their body (Sender et al., 2016). This staggering total is more than the number of human cells. Thus, the commensal archaea, bacteria, fungi, protozoa, and viruses, which collectively form the human microbiome, outnumber the human cell population. Although it was largely believed that these microbes only inhabit and affect our gut, mucosal surfaces, and skin, recent research has led us to understand that our microbiomes play far larger roles in our health and well-being than previously thought (Khanna & Tosh, 2014). Disruptions of the formation and function of our microbial communities can have critical consequences for host health, including gastrointestinal disorders, allergies, obesity, and stress. The composition of these microbes not only influences the balance between health and disease, but also are markers of our genetic makeup, geography, and the environments we live in (Guarner & Niño,

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2016). In fact, research revealing the importance of the human microbiome has not only dramatically impacted the scientific community's understanding of human health, but also environmental health and sustainability of planetary life as well. Many studies have shown the microbiomes of animals and plant species on which human civilization depend are critical for maintaining sustainable systems. However, much of this research on microbiomes has yet to become accessible to the general public.

The lack of communication between scientists and the public can be seen as a social justice issue in light of recent studies showing that we are failing to produce scientifically literate citizens. Since 2000, the Program for International Student Assessment (PISA) has measured the academic achievement of 15-year-old students in dozens of countries around the world every 3 years. In their most recent survey, conducted in 2015, PISA assessed science literacy in the educational systems of 73 countries. Although the United States spends more money on each student's education than most countries, students' scores on measures of science literacy are below average (Kastberg et al., 2016). Smaller studies tracking science achievement, specifically in the United States, have found that students' attitudes towards science, in addition to their scientific literacy, have significantly declined over the past few decades (Kelly et al., 2013). Osborne et al. (2003) recognized the decline and undertook a comprehensive review to better understand students' attitudes towards science. The study concluded that the decreasing number of students choosing to pursue science should be remedied by a dramatic pedagogical shift to teaching science in a more accessible rather than alienating way. For science learning outcomes to increase, students must be actively engaged in the material and see how their classroom learning applies to real-world situations. Syndemic, a video game inspired by the current research on the microbiome and its potential to engage students, attempts to fill this need. In this chapter, we will use the process of field testing Syndemic in the US and Nicaragua as a lens to explore:

1. How Digital Game-Based Learning can be an innovative tool to engage and motivate students in science
2. Lessons learned from our mission to make Syndemic inclusive and accessible to diverse populations in global contexts
3. Ways undergraduates, as novice researchers, can have authentic real-world fieldwork experiences

12.2 Microbial Ecology and Human Health: Catching the Curriculum Up to the Research (Tal Danino)

As we study the coevolution of the microbiome alongside humans, we see the progression of specific microbial communities developing in different environmental "niches" throughout the body. As these microorganisms both impact and adapt to their environments, they reach a state of dynamic equilibrium, which is influenced constantly and profoundly by modern society's innovations in food, medicine, and agriculture. It is now widely accepted that the majority of these microbes are not detrimental to human health, but rather exist in a largely mutualistic relationship with us, in which both parties benefit from the symbiotic interaction. The formation and function of microbial communities changes as human lifestyle evolves and alters the microbial environment. Moreover, given the natural co-evolution of humans and their microbes, there is generally a beneficial and protective effect. Researchers are currently investigating how many commonly used products could affect a microbial balance both within the body and in the environment.

Understanding our relationships to the microscopic world is critical to guiding our behaviors towards the environment and ourselves. Unlike animal and plant diversity visible at the macroscale, the microbial world is more difficult to perceive with the naked eye. Yet there are profound issues caused by local extinctions or excessive proliferation of microbes inside humans or in their environments, analogous to the loss of animals such as keystone predators or the proliferation of pests, deforestation, or problematic invasion of non-native plants. For example, bees are cornerstones for terrestrial ecosystem stability and critical components in agricultural productivity (see also Snow, this volume). Honey bee population declines have been partially attributed to increased parasite loads which are prevented by prophylactic use of antibiotics. This practice of using antibiotics such as tylosin results in persistent effects on both the size and composition of the honeybee microbiome, which increases susceptibility to opportunistic pathogenic infections, leads to antibiotic-resistance, and decreases survivorship (Raymann et al., 2017). Understanding these complex macro- and micro- relationships is critical to developing sustainable solutions for the health of bee pollinators and across many other industries.

At the Synthetic Biological Systems Laboratory at Columbia University, our research focuses on understanding and designing the microbes within the human body. As principal investigator, I first became interested in bacteria as some of the simplest organisms that could be genetically engineered. There was excitement in the newly established field termed, Synthetic Biology, that focused on engineering new functions and behaviors in microorganisms. In one of my research projects, I was able to engineer some bacteria that controlled the coordination of a bacterial community to produce a fluorescent protein in synchrony, all by manipulation or 'programming' of their DNA. We realized that because the many bacteria in and on our bodies are intertwined with human health, we could design and engineer them in the hopes of diagnosing and treating disease.

One of our lab's major goals is to specifically understand microbes in relation to cancer, and engineer bacteria to detect and treat this dreaded disease. From the scientific perspective, the complex interplay of different fields here is often difficult to communicate to many audiences. Our work includes elements of microbiology, human anatomy, cancer biology, engineering, and biotechnology. While doing demonstrations for kids at science fairs and museums, I found that visual representations of our research were the most engaging. In particular, the microscopic images and 'movies' we made garnered the most attention, not just for kids but also for a general audience and scientists. I began to focus my efforts on making our work as visually exciting as possible, teaming up with artists such as Vik Muniz and Anicka Yi. I later did two artist residencies to focus on making visual art. It was this first inclusion of art with science that I found attractive to young scientists and I have been continuing to develop engagement and learning programs based on this ever since.

Beyond communicating science to the general public, developing “bioartworks” has become a thrust of our lab. I share the vision of our research by creating art from materials in the laboratory and reflect more broadly on the themes in biotechnology that are shaping society (taldaninoart.com). Beyond engaging with people at a fundamentally more profound level, the hope is that these works will allow for inquiry and self-reflection, connection with the human experience, and help shape dialogue and future policy for how science integrates with society. For example, many projects utilize soil microbes, which form collective, fractal-like patterns on petri dishes (one instance is a series called *Microuniverse,* shown in Fig. 12.1).

These images reflect on the beauty of the microscopic world and the ecosystems of soil health. We depend on soil for the vast majority of our foods, use it as an energy source, and it is fundamental to our existence. Soil can be considered in some ways more valuable than oil. While critical to our society, soil has become unappreciated in the increasingly city-dwelling world that is disconnected from the land beneath it. Many farming practices such as deforestation and overgrazing are some of the causes of degraded soil. Additionally, the use of agrochemicals such as pesticides that help increase yields in the short term inevitably disrupt the balance

Fig. 12.1 Microuniverse. Various bacteria species grown on petri dishes. (Courtesy of Tal Danino)

and quantities of microorganisms in the soil and stimulate the growth of harmful versus beneficial bacteria. Degraded soil now covers 15–30% of the Earth's land surface, making them less useful for food and fiber production and carbon dioxide sequestration, which significantly impacts climate change. A broader appreciation of the need for soil erosion management and the development of effective legal frameworks are increasingly needed. By directly exploring the microbial species in the soil and other ecosystems, our projects bring attention to the connection between our collective health and that of the planet.

Similarly, in our cancer-art projects, we utilize cancer cells to print images with the theme of the "medium is the message." In *Colonies*, we created images of mandalas out of HeLa cells (with artist Vik Muniz), and in *Cancer Medium,* screen-printed cancer cells to explore cancer history, advocacy, and disparities. Using immortalized cells of Henrietta Lacks' (HeLa) cells to create an image of a mandala, a symbol of life, creates a conversation about mortality and bioethics and allows basic researchers to connect with the patient experience on a deeper level. In *Cancer Medium*, we charted the landscape of communication surrounding cancer research and advocacy, where producing large poster-sized prints with cancer cells as the medium provides a model of integrated communication on policy and disparity. Here the artworks create conversations about researchers' responsibilities regarding appropriate biospecimen consent, patient privacy, and supporting concrete actions to improve research participants' rights, as was brought to light in the case of HeLa cells. Furthermore, they highlight disparities in cancer research that are known to exist across geographic regions and ethnicities. For example, certain ethnic minority groups experience poorer cancer outcomes, which can be due to factors such as healthcare access barriers, stigmatization, under-representation in clinical trials, cancer literacy, and cultural beliefs, all of which can delay help-seeking and affect timely diagnosis. Here the universal language of art can transcend cultural and economic boundaries to raise awareness and provide accessible benefits for patients.

I first learned about Syndemic when I was searching for games that related to bacteria in the human body. What immediately struck me about the video game was how attractive the visuals were and that it was fun to play. I contacted the game's creator, Alex May, to see if he would be interested in collaborating to make the game more related to our research and to have scientific, educational value. We worked together to create levels in the game where bacteria would swim through the body to find and kill cancer cells, an aspect that was very similar to our laboratory's research. In this way, Syndemic is an excellent introduction to our laboratory's work and Synthetic Biology in a hands-on and interactive format. The game creates an authentic learning experience for students by accurately mirroring the work of our laboratory. While it specifically focuses on microbes swimming through the human body, the principles are fairly universal and could be applied to teach about microbiomes in other animal and plant species, as well as about microbiomes that are important in planetary health. Furthermore, the game teaches synthetic biology and biotechnological principles in the way that bacteria are engineered to produce new behaviors when they pick up DNA elements. Thus, it can lead teachers and audiences to think about the use of microbes in applications for the degradation of plastics, improvement of material yields, and other biofabrication and bioeconomy principles. More broadly, the game embodies our teaching philosophy that science education is about discovery and experience rather than textbook memorization. This philosophy is not only relevant to our work inside the lab, but it is also what led me to use the beta testing of Syndemic as an educational opportunity to engage undergraduates out in the field.

12.3 The Testing Phase: Bringing Syndemic to Students (Emma Ruskin)

Syndemic is named after a term coined in the 1990's that refers to ways that diseases co-occur and interact depending on their social, cultural, economic, and geographic contexts. The video game takes this concept to the microscopic level by exploring the synergistic interactions between microbes and their environments. Using the concept of syndemics as a framework to explore the relationship between humans and the microbiome is particularly timely given the on-going COVID-19 pandemic. In fact, some argue that COVID-19 should be more accurately described as a syndemic, rather than a pandemic. Instead of viewing the spread of COVID-19 from solely an infectious disease lens, its characterization as "syndemic" forces us to acknowledge the interplay of social and economic disparities that dictate its impact (Horton, 2020). The COVID-19 syndemic also showcases the need for a scientifically literate population that understands abstract concepts such as prevention and hygiene. By making the relationship between humans and microbial communities visually accessible, Syndemic is a critical tool to improve our current collective scientific and public health engagement.

Syndemic takes place in the future where a genetically-engineered microbe has been designed to aid the immune system in killing bacterial infections, metastasizing cancer cells, chronic allergies, and other health-related antigens. The characterization of this microbe as a useful aid helping the body promotes the idea that not all microorganisms are harmful to human health and that many are actually helpful. Moreover, this format encourages players to practice building the skills of imagination and intentional creation of a desired future. Although the game is not set in the present reality, the graphics are scientifically realistic and accurate. Cell biologist and Syndemic creator, Alex May, set the game within a stylized version of the real microbial/immunological world that is hidden from the naked eye in order to allow the learning to come from gameplay itself. This approach is in direct response to May's growing frustration that, "Many educational games simply ask questions and expect answers as if they were written exams with good graphics" (personal interview, 2017).

In our mission to meet the needs most current and relevant to the educational community, Syndemic directly builds on the following learning objectives outlined in the New York City Department of Education's Science Scope and Sequence for grades 6–12:

- Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the shapes, composition, and relationships among its parts; therefore, complex natural and designed structures/systems can be analyzed to determine how they function (7th grade, unit 4).
- Living things are composed of cells. Cells provide structure and carry on major functions to sustain life. Cells are usually microscopic in size. Cells take in nutrients, which they use to provide energy for the work that cells do and to make the materials that a cell or an organism needs (6th grade, unit 3; 7th grade, unit 3).

Some of the game's visuals were closely based on images from the Synthetic Biological Systems Laboratory at Columbia University in order to make the world of Syndemic as scientifically realistic as possible (see Fig. 12.2).

In each game-play session, players choose to enter either a resistance mode or a transmission mode. In resistance mode, the objective is to maximize high scores by harvesting nucleic acids from the environment and defeating infectious pathogens. The player can also upgrade their character by converting nucleic acids into new genes, which aids in their survival, energy, speed, and weaponry. In transmission mode, players can enter a more story-focused atmosphere, which involves curing various human hosts of their diseases. The player jumps from person to person, fighting bacterial infections, destroying cancer cells, and preventing tissue damage caused by allergies. In this mode, players can collect weapons from the environment, including new experimental antibiotics and plasmids. In order to help players understand the relationship of the game to real-world applications, there are various "reality checks." These include factual statements such as:

- Viruses are actually much smaller than bacteria and can range in size from 1/10 to 1/100 of a bacterium.
- Bacteriophages are viruses that target bacteria specifically. They are highly specialized to attack individual strains.

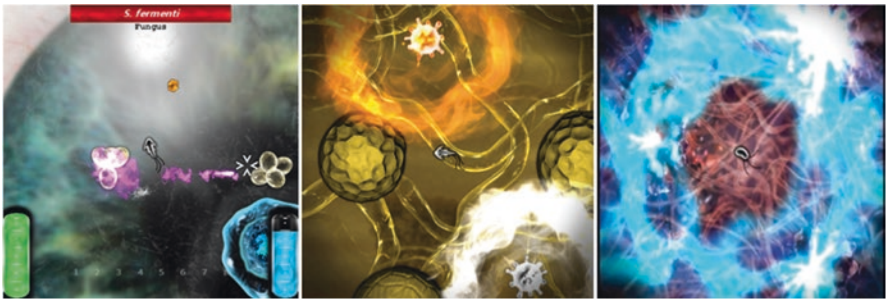

Fig. 12.2 Screenshots from Syndemic. (Courtesy of Alex May)

- The presence of pathogens in the bloodstream is a serious and potentially fatal condition called Septicemia. If untreated, it can lead to septic shock and organ failure.

Syndemic uses a variety of game design techniques to maximize player engagement. Instead of relying wholly on statistics and numbers (such as weapon power) to determine the player's "success," the player's reflexes and scenario anticipation skills are rewarded. Unlike the typical action shooter game, where pressing the fire button kills the target, Syndemic pushes its user to adapt to the host environment by requiring them to use specific tools against each antigen.

12.4 Testing Syndemic Across New York City

In the fall of 2016, a demo of Syndemic was ready for testing. As an undergraduate Biology major at Barnard, I had the opportunity to implement the beta testing phase of Syndemic**.** I started by contacting schools that pride themselves on their use of technology since I thought that computer availability for each student to play the game individually would be my biggest hurdle to testing Syndemic. However, I soon found that the more "technologically advanced" schools were also the most hesitant to allow any sort of research into the classroom, even though I had obtained approval from the Barnard College Institutional Review Board. I was surprised to find that getting administrators to allow research in their schools would be a minor hurdle compared to getting teachers on board. I showed Syndemic to numerous educators and consistently heard negative responses. In trying to understand their reaction, I met with a team of middle school science teachers at a college prep K-12 school on the Upper East Side. After watching a walk-through of the game, most of the teachers understood why kids would enjoy playing it, but did not see the game's educational value. After the meeting, one teacher wrote in an email, "I don't see how we could use it [Syndemic] – a lot of shooting – I really don't see how they will learn about the immune system from that." I understood their concern. Educators did not develop syndemic, and it was not a didactically instructive game. For example, names of bacteria would appear when the user scrolled over them, but the game did not make names or definitions an integral part of the experience. Instead, the game immersed its users in a world that represented scientific accuracy, whereas most "educational" games of this type often employ cartoonish unrealistic imagery. The responses from teachers made me question the game's value. Does Syndemic's departure from traditional educational tactics lessen its pedagogical value? Does Syndemic's use of shooting enemies engage users in the game or make it less appropriate for classroom use? Past research helped provide some answers. A growing body of academic work supports the value of games like Syndemic in educational contexts. This research has produced a pedagogical movement called Digital Game-Based Learning (DGBL).

12.4.1 Digital Game-Based Learning in STEM Education

DGBL directly responds to mounting concern that our educational system is failing to provide adequate STEM education to the greatest numbers and diversity of young people (Snow & Dibner, 2016). DGBL defined as, "a type of gameplay with defined learning outcomes" has been identified as a successful educational tool that can help improve student attitudes towards science (Plass et al., 2015). Researchers have evaluated variables in game-based learning such as gender (Papastergiou, 2009), level of collaboration (Chen et al., 2015), and contextual integration (Miller et al., 2011) while measuring knowledge gained through pre-and post-game tests. These studies have shown that DGBL can significantly enhance overall learning and knowledge acquisition under testing conditions (i.e., Chen et al., 2015). Despite this breadth of work, a meta-analysis of DGBL studies concluded that a gap exists between the possible benefits of game-based learning and the outcomes being assessed. Li and Tsai (2013) found that only a few studies measured student engagement and motivation, even though what makes digital games most appealing is their ability to create an enjoyable and engaging user experience. Since Syndemic is not a didactic game, I focused on assessing student experience and changes in learning motivation. This research attempts to fill the gap identified by Li and Tsai (2013) between the potential benefits of using digital games and the outcomes being measured.

12.4.2 Designing and Implementing the Study

After my lack of success with classroom teachers, I tried another approach: after-school programs. If teachers didn't feel that Syndemic belonged in the classroom, perhaps it would be easier to integrate the game into after-school hours. This approach proved to be a far more effective approach. Between December and April of 2016, I conducted workshops with a total of 94 students at four afterschool programs affiliated with New York City Department of Education public schools. The groups included a STEM and arts (STEAM) program, a Kids Who Code program, and a general afterschool program in Jamaica, Queens. Of those 94 students, 63 attended both workshops and fully completed both the pre-and post-surveys. Data from these 63 students were analyzed during our study of Syndemic.

The overall goal of the study, to assess students before and after their gameplay, was accomplished in two sessions at each afterschool location. Each student filled out an anonymous pre-survey with questions regarding demographic information and computer experience, including their frequency of computer use, liking of computer games, and computer gaming experience. Questions were adapted from the Science Motivation Questionnaire (SMQ-II) developed by Shawn M Glynn (2011) to assess a baseline for the student's level of motivation to learn science. Students were prompted with the statement: "In order to better understand what you think and how you feel about your science courses, please respond to each of the following statements from the perspective of ‘When I am in a science course…’” The questionnaire used a Likert scale to measure: intrinsic motivation, self-efficacy, self-determination, and career motivation.

After completion of the pre-survey, students played Syndemic individually for 30 min. A week later, students played Syndemic for the same amount of time and took a post-survey directly after their second session. The post-survey contained the same measures of science motivation but excluded the background information on demographics and computer usage. In addition, the pos-survey measured the students’ game playing experience. In past studies, Csikszentmihalyi’s (1975) flow theory has been adapted to assess gameplay experience quantitatively. Flow is a psychological state that is intrinsically motivating, enjoyable, and challenging. Bressler and Bodzin (2013) use a qualitative analysis to show that the common features of flow experiences are: a feeling of discovery, a desire for improved performance, and flashes of intensity. The flow state can be assessed quantitatively by a short questionnaire developed by Csikszentmihalyi (Lester et al., 2014). This questionnaire was adapted for the post-survey used in the study of Syndemic. Theoretical underpinnings, such as flow theory, have increased the legitimacy of DGBL research and allowed studies to distinguish between games that are unable to engage users versus games that simply fail to deliver educational content. Therefore, in studying Syndemic, we attempted to add to the existing literature by using previously tested methods and questionnaires. Figure 12.3 shows an overview of the study design and protocols.

12.4.3 Results

The majority of the students surveyed were male (59%) and many of them were Hispanic (49%). Although there were significant demographic differences between the students in the four afterschool program groups surveyed, the Science Motivation Questionnaire results indicated no statistically significant differences among groups, motivating us to present combined data (Fig. 12.4). Students responding on the post-survey more frequently agreed with all statements, including questions like “Learning science is interesting” to evaluate intrinsic motivation, “I believe I can master science knowledge and skills” to evaluate self-efficacy, or “I study hard to learn science” to evaluate self-determination. For survey items in all three of these categories, post-surveys documented statistically significant increases ($p \leq 0.005$), but items assessing career motivation were not significantly increased in post-workshop surveys ($p = 0.105$). Despite these varying significance levels, all four measures of motivation showed increases from pre- to post-survey of a similar magnitude. The mean differences (post-score minus pre-score) across all categories of motivation were between 0.15 and 0.26,suggesting 15–26% of all students responded with answers at least one integer higher on the Likert scale (0–4) after playing the Syndemic game (see Fig. 12.4).

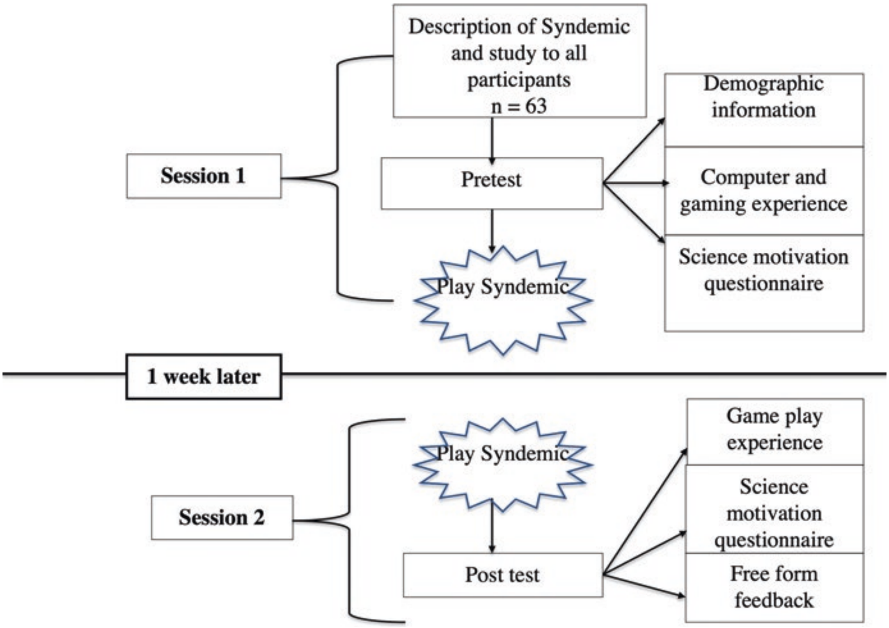

Fig. 12.3 Study design for syndemic evaluation

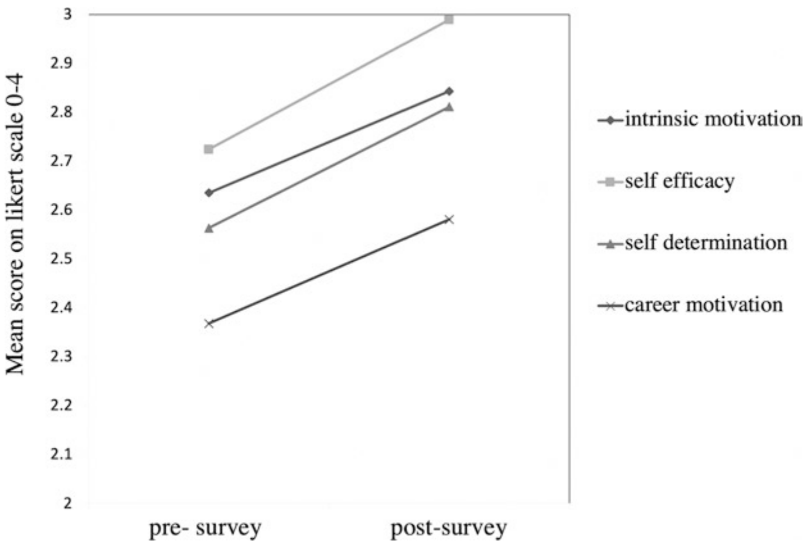

Fig. 12.4 Pre-and post-survey responses for all groups on the Science Motivation Questionnaire

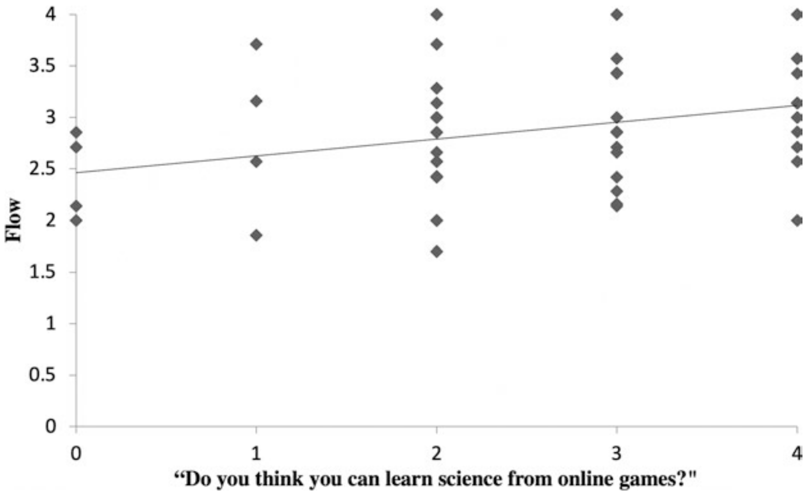

Fig. 12.5 Correlation between flow and student belief that online games can teach science ($R^2 = 0.303$, $p = 0.0360$)

When looking at student engagement, investigated using an additional seven items on the post-survey, 67.5% of students reported "strongly agree" or "agree" across the full set of questions, with even larger proportions reporting agreement about two questions: "When I was using the game, I wanted to do as well as possible" (80.4% selected "strongly agree" or "agree") and "I was able to make the game do what I wanted it to" (70.1% of students selected "strongly agree" or "agree"). Variation in flow scores was not explained by gender, race, gaming experience, computer usage, or any of the variables measured on the Science Motivation Questionnaire. However, as shown in Fig. 12.5, there was a significant positive correlation between the way students answered the question, "Do you think you can learn science from online games?" and how they scored on measures of flow experienced while playing Syndemic ($R^2 = 0.303$, $p = 0.0360$)

12.4.4 Analysis

Significant increases in survey scores from pre- to post-assessment indicate that Syndemic can increase students' intrinsic motivation, self-efficacy, and self-determination to learn science. However, career motivation did not significantly improve from pre- to post-survey. Career motivation was assessed using statements such as "my career will involve science" and "learning science will help me get a good job." This category aims to determine the level of relevance students feel science has to their career paths (Glynn et al., 2011). It is not surprising that this study, with its limited timeframe, could not create such a fundamental shift and significantly impact student responses to questions in this category. Responses to career-related questions may be inherently higher in variability among middle-school students, or even in an individual student's response from day to day. Further investigation, in which students have increased exposure to Syndemic over a more sustained period of time, could help to reveal such variability while also discerning whether Syndemic can potentially impact students' career motivations. If Syndemic still has no impact on student career motivation after increased gameplay, additions to the game itself would likely be needed. Some of these changes are already in progress. Alex May is currently completing an updated version of Syndemic to address the issue of career motivation. Possible additions include pop-ups explaining the jobs of the scientists who discovered each type of bacteria and more fundamental adjustments such as features allowing students to design their own microbes and experiments.

Although the majority (67.5%) of students experienced maximal amounts of flow, the flow scores reported by students in this study are over 10% lower than those found using a forensic science game called SSI (Bressler & Bodzin, 2013). The lower rates could be due to many factors, including differing subject matter and implementation settings; however, it is worth noting that, unlike Syndemic, SSI utilizes a collaborative game design. SSI allows students to play and problem-solve in small groups, while a single student can control the microbe while playing Syndemic. Students clearly noticed the limitations of this format, as requests for a multiplayer version were the most frequent suggestion written in the free-response portion of the post-survey. The request to create a more collaborative gaming environment, like SSI, reflects students' desire to maximize their own flow experience. Both Meluso et al. (2012) and Chen et al. (2015) explicitly tested the role of collaboration during gaming. The studies employed similar experimental procedures in which the control group played a game independently, and the experimental group played the same game in small groups. Both studies did not find a significant difference in learning outcomes or motivation between the independent and collaborative groups. However, Chen et al. (2015) acknowledge the need for further research on games specifically designed for cooperative play. Our goal is to make a multiplayer version of Syndemic, allowing for the results of this study to be directly compared to a collaborative game design. Testing a multiplayer version of the game would add to the existing literature as past studies have only tested the same game under different scenarios.

We tested both the Science Motivation Questionnaire and flow assessment results for correlations to the demographic information gathered from the pre-survey. There was a strong precedent that gender would predict the variance in science motivation or flow experience because Syndemic is a science game. Females have typically been less responsive than male peers to many STEM education initiatives (Tsai et al., 2012). However, gender did not significantly correlate with either flow or science motivation. These results are supported by numerous studies in DGBL, which have not found differences in how genders engage with games that create a narrative-driven virtual environment (i.e., Papastergiou, 2009). Therefore, DGBL provides a uniquely inclusive approach to engaging boys and girls. However, not all games have been able to create equal engagement. Inal and Cagiltay (2007) found that a game's narrative is critical to allowing females to achieve flow, while the rules and features of a game are more significant to males' flow experience. Therefore, Syndemic's ability to create equal engagement in this study is likely a direct reflection of its narrative-driven design.

The only significant correlation identified was between flow state and students' belief that online games have the ability to teach science. The more a student believed that games possess educational value, the more engaged the student was while playing Syndemic. Although Syndemic had a demonstrable impact on their motivation to learn science, students most often responded that games are only "sometimes" useful for teaching science. This hesitancy to acknowledge the potential of games as learning aids mirrors data reported by Anderson and Barnett (2013) on the ability of an online game to teach middle school students abstract concepts in physics. Anderson and Barnett (2013) found that although the game significantly improved learning outcomes, students did not consider playing the game to be a learning experience. This disconnect between the game's potential benefits and its perceived value is not limited to students. I saw it firsthand in teachers' responses when we asked them to consider using Syndemic with their students. Shaffer et al. (2005) comment specifically on this trend and explain, "there is a lot being learned in these games. But for some educators, it is hard to see the educational potential of the games because these virtual worlds aren't about memorizing words or definitions or facts. But video games are about a whole lot more."

Our society has deeply ingrained perceptions of video games as a "waste of time," notions that are undoubtedly true of some games but that must shift to address the proven educational value of others. Shaffer et al. (2005) argue that our education system must catch up with technology and stop perpetuating the harmful perspective claiming that games are only "entertainment." These pervasive societal beliefs mean that it is not enough to present middle school students with games and expect them to be accepted, without bias, as new learning tools. Instead, schools, parents, and teachers must integrate DGBL effectively by helping students recognize the power of games as a new facet of their educational experience. Over a decade ago, Shaffer et al. published their piece and predicted that the next challenges to DGBL would be helping learning environments acknowledge the power of games and integrate them effectively. The results of testing Syndemic illustrate that the challenges Shaffer et al. identified a decade ago are still relevant to the current climate and future success of DGBL.

12.5 Expanded Testing: Syndemic Goes to Nicaragua (Emma Ruskin)

12.5.1 Why Nicaragua?

I remember the cries of disgust that continued each time a new group was given the mouthwash. I tried to explain that microscopic bacteria live in our mouths and that mouthwash is a way to prevent the harmful ones from causing problems. This idea *was met almost universally with blank faces. On the count of three, the children tipped the little cups into their mouths, ridden with skepticism, and gurgled. After encouraging some vigorous swishing, we instructed the children to spit out the foreign liquid. Sometimes, the volunteers also handed out toothbrushes. These were met with fewer complaints, but the children's sentiments towards them were made plain by the litter of toothbrushes left behind in the dirt after dismissal.*

After my sophomore year at Barnard College, I volunteered with a small NGO in Nicaragua for the summer. I focused on executing the tasks given to me as part of their effort to improve hygiene among students in some of the poorest neighborhoods outside of Granada. The volunteers treated any complaints like typical children's shenanigans and tried to hand out as much mouthwash and as many toothbrushes as possible. I did not reflect on this aspect of my experience in Nicaragua for months afterward until I found myself testing Syndemic in afterschool programs across New York City. As I began to work with kids using Syndemic, I started to think more and more about the children's repulsion towards the mouthwash and toothbrushes donated by La Esperanza. I realized that the children's "shenanigans" in response to the toothbrushes and mouthwash were not a nuisance to be ignored but a key for understanding why a game like Syndemic might be an invaluable teaching tool. The explanation I had attempted to give when the children asked me why they needed to use this gross-tasting mouthwash was accurate but wholly inadequate. Without having any conception of the microscopic world, talking about the role of bacteria in their bodies and environment was meaningless and confusing to the children, just like handing out cups of mouthwash and toothbrushes. How can children be expected to participate in these critical acts of hygiene if they have no idea why these actions are important? How can children comprehend the need for these behaviors when the microorganisms responsible remain unseen, allowing them no conception of the microbiome?

As I began to wrap up my work with Syndemic in New York, I reached out to La Esperanza to see if they would be interested in my coming back again to test Syndemic and expand on the data gathered from after school programs in New York. The organization was excited to participate in the initiative, mainly because they had recently opened their first learning center, equipped with donated computers. I received funding from the Barnard Biology Department, which allowed me to include research on Syndemic in a larger biology education project I was conducting through Davis Projects for Peace. The game's creator, Alex May, set to work devising a way to input translated text into the game, and I printed translated copies of the pre- and post-surveys I had used during the workshops in New York. The computers at the center were offline, which allowed me to download Syndemic but not to use SurveyMonkey to collect data, as I had done in New York. Besides these technological limitations, I did not foresee too many other hurdles.

12.5.2 Syndemic Workshops at the Learning Center

Although the organization supported the idea of my work at the learning center, the reality of the project was met with skepticism similar to when I was handing out mouthwash 2 years before. I was expecting the local staff to be excited when I showed them Syndemic and the other materials I had brought to use with the kids. Instead, I met with hesitation and confusion. Unlike many of the classroom teachers I encountered in New York, who were hesitant because they did not see Syndemic's educational value, these educators were wary because I was treading in unfamiliar territory. I soon learned that children and local staff at the learning center had never been taught science as an academic subject. To get them on board, I needed to introduce the concept of microbiology and then place Syndemic within this framework so that they could understand its relevance. As a novice researcher, I was learning on the ground that making this learning tool accessible to a new geographic setting would require thoughtful changes in study design to meet the needs of this cultural context.

As much as I wanted to gather data on Syndemic that would allow me to draw fruitful comparisons to the data from after-school programs in New York, I was ill-equipped to make the major modifications needed to translate the study to this environment. One hurdle was that the entire basis of the survey at the after-school programs in New York included statements like "I put enough effort into learning science" and "I study hard to learn science." These pre/post surveys proved utterly irrelevant to the students at the learning center, who had not learned science as a separate classroom subject. In Nicaragua, Syndemic would need to introduce students to biology for the first time rather than help increase engagement in science so that students would be more receptive to the science taught in their classrooms. Based on anecdotal evidence, it was apparent that Syndemic was far less effective at engaging children with such limited exposure to science. The kids tended to be noticeably less interested in the game, and the ones who did get into it made comments indicating that they viewed it as a shooting game without grasping its intended purpose.

Moreover, written surveys proved to be an unusable form of data collection. Even after making substantial changes to the surveys to make the statements more relevant to the students' lack of science exposure, we found that their literacy levels were too low to allow them to complete many of the questions. As an alternative, we tried recording children's answers to questions about their experiences with the project using a video camera, but this approach raised a whole different set of concerns. The children strictly defer to the teachers at the center. As a result, we rarely felt as though the children were responding honestly in their answers. It often seemed as though they were hoping to guess the right thing to say that would please the interviewer. For instance, when asking a child what they thought of the activity, such as playing Syndemic, the typical response was "*Si* (Yes)," or "Bien (Good)," even if their behavior during the workshop indicated that they were not engaged or enjoying it. Perhaps we would have found the same answers on written surveys, but the issue seemed compounded when the children were giving their answers looking straight at the teacher holding a video camera. Upon review of the video footage, the only responses that differed from the above phrases involved comments about the game's look. The children seemed particularly impressed by the graphics and often exclaimed, *"Que lindo!* (How pretty!)" Based on this footage, it is hard to reach many data-driven conclusions about the efficacy of Syndemic at the learning center.

I had never attempted to perform research outside the U.S as an undergraduate. Although formal data collection was compromised due to my inexperience, this was a critical stepping-stone in my growth as a scientist. Completing fieldwork in Nicaragua, I often noticed the line between volunteer and researcher becoming blurry. It felt impossible to be present with the children, implement a biology education project, and observe or record useful data. When using Syndemic in workshops in New York, there were always other adults in the room helping to supervise and work individually with the kids. At the learning center, we were often alone with large groups of kids, making the task of assisting children in engaging in an activity and collecting data on that activity feel impossible.

12.6 Concluding Thoughts

Although the conclusions that can accurately be made about the children's learning gains from Syndemic are less than I had hoped, I can see my own learning gains as an undergraduate student. Implementing Syndemic in New York taught me many skills, allowing me to practice the scientific method step by step as I learned how to design and implement a small study. Although working in Nicaragua allowed less practice of the traditional scientific method, the experience gave me invaluable insight into the approach of a researcher trying to adapt their work to diverse settings. I thought that to be consistent, I would need to make as few adaptations to the study of Syndemic as possible. I look back now with embarrassment that I boarded the plane to Nicaragua with 100 copies of the same exact survey I had used in New York, only translated into Spanish, ready to hand to the kids at the learning center. I now know that adapting research to a particular culture and context is not a shortcoming or limitation to my work. It is an integral part of developing research that is accessible and relevant to a diverse range of communities

Future study of Syndemic is critical to completing a more accurate picture of the game's potential. Alex May is currently utilizing the data collected so far to create an updated version of Syndemic that addresses the feedback from students. Changes will include new levels of varying difficulty and opportunities for collaborative play. Long term, May explains,

> My dream version of Syndemic would involve pathogens that digitally 'evolve' alongside your player, so that you must constantly mix up your strategies in order to defeat them. Ideally, there would be no limit to the types of enemies you could encounter, as they would continually adapt to your weapons and tactics. I can also envision a more 3D or perhaps even virtual reality version, where it would be possible to physically explore the human body from the perspective of a microbe. You could examine firsthand how the body gets infected and help the immune system fight it off at the 'ground floor'!

In addition to testing the efficacy of these changes, variations in the study design will also play an important role in future work. A big limitation of the past research conducted with Syndemic has been the short length of each gaming session. Our next step is to assess Syndemic after students have played it for longer intervals over a greater period of time to see if that produces a more significant effect. The impact of doubling the number of game-playing sessions from two to four or six will be compared with the current results to determine the number of times students need to play Syndemic for optimal benefit. Digital games can support science instruction by increasing student engagement and motivation when the games are appropriately designed and tested.

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