



**UNIVERSITY
OF ICELAND**

**Master's thesis
MA Degree in Sociology**

Simulations for Sociology

An Agent-Based Model of Peer-Influence testing the Protective
Effects of Social Capital on Adolescent Substance-Use

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Supervisor: Thamar Heijstra
June, 2024

FACULTY OF SOCIOLOGY, ANTHROPOLOGY AND FOLKLORISTICS

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This thesis counts as 60 credits towards an MA degree in Sociology in the Faculty of Sociology, Anthropology and Folkloristics University of Iceland, School of Social Sciences

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Reykjavik, Iceland, 2024

Preface

I would like to thank my supervisor, Thamar Heijstra, for her continuous and consistent support throughout the year. I could not have done this without her willingness and openness in helping me see this project through to the end, despite its challenges. I would also like to thank Caine Meyers for his help and expertise, always challenging my knowledge on the topic and improving my understanding and reasoning in the process. Likewise, I want to thank the team at the Icelandic Institute for Intelligent Machines, Kristinn and Gonçalo specifically, who made my goal of conducting agent-based modeling research possible. This master thesis is submitted in partial fulfillment of an MA degree in sociology and counts for 60 ECTS.

Abstract

Adolescent substance-use remains a significant societal concern, with implications for individual well-being and community welfare. Drawing on Icelandic sociological research and core sociological theories, this thesis seeks to computationally model the phenomenon of deviant peer-influence and adolescent substance-use by testing different experimental conditions of peer-smoking and social capital among agents. This research uses agent-based simulations to examine the complexities of adolescent substance-use, focusing on the protective impact of social capital and the influential role of deviant peers. I hypothesize that agents who are more highly connected to their communities with higher social capital should experience less substance-use and receive less deviant influence from their peers. To conduct this research, I simulated varying friend group compositions to observe the outcomes of differing group dynamics based on social attributes of the agents. Agent friend groups, comprised of six agents each, were simulated through 20 school days with different combinations of high and low levels of social capital and high, medium, and low levels of peer-group smoking. Social capital was represented as a cumulative value based on an agent's involvement with sports, time spent with their parents, and their commitment to school, and are based upon the domains of intervention underlying the Icelandic Prevention Model. Levels of deviance were represented using smoking behavior among agents, who all have a propensity to smoke but will only do so if their urge to smoke surpasses a certain threshold. In these simulations, an agent's urge to smoke was influenced by their peers and social capital value alike throughout the 20 school days. The results of the simulations reveal that agents with greater levels of social capital were least impacted by the influence of peer-group smoking behavior, and that group dynamics heavily influenced group substance-use. These findings are in line with what was hypothesized based on the empirical research from the Icelandic literature, namely that social capital would serve as a protective factor against the influence of peer substance-use. This thesis contributes to the development of a sub-model of peer-influence within the SocialInsight framework, an ontology-driven agent-based model of risky adolescent behavior. Additionally, these findings contribute to the ongoing theoretical discussion on the complex and dynamic nature of adolescent substance-use and the ways in which we may employ novel techniques to study such phenomenon.

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1. Adolescent Substance-Use: An Ongoing Issue

Upon reading the literature on adolescent substance-use prevention in Iceland, I noticed the consistency of methodological techniques and tools that have been employed over the past few decades. In an attempt to broaden the sociological view regarding adolescent substance-use, I have the aim of introducing agent-based modeling to this particular social phenomenon. As Iceland has a wealth of data and research on the topic, this makes it an optimal location to begin the study. Addressing concerns around adolescent substance-use is an area that garners consistent attention by researchers, communities and government bodies around the world (Dennermalm et al., 2022; James et al., 1996; Sigfúsdóttir et al., 2009; Sumnall, 2022). This is due to the fact that substance-use can severely alter an adolescent's quality of life, as well as their development into adulthood (Gray & Squeglia, 2018; Newcomb, 1987). Substance use in and of itself is quite common, especially among adolescents as they enter a more experimental stage of life and seek individual autonomy from their familial restraints, while also navigating their way through their newfound development, where physical and mental changes are occurring at an elevated rate (Telzer et al., 2018). When the European School Survey on Alcohol and Other Drugs (ESPAD) survey was conducted in 2019 (which included Iceland), 41% of respondents indicated at least one incident of smoking in their lifetime, with 11% having tried e-cigarettes, and 33% having consumed alcohol at age 13 or younger (Mokinaro et al., 2020). While experimentation and single instance use of substances seems to occur quite often, disorderly, and irresponsible use of these drugs can lead to substance abuse, where individuals often display compulsive behavior of engaging in substance use, despite the negative social, legal, or occupational consequences. The impact of substance abuse on an adolescent can directly impact their social relationships, economic prospects, and physiological development (Vergunst et al., 2022). Major developmental milestones in cognition can also be disrupted through early substance abuse affecting cognitive aspects of development, such as attention-span issues and mental health issues such as depression and anxiety (Hamidullah et al., 2020). Iceland differs in many ways from mainland Europe given their relative geographical isolation and demographic make-up, but many cultural

values are shared between Iceland and continental Europe, therefore I will make a brief comparison on the matter regarding adolescent substance-use throughout the continent.

Alcohol and drug use disorders, along with the burden of such disorders, are among the highest in the world in Europe for adolescents (Mokdad et al., 2016). This inevitably leads to concerns over the consequences of uncontrolled substance-use by adolescents, the most concerning being the development of a substance-use disorder, addiction, or death. Substance-use disorders are a complex condition where the use of substances is consistent despite its negative consequences, potentially leading to addiction or disability, resulting in an inability to function in everyday life (American Psychological Association, 2023). According to a Global Burden of Disease study (Castelpietra et al., 2022), the prevalence of alcohol and drug use disorders among adolescents in Europe appear to have decreased over the past three decades. This is encouraging, though the proportion of adolescents who develop disorders or live with a disability from substance use has increased. This is particularly the case among adolescent boys who experience greater years of life lost due to disability and years of life lost compared to adolescent girls in both absolute and relative terms. Research has also indicated that the earlier the onset of substance use begins, the greater the risk of that individual using illicit drugs in the future (Sobeck et al., 2000), developing a substance use disorder (Patrick et al., 2016), and engaging in deviant behaviors (Newcomb, 1987).

Seeing how adolescent substance-use is an ongoing problem, I believe it is important to advance our understanding of the mechanisms that lead to risky adolescent behavior. A prominent component of adolescent substance-use is the role that peers and friend groups play in the promotion and adoption of substance-use behaviors (Kristjansson et al., 2010; Meyers et al., 2023; Thorlindsson & Bernburg, 2006). Peer-influence alone proves difficult to accurately model, given that peer influences happen through time and within different contexts. For this reason, I chose to use a model of peer-influence in an agent-based model for this research. Agent-based models (ABMs) are a methodological tool that create rules-based simulations, allowing researchers to simulate artificial social systems or specific processes. As social capital, peer-influences and substance-use outcomes occur in a dynamic and interconnected system, this seemed like the ideal opportunity to use agent-based modeling to explore these factors in a different light. This type of model has yet to be attempted using Icelandic data, and as communities continue to face the challenges of

adolescent substance-use, new methods that aid in reducing substance-use should be leveraged to improve our theoretical and practical understanding. To make this model, empirical and theoretical research must be used to realistically create the simulation. Luckily, Iceland has a wealth of data and research given its efforts in developing effective adolescent substance-use prevention programs.

1.1 The Origins of the Icelandic Model of Substance-Use Prevention

To build a model that incorporates the essential aspects of the Icelandic approach to substance-use prevention, the history behind the Icelandic Prevention Model and its accompanying theoretical basis must first be explored. The story of Iceland's adolescent risk prevention research began at the end of the last century, and from the two decades of research that came since, the action taken by Icelandic institutions has led to the current state of their effective preventative community-based policies. Iceland has made itself known through its efforts to combat adolescent substance-use effectively, while using sociological, health, and policy research to implement long-term interventions that support the protective aspects of society and community; aspects that reduce an adolescent's likelihood of engaging in substance-use on a communal level. Showing that substance-use may be attributed to social processes begs the questions from the sociological perspective, namely, how have the sociological and criminological theories been used to research, comprehend, and implement Iceland's effective protective measures for adolescent substance-use prevention, and what are the underlying components of the model that make it so effective? This reduction in adolescent substance-use has been attributed to the Icelandic Prevention Model (IPM) which implemented social changes at the community level. This model is based on core sociological theories of deviance and socialization inspired by the work of Durkheim (1897; 1902), Merton (1938), Hirschi (1969) and others that will be discussed later. The main aspect of these theories being that adolescents would develop patterns of deviant behaviors in specific social environment, and this could be averted through changing the environment of the community and family by allowing more opportunity for adolescent to engage in positive activities in the form of clubs, sports, and other prosocial activities within the community, while also applying negative sanctions through parental monitoring and familial involvement.

The consequences of adolescent substance-use that sparked this work were seen first-hand in Iceland in the 1990s and early 2000s. At this time, around 42% of adolescents reported being drunk in the past 30 days, 23% reported cigarette smoking, and hashish use was up to 17% (Kristjansson et al., 2016). Given these numbers, action was taken to try and reduce the high rates of substance-use among adolescents. This was done by enacting multiple community level and national level initiatives to reduce substance-use by promoting community cohesion and offering opportunities (such as sports participation and constructive community involvement) to the adolescents around the country (Sigfusdottir et al., 2010). The transformation of the adolescent environment was focused on building social capital, ensuring proper social control, and supporting the known protective factors in the community that impede adolescent substance-use. The social control in this equation was the pressure that parents and community members would exert on adolescents. Social control may sound negative, but it is what serves as the socially acceptable template to restrict the undesirable and deviant behaviors that adolescents would otherwise engage in if left unsupervised. Secondly, the widespread promotion of protective factors within the community was essential in creating an environment where substance-use and deviance was to be diminished through a connected social network within the community. These protective factors included efforts to ensure a strong and involved family structure, having access to organized and high-quality leisure activities such as sports and youth centers, and having schools serve as a community hub to foster stronger social connections within these communities.

This method was essentially aimed at reducing identified risk factors associated with risky adolescent behavior. Within the risk factors that are known, most notably is the risk associated with adolescents who have friends who also use substances. This has been shown to be one of the most salient risk factors for substance-use by adolescents (Ennett et al., 2006; Henneberger et al., 2021; Nash et al., 2005; Thorlindsson & Bernburg, 2006). By promoting supervised and organized activities for adolescents, Icelandic communities aimed to increase the known protective factors such family involvement, curfews, social support, and community participation and intergenerational closure (the extent to which parents know their children's friends and parents in a community). Consequently, these protective factors also lend themselves to increasing the social capital and integration of adolescents in their respective communities. Social capital serves as a form of social resource, existing in the social connections and relationships themselves. Through efforts

of community building and policy implementation, supported by sociological and criminological research, a drastic reduction in adolescent substance-use was seen throughout the country. By 2014 the prevalence of smoking (23% to 2%), drunkenness (42% to 6%), and marijuana use (17% to 6%) all drastically decreased. This decrease has been noted to be exceptional, even when comparing to other neighboring countries in Europe and while also accounting for overall European trends (Kristjansson et al., 2021).

1.2 Why Agent-Based Modeling?

By breaking down the theories of deviance and social order that the success of the IPM has been built upon, I hope to gain an understanding of the mechanistic level of how these theoretical social processes work to produce the reduction in deviant behavior. By using a model of peer-influence, I will account for the dynamic nature of peer-groups (one of the most salient risk factors), and also incorporate the domains of intervention of the Icelandic Prevention Model to account for the social capital that is generated from these domains, modeling their protective effects. Developing an ABM that can reproduce accurate system dynamics of adolescent substance-use and peer-influence should help garner a greater understanding of how these theories of deviance and social structure work in conjunction with different social institutions, such as the family, peers, school, and sports. I chose this method because ABM research presents an opportunity to test and model my understanding of the social theories of deviance and social systems and gain insight into the underlying dynamics of these theories. I will conceptualize adolescent substance-use as a function of other social variables and parameters, and then observe how peer-influence impacts substance-use behaviors in the model. This research will be done by modeling the social environment from the bottom-up and designing agent and environmental rules according to the sociological theories that the IPM is built upon as well as creating a simple model of decision making. Once complete, observations from the ABM output should detail how agent decisions are made and how peer-influences and social capital have contributed to the overall substance-use by the agents within the simulation. The secondary purpose of developing and using this model is to test a new methodological tool that is being developed at Reykjavik University, an ABM called SocialInsight. SocialInsight was created as a part of a larger project that seeks to allow for the simulation of policy interventions, academic research, and educational purposes and this thesis will be the first

step in building its capabilities to model the social world for studying adolescent peer-influence on substance use and the protective and risk factors of the IPM.

To do this, six experimental conditions will be tested to explore how peer-influence and the protective effects of social capital influence substance-use. The tests will include agents within a friend group containing high and low levels of social capital against high, medium, and low levels of deviant peers (this will be represented by an agent's urge to smoke parameters in the model, a high urge to smoke, the more "deviant" the agent). Although this model uses smoking as the substance of choice, it may serve as a proxy for any substance of interest as the model is not specific to the substance yet, though it is specific to the adolescent routine and social environment. The outcomes of these simulations should in theory align with the previous research on the effects of social capital (working as a protective factor against deviance) and adolescent behavior.

1.3 Thesis Outline

To develop such a model, I will first outline the theoretical foundations of the Icelandic Prevention Model, the community-based model that has likely been responsible for the significant reduction in adolescent substance use in Iceland and throughout other communities around the world. Then I will introduce how James Coleman's (1990) concept of social capital has been pivotal in understanding how these communities' efforts offer protective effects from deviance and how social capital may increase and decrease in a given community setting. I will begin by examining the oldest among the theories, namely the works of Durkheim and his theory of social order and integration. Durkheim outlined specific forms of social integration that are crucial in building a connected and cohesive social structure (1897, 1902). The theories of integration and anomie that Durkheim put forth have been received and studied in Iceland, particularly in the context of adolescent deviance and social cohesion (Thorlindsson & Bernburg, 2004). These theories and their role in Icelandic research will be examined and serve as a base for the conceptual role of the protective factors within the agent-based model of peer-influence. Secondly, Hirschi's (1969) theory of social control and bonding. Icelandic research has come to understand the role of how communities and institutions in Iceland exert social control on its adolescents and the benefits that this conveys in the form of providing adolescents with a form of pro-social learning. This serves as a way for adolescents to form and keep bonds in their community through sanctions and bonding, promoting a stronger

social network with shared features among its members. Social capital has also been adapted to the adolescent world and applied to their particular social stage in life which they occupy, namely school, sports, family, and their social networks. Lastly, I will report the results of the simulations conducted, as well as a discussion of the implications of these results and their relation to previous research to see if the model accurately produced results in line with what would be expected. While this research is focusing on the social phenomena of peer-influence on substance use along with the protective effects of social capital, there will also be discussion about the computational basis of the modeling and use of the agent-based model in question, therefore, a table of terms and concepts will be included in the Appendix with an Overview, Design Concepts and Details protocol listed in the methodology section that covers all pertinent details of this model.

1.4 Purpose of this Research

Even though Iceland has been largely successful in reducing proportions of substance use among its adolescent population through targeting these specific domains of intervention over the span of two decades, approximately 5-8% of students still engage in some form of substance use every year (Icelandic Centre for Social Research and Analysis, 2022). This potentially indicates that the theories of deviant adolescent behavior do not apply to certain children, or the factors embedded within the domains of intervention are simply not applicable in certain contexts. Hence, while targeted policy interventions have been successful for the majority of adolescents in Iceland (such as with the introduction of the Reykjavík leisure card: 75,000kr for adolescent recreation per year), from my perspective, more refined and context-specific policies and intervention practices are needed to better understand this.

So far, computational techniques in sociology have not been widely explored in Iceland. This has created a blind spot in the modeling of the mechanistic level of social phenomena. First and foremost, by creating this model, I aim to capture the dynamic nature of adolescent decision making when it comes to substance-use. I will focus on how peer-influences and social capital affect adolescent substance-use given that peer-influence is one of the strongest risk factors in adolescents beginning to use substances (Ennett et al., 2006; Nash et al., 2005; Thorlindsson & Bernburg, 2006). Secondly, the protective factors of the Icelandic Prevention Model will be modeled to serve as integral parts of the Icelandic adolescent's environment to understand how the social environment can serve as a

protective factor and contributes to an adolescent's social capital, in turn influencing their decision-making process when deviant peer-influences are present.

1.5 Objectives of the Thesis and Experimental Hypotheses

This research has three main objectives:

1. To assess if Icelandic sociological data can be applied to an agent-based model to accurately simulate substance use dynamics among adolescents.
2. To develop a functioning sub-model of peer-influence within the SocialInsight ABM.
3. To test how variations in social capital protect against peer-influenced substance-use behavior among adolescents' social networks.

The validity of the model will be evaluated to see if the results produced replicate past empirical results from the Icelandic sociological data on adolescent peer dynamics and substance-use and the domains of intervention and their respective protective qualities.

After the experimental conditions are set, I hypothesis the following outcomes:

H1: Agents with higher social capital will be less likely to engage in substance use, regardless of the presence of deviant peers, due to the influence of strong social capital.

H2: The presence of deviant peers will increase the likelihood of substance use among agents, particularly those with lower social capital, as they may be more susceptible to peer influence and less inclined to resist deviant behavior.

2. Theoretical Foundations: Icelandic Research on Social Capital and Adolescent Substance-Use

The modern theoretical approaches to the study of adolescent deviance and substance-use in Iceland are derived from a collection of the foundational theories within the sociological tradition. Theories of social order and anomie based on the works of Durkheim (1897, 1902), as well as the later developments of Merton (1938), Hirschi (1969), Akers (1995), and Sutherland & Cressey (1992) have all contributed to the theoretical grounding of this research throughout the past two decades while also balancing the theoretical views on the causation of adolescent delinquency, namely social learning and social control. James Coleman's (1990) theory of social capital has also served as an important framework for understanding the protective and detrimental effects of society and community on an individual and their placement within it. Icelandic research has used these theories to examine how social institutions such as sports, school, religion, family life, and peer groups are associated with substance-use and other adolescent behavioral outcomes, particularly those that prevent or encourage risky behavior (Sigfusdottir et al., 2010; Thorlindsson et al., 2012; Thorlindsson & Bernburg, 2004, 2006). Excluding a handful of pseudo-longitudinal studies (i.e., repeated cross-sectional), the majority of research that has been done has used cross-sectional regression models to determine the strength of associations among certain variables and outcomes. While these models have been crucial for identifying correlates between certain social and individual level factors and relation to deviance, I find that they remain constrained in their explanatory power due to the limitations inherent in the models themselves, such as assumptions of linearity, independence between variables, and limitations in causal inference. In this literature review I aim to explore the theoretical and empirical foundations of Icelandic research on adolescent deviance and substance-use, social capital, and the known protective and risk factors in the Icelandic context. I will also discuss the literature surrounding the inclusion of ABM research on the topic of substance-use and how it can enhance our understanding of this field and improve upon traditional methods.

2.1 Domains of Intervention and the Icelandic Prevention Model

When examining previous Icelandic literature on the topic of adolescent deviance and substance-use, four domains emerged as critical factors in the social lives of adolescents that had a disproportionate impact on their individual and community levels of deviance. These factors can be broadly grouped into four interdependent domains: family, peers, school, and leisure time activities, such as sports (Kristjansson et al., 2020; Sigfúsdóttir et al., 2009). It seems that the level of integration of adolescents, as well as the levels of social control in a community offers protection against deviant behavior, including substance use (Thorlindsson & Bernburg, 2004). Icelandic scholars across several disciplines have identified these protective factors associated with substance-use among adolescents and have made these the main components of the Icelandic Prevention Model itself (Kristjansson et al., 2021; Sigfusdottir et al., 2017; Thorlindsson & Vilhjalmsón, 1991). These protective factors can be thought of as characteristics of an adolescent's environment that are associated with a lower likelihood of developing a substance-use disorder or engaging in deviant behavior (Stone et al., 2012). The domains of intervention, specifically that of the family, peer group, schools, and leisure time activities serve as the areas with the greatest influence on population level behavior regarding adolescent deviance within the Icelandic context. Each of these domains is theorized to exert a certain level of social control and bonding on the individual adolescent. This type of model serves as an ecological system that when structured in a prosocial way, meaning that it supports those behaviors most desired by a community, it produces macro level changes that are beneficial both for the adolescent and the wider community. By focusing on these domains and developing a collective effort within communities, this gave the IPM the ability to drastically reduce adolescent substance-use. To understand these domains and the theory behind how they function is paramount for creating an accurate model that can serve as a simulation containing the most prominent aspects of adolescent life in Iceland. Therefore, I will explore the theoretical foundations of these domains of intervention and examine how they purport to buffer against deviance and improve adolescents' overall social capital in a constructive and prosocial manner.

2.2 Social Capital

When examining these domains of intervention there appears to be a connectedness that is fostered within a given social network (on a community level). As I see it, what links these

domains together and allows for interconnected beneficial effects is an increase in social capital. Although these domains may seem distinct, I believe looking at them more like a network with interconnected nodes serves to generate a more accurate depiction of the reality of the social world. Social capital, as described by James Coleman (1990) is the 'social' assets one possesses, similar to material assets of money, except these assets reside within their social connections, and allows one to leverage these assets in the social environment. This measure of social capital is the culmination of all the social connections an individual may have with their family, friends, co-workers, etc. An individual may leverage these connections in diverse ways to provide a myriad of benefits such as employment connections and otherwise unobtainable social benefits that could not be achieved without leveraging their social networks. In the realm of adolescent life, social capital is theorized to confer an overall protective effect against deviant behavior, including substance use (Coleman, 1998; Hirschi, 1969). When conceptualizing social capital in the adolescent world, their connections to the domains of intervention can serve as a measure of social capital through forming social connections with members of their community via their participation in sports, clubs, schools etc. And while this does not translate exactly to Coleman's description of social capital, I believe these domains of intervention to be a more appropriate version for adolescent life, as this incorporates the most salient social domains for adolescents. Coleman (1981) spoke of the concept of intergenerational closure. This involves the degree to which parental social ties between other parents and their children exist in a given community. This can be viewed as a form of social control over adolescent behaviors that are socially approved by the community. This intergenerational closure can serve as a protective factor against deviant adolescent behavior and may be one of the more prominent components of social capital within adolescent life (Kristjansson et al., 2010). This social capital is what I believe has the capability to protect adolescents against the pressures felt by other social forces (e.g. peers) that promote "undesirable" behavior, such as substance-use.

The influence of peers in adolescent substance-use appears to be mitigated through protective or buffering factors such as the family, community (via the local school), and involvement in high quality leisure activities (Thorlindsson & Bernburg, 2006). For example, parental monitoring (i.e., knowledge of whereabouts of child and with whom they are with), parental support (e.g., providing care and warmth), parents spending time with their children (e.g., after school and during weekends), and intergenerational closure

(i.e., parents knowing friends and parents of friends) are all associated with decreased likelihood of substance use through direct and indirect influence on friend choice (Sigfúsdóttir et al., 2009). Similarly, engagement in high quality leisure time activities such as sports reduces the likelihood of adolescents, and their peers, engaging in unsupervised activities and unstructured leisure time, when substance use is most likely to occur. More specifically, leisure activities of high quality seem to promote prosocial behavior and positive development for Icelandic adolescents (Kristjansson et al., 2021; Sigfúsdóttir et al., 2009; Thorlindsson & Bernburg, 2006). The negative effects of low social capital has also been seen through the work of Thorlindsson et al (2012) who saw that single parents households, having less ability for parental participation in their child's sports and organized leisure activities, experienced lower levels of social capital. This was due to having less time and energy to build social capital through engaging with other parents in community activities. When this was studied in a community with a large number of single-parent households and low social closure, more smoking was also observed. From these studies, it seems that these factors to fit into a broader measure of social capital, where the bonds between parents, children, and their peers are strengthened through the local community via activities and connections, and thus promote certain behaviors. The weaker these bonds to community become, the less capital is built within the social network, and thus the cohesion of community values, closure, and control diminish.

2.3 Social Order and Integration of Icelandic Adolescents

When researching at the community level, Durkheim's theories have offered Icelandic researchers a base for their theoretical framework in understanding community dynamics and outcomes. These community dynamics are what appear to give rise to the social environment that can promote or inhibit deviance among adolescents. The first foundation theory in this framework is based off of Durkheim's theories which suppose to build social order. Durkheim's theories attempt to provide a foundation for understanding a variety of social factors that can influence behavioral outcomes caused by social forces. Durkheim identified specific social forces that emerge from society and exert a downward social pressure on the individual (see Figure 1). Since then, we have come to call this concept social emergence (Gilbert & Troitzsch, 2005). These emergent social phenomena are outside the individual and stem from the interactions of individuals, creating macro-level phenomena that in turn influence the meso and micro-level. Over time, these interactions

produce certain behaviors and thought patterns that linger outside the individual, and then exert a downward force onto the individuals within that social system. A very well-known example of an emergent social phenomena from Durkheim is a social norm. For example, it is a norm of society to not become overly intoxicated while in a formal setting. This social norm has emerged (emergence) from social standards and is the same force that will prohibit (downward pressure) the behavior of most individuals in that setting from becoming intoxicated, thus the majority of people will adhere to the norm without needing to be explicitly told to. These emergent social phenomena (norms) are a crucial aspect to consider when attempting to understand societal forces that contribute to adolescent substance-use, as these norms occupy space in the social environment that adolescent and adults alike will consciously or unconsciously process as acceptable or unacceptable behavior.

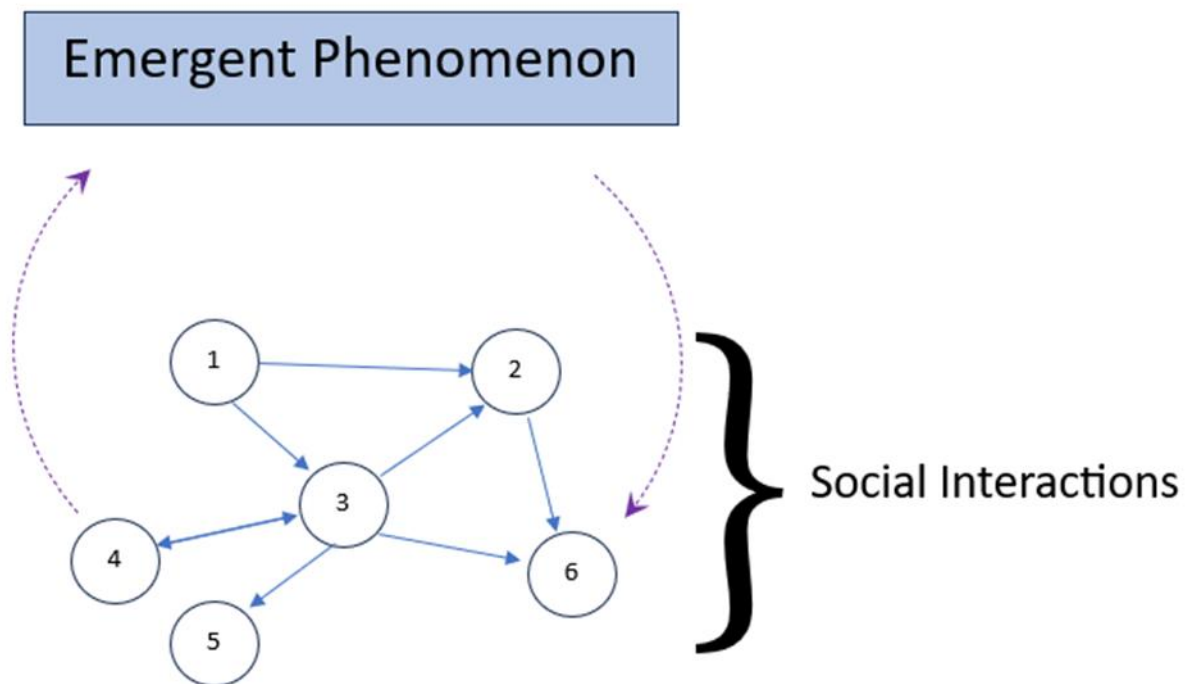


Figure 1: Basic Diagram of Social Emergence. This diagram illustrates how social interactions among six individuals generate emergent phenomena, such as social norms or culture. The arrows that ascend from the individuals represent how the emergent phenomena are produced through individual interactions and descend from the emergent phenomenon as it also exerts some form of downward pressure onto those individuals in turn.

2.3.1 Adolescent Integration into the Community

Icelandic research has sought to understand how adolescents embed themselves into the community, and if this has an impact on their deviance and substance-use behaviors. Some specific concepts that have been studied in accordance with adolescent substance-use in Iceland specifically include integration, anomie, and imitation. Social integration refers to the degree to which an individual is socially embedded within certain social structures in a society (e.g. community). In *Suicide* (1897), Durkheim identified three domains of integration: family, religious, and political. Though adolescents do not necessarily participate in politics, the more poignant area of social integration for this population is school, since the three aforementioned domains are not exhaustive, liberties may be taken when choosing what domain to include, so long as it remains critical in the life of adolescents and contributes to promoting social order. Familial integration comprises the level of involvement and unity within a family structure. This can be thought of as the family unit exerting a level of social control and intervention upon its members, thus working to ensure cohesion among the family's members. Family has since become a domain of intervention in the Icelandic prevention model as family support and involvement is a known factor in preventing adolescent substance use. This knowledge stemmed from research by Thorlindsson & Bernburg (2004) who found that those who are part of a two-parent household also reported significantly less delinquent behavior, and those communities that had a higher density of two-parents households experienced overall lower levels of delinquency despite individual family structure. This is inferring that those who have a stable household family unit are less likely to engage in substance-use and also contribute to a greater effect on the community level. Likewise, research established the importance of family structure, namely having a two-parents household, in procuring beneficial levels of social capital and reducing substance-use (Thorlindsson et al., 2012). Through the family, a child's social capital seems to develop via familial standards (control) and activities, such as going to church, attending organized sporting activities, and promoting academic achievement for their children.

When considering the realm of academic achievement and school integration, this refers to the levels of involvement of the adolescent in the school culture and environment, as well as an adolescent's desire for academic achievement. This is of course heavily related with the parental involvement mentioned above. Thorlindsson et al. (2007) have noted the

importance of school as an area of social integration, promoting socially acceptable behaviors, expectations, and goals. School is where adolescents spend the majority of their social life, interacting with peers and teachers, learning prosocial behavior, and setting future academic goals. Research on the effects of school integration and deviant behavior can be examined through individual levels of commitment to school and levels of academic achievement and school anomie. The concept of school anomie (anomic feelings towards school) is based off of Durkheim's (1897/1951) original concept of anomie and is characterized by a tumultuous relationship between the individual and societal standards and expectation. Durkheim describes this as a state of confusion regarding what is permissible, just, or legitimate and what is not. He notes that the social order must be predictable and accessible, or a state of normlessness and confusion will emerge resulting in social instability. Merton (1938) further expanded Durkheim's theory of anomie and took it a step further, hypothesizing that if one's opportunities and legitimate means of achieving socially approved goals is blocked, then anomie will arise in the individual or group who can not reach these goals, resulting in what Merton referred to as 'strain'. As strain increases, it is suggested that the propensity to engage in deviant behavior, especially to achieve these goals through illegitimate means, will also increase. Social ambiguity and uncertainty are the hallmarks of anomie. This is a phenomenon that may not be all too foreign to adolescents. Feelings of discomfort and confusion are ubiquitously felt at these ages when their neurological, psychological, and hormonal development are occurring at an unprecedented rate (Blakemore, 2012). This likely results in the "teenage angst" that is so commonly described by adolescents that contributes to their questionable decision making during this time. In terms of testing theories of anomie on adolescent delinquent behaviors, researchers have measured and analyzed anomic feelings towards school and academic achievement, and if adolescents felt their academic goals were possible to achieve. Thorlindsson & Bernburg (2004) saw significantly higher adolescent involvement in delinquent behavior if they reported higher levels of anomie towards school and academic commitment. This research suggests that levels of normlessness and school anomie felt by adolescents has a role to play in their delinquent behavior. Since adolescence is a time of increased physical and mental development, the addition of anomic feelings may contribute to delinquent behaviors and cause a breakdown of their sense of integration in the wider community. Naturally, adolescent changes in conduct and attitude would impact their social capital through changes in their behaviors and priorities

and friend groups. This could result in a systemic change in the adolescent social world, both in their peer-groups and their overall social integration within their communities.

The third domain of integration is the religious domain, which was based on Durkheim's (1897) observations that religious integration is a communal experience where social bonds are formed over spiritual cohesion. In this domain, emotional and psychological bonds are formed with members of the community. This led researchers to wonder what the impact of religious activity was in the Icelandic communities when it came to adolescent behavior and delinquency. It was found that Icelandic adolescents who were part of a more religious community showed significantly less delinquent behavior, net of their own self-reported religious behaviors (Thorlindsson & Bernburg, 2004), and that those who participated and maintained some spiritual tendencies saw a protective effect against the effects of past psychological trauma and likelihood of engaging in substance-use (Sigurvinsdottir et al., 2020). This research indicates that being part of a local religious organization contributes to some protection against substance-use and deviance. This also exemplifies some of the positive impacts of peer-influence, and while research typically studies the ways in which peer-influence leads to deviant outcomes, there is likewise a positive influence as well.

When examining the domains of intervention of the IPM and the domains of social integration studied by Icelandic researchers, I believe these domains can be thought of as social agents that directly or indirectly have an effect on adolescents' outcomes. I conceptualize a social agent in the following way: a social agent can be thought of as a part of the social environment that individuals interact with. For example, a school, a church or one's family can be thought of as social agents that transmit certain cultural, social, and normative information and values to the adolescent, such as what is appropriate social behavior and what are legitimate social goals to have. This information is transferred through their interaction with these social agents, thus influencing their beliefs, behaviors, and values. Through these social agents, their protective effects and pro-social advantages may be acquired by the adolescent simply by having them be part of their social system. Although institutions such as school, religion and family may be highly structured, one factor that is not as stable or always controllable is that of the peer-group. Adolescence is a time where more freedom is being sought from the family, and this opens the doors to

introducing new and highly influential factors in an adolescent's life, namely that of peer-influence and conformity.

2.3.2 Peer-Influence and Association

Peer-dynamics has become one of the most prominent areas of study for adolescent behavior and substance-use. This has evolved into contemporary social learning theories (Akers et al., 1995) and differential association theory (Sutherland, 1972). The logic of these theories is that the more you identify or feel a social connection with some individual or group (one's level of solidarity), the more you will engage in the imitation of their thoughts and behaviors. Peers have been noted to be one of the strongest social influences of adolescent substance use and appear to maintain predictive value across different contexts (Icelandic Centre for Social Research and Analysis, 2022; Kristjansson et al., 2010; Meyers et al., 2023; Vilhjalmsson & Thorlindsson, 1998). Some researchers suggest that this is explained by the propensity to conform, which becomes more salient during adolescence through peer-pressure or perceived peer-pressure and is critical for behavior and group-affiliation during these years (Brown et al., 1986; Henneberger et al., 2021). Having peers who drink, smoke, or use cannabis has been repeatedly shown to be associated with increased use of these substances among adolescents. On the contrary, adolescents who report having few or no peers who engage with these substances tend to report less substance use themselves (Kristjansson et al., 2010; Meyers et al., 2023). Furthermore, believing it is necessary to drink, smoke, or use cannabis in order to be included into the friend group is associated with increased likelihood of the use of that particular substance (Meyers et al., 2023) as well as engaging in a party subculture. Thorlindsson & Bernberg (2004) also found significant effects regarding peer-influence where association with deviant peers significantly predicted an adolescent's own delinquent behaviors. Those who experience higher levels of anomie, lack of a two-parent household and low levels of social integration were much more likely to associate with delinquent peers. Likewise, the opposite was found to be true, in that those adolescents who had higher levels of social integration with community, family, religion, and school were less susceptible to peer-influence or delinquent behavior.

This previous research indicates that the domains of integration seem to evoke an effect not just on the individual, but the entire community. Likewise, when anomie is measured in the context of school for adolescents, it seems to accurately reflect the frustration and

negative sentiment that would potentially lead to deviance according to the strain theory of Merton. Similarly, while peer-influences are at play, those who identify most with deviant peers and have low levels of social integration and elevated levels of anomie were seen to exhibit more delinquent behavior. Which supports the main notion of the IPM, namely, to target the domains of intervention and social integration that most encourage the protective factors that reduce or prevent adolescent substance-use.

2.4 Social Bonding and Control within the Social Domains of Intervention

Expanding upon the foundations of social integration and deviance, Hirschi's (1969) theory of social control and social bonding has also been used to lay the foundational work of the IPM's approach to substance-use prevention. Though, contrary to the other theories explored earlier that assume the deviant response is a learned phenomenon, Hirschi proposes that the bonds that an individual forms to society and family serves as a control, or a limit on the individual's outward behavior in society. Hirschi proposed that deviant impulses are innate in human behavior, and that it is the repression (or control) of these impulses through prosocial means that is the real object of investigation when it comes to studying deviance and its outward manifestations. Hirschi noted three social bonds that are important in determining strong social bonding and control. These being attachment, commitment, and involvement. These bonds and controls are part of adolescent social capital as they serve to promote the norms of the community and establish appropriate behavior (Coleman, 1988).

The first crucial bond is that of attachment. This refers to the level of psychological bonding we have with pro-social persons, like family members, or pro-social institutions such as school and church (the parallel here to Durkheim's theory of social integration is visible). Prior research has supported this by showing that those children who spend more time with their families acquire a protective effect against negative peer-influences such as being pressured to do illegal activities or engage in substance use (Nash et al., 2005). Likewise, within Iceland this has been explored by Bernburg & Thorlindsson (2005) who were investigating how social bonds to school, family, and community influence aggressive behavior (such as physical violence: punching, kicking) in Icelandic adolescents. They found that community level values of appropriate conduct were significantly associated with the levels of aggressive behaviors among both boys and girls. Likewise, aggression among boys was significantly influenced by community level

contextual effects of school and community (net of individual level of aggression), though there appears to be an individual as well as a contextual effect regarding this phenomenon. This indicates that there is a significant amount of control influencing the aggressive behaviors of adolescents in Icelandic communities, though given these results, there is most likely aspects of social control as well as socialization effects at play regulating Icelandic adolescent behaviors, making it difficult to say if it is the proposed theoretical mechanisms of integration or attachment at play.

The second is commitment, specifically to social relationships that the individual would not want to jeopardize or risk losing (such as a job, status, friends, teachers etc.). Engaging in deviant or criminal behavior would potentially lead to a loss of these relationships. Thus, the potential of loss is what keeps behavior in line and suppresses the deviant impulses. Thirdly, and most salient in the Icelandic approach to reducing adolescent substance use, is the notion of involvement. This implies that structured leisure time activities support pro-social behaviors, and this reduces the chances that an individual can engage in any deviant activities (with time as the limited resource). There is support for this notion in Iceland through the Icelandic Prevention Model, the Reykjavik leisure card, and implementation of sports facilities throughout the country coinciding with a significant decrease in substance-use amongst adolescents (Sigfúsdóttir et al., 2009). Likewise, unstructured leisure time, meaning without adult supervision, is seen to have the opposite effect, leaving time and little social control to inhibit deviant behavior (Thorlindsson & Vilhjalmsón, 1991). Taken together, these components are the foundation of social control that dictates our social behaviors according to Hirschi. Based on the previously mentioned research, this theory has appeared to be supported in Icelandic adolescents.

Icelandic researchers have noted that the levels of explanation of these theoretical foundations mentioned above transcend any single level of analysis and requires a multi-level approach (Kristjansson et al., 2021; Thorlindsson & Bernburg, 2004). That is to say that when studying these concepts and their relation to adolescent deviance, one must analyze the micro or individual level, as well as the mesoscopic and macroscopic social scale to understand the full scope of both social control and social order and their impacts on the individual. Doing this would enable researchers to explore these theories on a larger scale and with a wider scope by studying the phenomenon of deviance and peer-influence at all levels of analysis (micro, meso and macroscopic). This past research has set the ideal

stage for agent-based modeling, specifically because it can test these theories explicitly and systematically within an interconnected simulated environment that can model behavior at the micro, meso and macro levels. I view the role of ABMs as a way of attempting to overcome the traditional methodological barriers that are normally encountered, such as lacking temporal ordering of events, establishing causality, understanding the effects of selection bias and homophily, and generally offering an alternative epistemological vantage point for understanding social phenomenon. The foundational theoretical explanations of social integration, order, control, and capital have provided a theoretical roadmap of how social interactions and mechanisms function together to create a social environment that alters the behaviors of its inhabitants. Though, in isolation, one of these perspectives alone can not truly capture the complexity of the social world. When considering the past literature, it seems that what has made the IPM so effective is its ability to create a systemic change within these domains of intervention, where a holistic shift occurs, thus influencing individual level behavior.

What is still unclear, is how exactly these factors all come together to play a role in adolescent decision making when it comes to substance-use under peer-influence. The effects of social agents on individual adolescent outcomes of deviance have yet to be explicitly modeled in the Icelandic context within an ABM. The usage of an ABM allows for the explicit creation of agents that will offer insight into the functioning of individuals in a simulated social system. I will use SocialInsight to incorporate these social agents such as the domains of intervention of the Icelandic Prevention Model to model the protective effects these have within the context of adolescent decision-making regarding substance-use and peer-influences. When examining the theories of Durkheim, Merton, Hirschi, and Coleman alongside the existing research into adolescent behavior, what is made clear is the extent of the interconnectedness of the social environment and the drastic effects it can have on deviance, substance use and social cohesion. This is observed in the concept of anomie and the protective effects that strong social bonds to institutions play in buffering negative effects on the individual's likelihood of participating in deviant behavior (Sigfusdottir et al., 2010). When considering how peer-influence plays a role in deviant behavior such as substance-use, the complexity of social dynamics is highlighted, and this will be examined in the analysis of these simulations.

To model these domains of intervention and adolescent life reliably, I must reproduce the system of the adolescent world and the main components of their daily life. Now that I have explored the foundational theories behind the IPM and how it supposedly functions on a theoretical level, I will use these theories to guide the agent parameters in the ABM and will use these theories to aid in the interpretation of simulation results. I will now explore agent-based modeling and how it can be leveraged to model adolescent substance-use using a model of peer-influence and social capital.

2.5 Agent-Based Modelling and Simulation

When studying social phenomena that are multifaceted and complex, such as substance-use, protective factors, and peer-influences, it is important to attempt to model all relevant and interconnected variables and parameters of interest. Agent-based models (ABMs) are able to account for all of the factors in question and allow me to simulate a complex social system. Agent-based modeling allows for a bridging between the theoretical mechanisms of interest and the possibility to observe the practical implications of interventions before actually implementing them in the real world (Bruch & Atwell, 2015). ABMs are computational simulations with agents, environments, and rules, that are used to model complex systems and phenomena by building these systems from the bottom-up (Epstein & Axtell, 1996). These rules can be derived from theoretical frameworks and empirical data, thus providing the ability to simulate these systems with theoretical grounding. In the case of social phenomena, a complex social system can generally be thought of as a system characterized by interconnections and interdependence among individuals that interact in their environment. When I apply this type of methodology to adolescent substance-use, the aim is to precisely model and program the agent's rules and environment according to the theories and research previously mentioned, but only at the simplest levels. This means that only behaviors and interactions may be programmed, while outcomes and final states of agents are to be produced on their own, without being programmed directly. In the case of peer-influence on substance-use and the protective effects of social capital, past research in Iceland has demonstrated the correlations between variables and their protective effects, but there has not yet been a model of the entire system of adolescent friendship groups in a simulation that can account for the non-linear nature of the phenomenon. The reasoning for the use of agent-based modeling in this case, is to further investigate the theoretical

propositions put forward by Icelandic research into the functioning of adolescent substance-use and peer-dynamics and how our social institutions can impact this relationship in a protective manner.

2.5.1 Epistemological Position of Agent-Based Modeling

ABMs have been applied across several disciplines, including but not limited to psychology, biology, epidemiology, and public health (Fenichel et al., 2011; Jackson et al., 2017; Tracy et al., 2018; Zhang & DeAngelis, 2020). Some of the phenomena that have been studied include social norms, diffusion of ideas and innovations, social influence, cultural dynamics, residential ethnic segregation, political coalitions dynamics, and collective opinions (Axelrod, 1997; Epstein & Axtell, 1996; Gilbert, 1995; Gilbert & Doran, 2018). These models were able to build these social phenomena from the bottom-up, and then study the exact mechanisms that gave rise to them within the simulation. It is through this modeling method that improvements and even the creation of new theories may emerge from conducting ABM research. While ABMs do not replace other traditional research methods, they allow researchers to verify theoretical assumptions by testing them directly in the simulation. This provides a computational approach to understanding social phenomena by testing hypotheses through different scenarios and counterfactuals and refining the governing rules of the theory to discover the mechanisms of action and the theoretical causal links. Social systems are nonlinear in nature, thus, rules-based models such as ABMs allow for the opportunity to study social phenomena in a more systematic fashion. Non-linear systems are next to impossible to model analytically given their positive (reinforcing) and negative (counteracting) feedback loops and chaotic behavior. This chaotic behavior is characterized by disproportionate outcomes due to slight changes in the system's initial conditions. An example of this chaos would be a drastic increase in substance-use within a peer-group due to a single peer adopting substance-use behavior, and this behavior cascading through the rest of the peer-group as seen in social networks (Ennett et al., 2006). This is one of the more valuable aspects of using an ABM, the dynamics and feedback loops in a system may be observed and studied to better understand how certain outcomes are produced. In the case of this research, how is social capital protective when agents encounter peers who are smoking? What are the positive or negative feedback loops in this process and how long does it take before an agent begins smoking?

2.5.2 Why use Agent-Based Modeling for Understanding Adolescent Substance Use

One of the major benefits of being able to model theoretical framework(s) in a rules-based system such as an ABM, is that it can provide a greater and more refined understanding of the theories in question (Bianchi & Squazzoni, 2015). This is done by breaking down theoretical frameworks in a way so they can act as rules for agents within the simulation. If this model is successful in replicating a true version of what would be expected in the real world, then it is possible to gain some certainty in the causal mechanisms of the theory and further test hypotheses and develop theories computationally. If while developing the rules of this model, the outcomes are far from what would be expected according to our theories, then I may need to reconsider how I conceptually think the theoretical framework functions and will also need to make some revisions to my understanding or double check if the model is an accurate representation of the theory in question. The practical applications of this and future research using ABMs is that of mechanistic explanations of phenomena as well as systems level perspectives that allow researchers and policy makers to create effective and efficient plans for social change through computational research, theory development, and policy implementation while avoiding pitfalls normally associated with this type of work such as wasted time and unforeseen pitfalls in implementation.

Much of the research on adolescent substance-use employs univariate methodological designs, such as looking at the individual or peer-level factors. It has been argued that this approach cannot accurately capture the nuances and complexity of adolescent life that contribute to substance use onset (Sercombe, 2014). The conventional method for studying the impact of peer-influence on adolescent substance-use involves employing regression analyses with cross-sectional data. In this method, adolescents usually self-disclose their substance-use and the substance-use of their friends. The substance-use of friends is subsequently used to forecast changes in an individual's likelihood of substance use in the future. The results of this analysis are treated as a latent variable that serves as a measure of peer-influence (Simons-Morton & Farhat, 2010; Wang et al., 2009). This traditional methodology, while useful in determining associations, is not able to determine exact mechanisms of action that lead to substance-use nor account for the interplay of multiple factors that influence decision making. Theories of peer-influence posit many complex and dynamic interactions that occur over time; thus, these cannot be studied systematically by the usual empirical or statistical methods. Because ABMs can model individual attributes

and the rules of social interaction, they serve as a tool for theoretical and/or data driven modeling of individual behaviors. Likewise, the history of agent action and decision making can be retrieved from each individual agent, allowing for a complete history of the peer-influence processes. In an ABM, it is possible to alter specific aspects (parameters) of the agents (i.e. ‘levels of academic commitment’, ‘time spent with family’, etc.) to test different scenarios through the manipulation of these parameters. This means that the theoretical causal mechanisms that lead to substance-use in the model can be identified and examined, allowing for an in-depth understanding of how peer-influence works at a more mechanistic level.

As these models simulate an entire environment, interdependence of variables is necessarily considered and the system level outcomes are directly related to the individual action and interaction rules of agents, which allows for the bridging of the micro-macro problem of analysis that sociology typically encounters (Bianchi & Squazzoni, 2015; James S. Coleman, 1990). Though it is known which factors are associated with adolescent substance use, less is known about the interplay of these factors within and across the domains of intervention (recall: family, peers, school, leisure time) and their precise mechanisms of action. That is to say, the causal links and social mechanisms that facilitate the phenomenon of adolescent substance-use in the social environment on a fundamental level and how social capital impacts adolescent decision making. These mechanisms are the underlying causal pathways that can explain how peer-influence and social capital affects adolescent substance-use. For example, as previously noted, scholars have come to understand the role of parents and organized leisure activities in mitigating substance use by directly and indirectly intervening on peer choice and affiliation, however, it is neither fully understood at a mechanistic level nor in terms of thresholds (e.g., at what point does peer-pressure become a more salient factor in substance-use than the protective effects of parents, school and organized leisurely activities, or in more theoretical terms, what is the minimum social capital threshold needed to prevent substance use among adolescents).

3. Methodology

In order to properly model peer-influence, substance-use and social capital, the SocialInsight ABM will be used as it contains multiple ontologies, meaning that it can support different frameworks within the ABM. For this project, I will be using the substance-use ontology while applying a submodel of peer-influence within it. Divorced

from the typical meaning of ontology that is normally encountered in social sciences, an ontology in computer science refers to a framework with its own specificities and unique characteristics. An ontology contains the fundamental rules for agents, their properties, and their social interrelations. I will use an example with names, representing agents and how they interact: in an ontology, Cody (agent) can perceive smoking behavior of his peers (property) and is friends (interrelation) with Sveinn. Cody and Sveinn may perceive, influence, and interact with each other in specific ways according to the substance-use ontology that is applied. The ontology will determine what the agents are (autonomous vs non-autonomous), how they act and interact in the simulation, and how they behave in their daily routines. Ontologies serve as a rulebook for a specific field or phenomenon of interest, containing the fundamental components of that phenomenon that are required for it to take place. The simplest way to think of an ontology may be that of a rulebook for specific domains of knowledge.

Generally, statistical methods aim to model the strength of relationships between variables, whereas a simulation will aim to model the underlying process that gives rise to these relationships. However, the statistical data serves as a guide to verify and compare the outputs of the simulation to real world observations. This is done to ensure the underlying processes of the ABM have been modeled in a way that produces realistic outputs and can verify that the process being modeled may be accurate in its underlying theoretical construction of the model rules. Modeling social phenomena such as peer-influence and substance-use involves making the basic components of the process explicit in the model, such as perception, friend-groups, influences and decision-making. One crucial methodological consideration in the study of substance-use is the dynamic nature of peer-influence, or in other words, the way in which peer-influence occurs over time. This will be modeled in SocialInsight. In this model, each tick of the model will represent one hour in a 16-hour simulation (0700-2300h). Figure 3 shows the daily routine of the agents, where decisions and choices must be made based on commitment to the prescribed schedule of an average school day. Should the influence of peers or individual levels of deviance be high enough, agents will deviate from this schedule.

To summarize, this research will focus on the social level substance-use ontology, while employing a sub model of peer-influence that incorporates the IPM domains of intervention to account for social capital and its protective effects on substance-use and the

ability for agents to be influenced by other agents substance-use behaviors (represented as smoking the model) who are part of their friend group. I will now describe the ODD (Overview, Design Concepts and Details) protocol which will explain all pertinent components of the model and agents within it.

3.1 Overview, Design Concepts and Details

The ODD (Overview, Design concepts and Details) protocol is the standardized reporting procedure of ABMs in an attempt to provide transparency in the structure and logic of the ABM. Below I describe each section of the model that is important to know if the experimental conditions would like to be reproduced in the future. This section is designed to provide a description as well as an explanation as to why and how the model of peer-influence functions.

1. Purpose

The purpose of this model is to theoretically explore how peer-influence impacts adolescent substance-use and how social capital may offer protective effects against this influence. This research is focusing on developing the ‘peer-influence’ sub-model within SocialInsight’s substance-use ontology and will also model the domains of intervention of the Icelandic Prevention Model (family, peers, school, organized leisure time) to account for the social environment Icelandic adolescents occupy. Although smoking is the substance used in this model, any substance that could be easily carried (flasks of alcohol, nicotine pouches, etc.) may be considered. Likewise, the daily routine may be somewhat generalized and the Move to Store action (which is performed when an agent has a high urge to smoke), may also be conceptualized as any similar means of acquiring the substance (e.g. visiting another adolescent who supplies cigarettes). Overall, the outcomes should be in accordance with the previously mentioned theories that the IPM is based on.

2. Entities, state variables, and scales

This model is made to represent the significant social factors in an adolescent’s day-to-day life during a normal school week. The agent(s) in this model represent individual adolescents and are labeled *Child* within the subclass *Human* which are in the *Autonomous* agent category - meaning they can move and interact on their own, make decisions, and change the state of other agents. *School*, representing the school environment of

adolescents, is a subclass of *Place* which are *Non-Autonomous*. This means that *School* is not able to alter its behavior or be affected by other agents. The only system level characteristic in this model is the daily structure, which includes starting the day at Home, Moving to Street (beginning the commute to school), visiting the Store (if the agents wants to smoke), attending School, Sports participation, and returning Home - the ordering of which is dependent on the individual agent and their decision-making process.

Table 1: Entities and variables within the SocialInsight substance-use model and their corresponding values.

Entity	Parameter Type	Meaning	Values
Child	childAge	Age in years.	14-16
	timeSpentWithParents	Amount of time per week the child spends with their family. This represents the overall parental involvement in the child's life, such as time with parents, parental support, parental monitoring, and intergenerational closure.	0-7
	sportFrequency	This represents the amount of times per week a child attends an organized leisure activity. Specifically, one of high quality where an adult is leading the activity.	0-7
	Grades	School grades, representing commitment to school and academic achievement.	1-10
	urgeToSmoke	A value representing the likelihood of smoking. This serves as the representation of substance-use in this model and a proxy for deviant behavior.	0-1

For each parameter of the agents listed above: time spent with parents, sports frequency, grades, and urge to smoke, a specific formula is used to calculate and recalculate their values based their behavior (e.g. attending sports, smoking) and influences from peers (perceiving peer smoking), creating a new value that changes over time based on their

interactions. These parameters represent the social capital of the agent. For this research, only urge to smoke (UtS) will be consistently updated based on interactions with peers, holding the other parameter constant throughout the model as to test their protective effects on substance-use.

When an agent perceives their friend(s) smoking, the following occurs for each parameter of social capital. In this example, time spent with parents is being used:

$$\text{NewValue (UtS)} = \text{CurrentValue (UtS)} + X \times \text{TimeSpentWithParents Value}$$

The new value calculated is the new urge to smoke of the agent, this is based on the current value of the urge to smoke, plus the value used in the validation test that gave the most realistic results. This is then multiplied by the current value of the parameter (time spent with parents in this example) to give the new urge to smoke. This is done for all parameters. This is how agents are influenced. If the new value calculated from peer smoking influence exceeds the urge to smoke threshold of 0.5 after calculating all social capital parameters, then the agent will seek out cigarettes at the store and smoke.

Time: Each time step in the model represents one hour in a 16-hour cycle. One iteration is equal to one weekday. This is meant to represent a typical school day for an adolescent, with their evenings free and the possibility of attending an organized leisure activity (represented by Sports). Within each time step (one hour) agents can then make their decisions and continue their day according to the typical weekday schedule or choose to divert from this schedule and acquire and smoke cigarettes. Physical distances between Home, School, Store and Sports are not represented in the model since this model is concerned with agent interactions rather than accurate 3D spatial representation for this research.

3. Process Overview and Scheduling

Process: This model is designed to simulate the average adolescent's weekday (Monday to Friday), therefore the process that is undertaken was done to simulate an "average" school day that the typical adolescent might experience. Below are the steps that are taken by agents and then potential choices that are made:

1. Agents begin by updating their initial state at the first time-step of the simulation (hour 7 of iteration 0). These update the internal state variables of agents such as their individual variables of age, as well as their urge to smoke, and their social variables such as family, sports, and grades.
2. After the agents have been initialized, they perform the decision-making process regarding smoking or going to school. Factors considered include the agent's propensity to smoke, location, and peer-influences.
3. If the agent passes the 0.5 threshold of urge to smoke, the model simulates the acquisition of cigarettes by the agent(s), moving to the store to acquire cigarettes (20 cigarettes per pack). Preconditions include the agent's location (e.g., store, street) and urge to smoke.
4. After cigarettes have been obtained, the model simulates the consumption of cigarettes by the agent(s). Alternatively, this decision to smoke may not occur if their initial conditions, peer-influences, and their calculated value of their social parameters (family, sports, school) reduces the urge to smoke below the threshold. In this case, the agent simply moves to the street and continues to school.
5. The effects of smoking or abstaining from smoking are then recalculated into the agent's final values, which subsequently determine the agent's future behavior. This is evaluated and recalculated every time step and is based on the social factors previously mentioned above. This may result in single use, continued use, or no use at all.

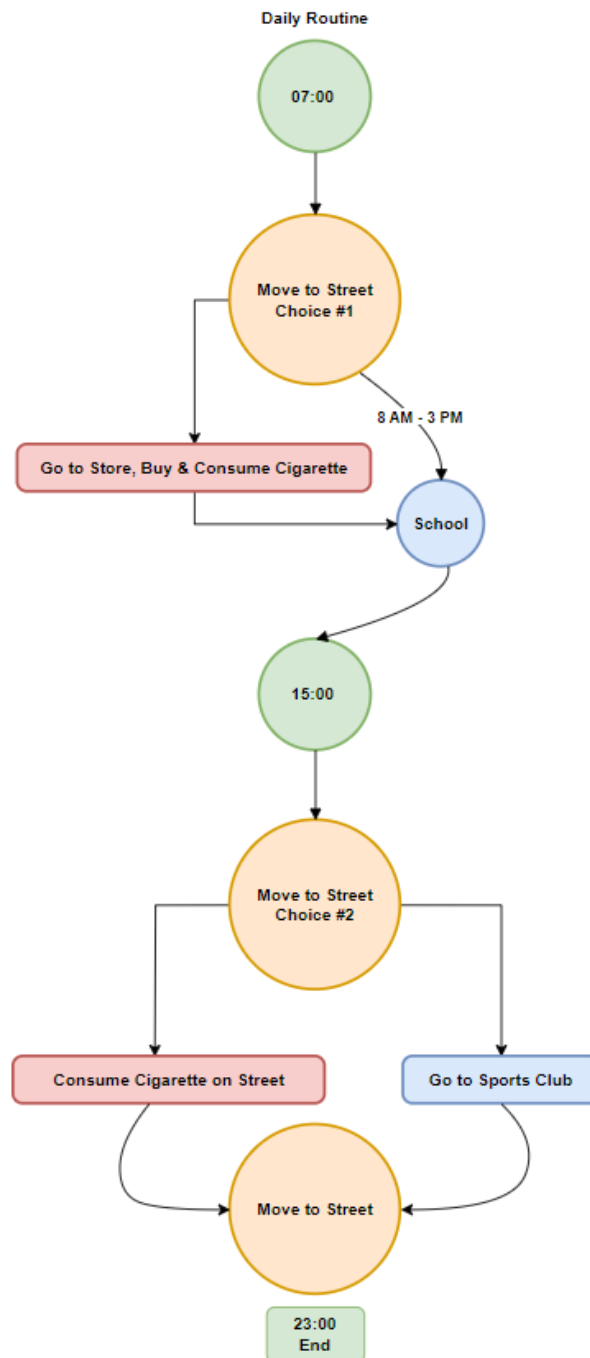


Figure 2: Daily routine and schedule for agents in the simulation.

Schedule: The simulation follows a structured schedule to govern the execution of various processes, ensuring realistic and coherent modeling of substance-use behavior, school and sport attendance, and the potential influence of peers: Initialization begins at 7:00 in the morning, where the simulation sets the initial values of agents’ parameters. This is done through assigning a random value within each parameter from a given range (i.e. 0-10 for Grades, the agent may be assigned a value of 7, representing a school grade 70%). After initialization, agents commit to going to school via move to street. In this time, if the urge

to smoke passes a threshold, the agent will go to the store (representing any means that adolescents would typically obtain cigarettes from, like a friend or dealer) to buy cigarettes. By 9:00, they will then proceed to school like other agents who did not have an urge to smoke. Those who wanted to smoke moved to the store, smoked, then moved to school. The use of cigarettes is not considered at school or while playing sports, as the most likely time for adolescents to use substances is while unsupervised. Agents finish school at 15:00, where they will then move to the street to then either attend sport, go to the store to acquire cigarettes, or smoke cigarettes with their peers if they already have the cigarettes acquired. Once cigarettes are acquired, they will have 20 uses before they must return to the store to buy more. They will be influenced according to their peer-group's rate of smoking, the agent's own perception, and their social capital (being the cumulative value of their time spent with family, sport frequency, and grades). If they are influenced enough to smoke (when their urge to smoke rises above 0.5), they will eventually smoke and miss attending sports. After sports or smoking, agents move to the street one last time before the end of the iteration at 23:00.

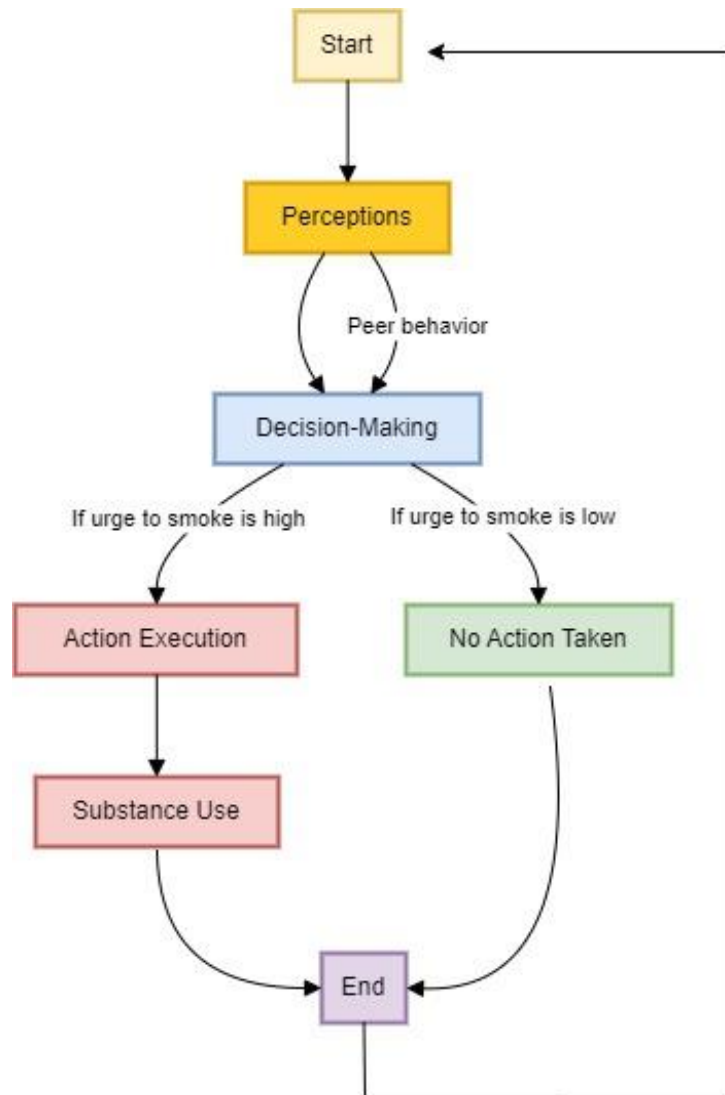


Figure 3: Diagram of the Agent Decision-Making Process. The agent decision making process takes place during each tick (1 hour) of the schedule above. The agent’s state is calculated (their social capital and their urge to smoke) and is then recalculated based on their perceptions (e.g. peer smoking behavior). If their recalculated urge to smoke is higher than the 0.5 threshold, after their social capital parameters (age, grades, time with parents, sports frequency), then the agent will decide to smoke.

4. Design Concepts

Basic Principles: The design of the model is intended to simulate the behaviors and decision-making processes of agents regarding the use of substances, such as smoking, while being influenced by social factors such as their friend group (peers) and their own personal wider social environment. It incorporates various concepts to capture the complex interactions between individual agents and their environment such as a cognitive model

for decision making, and the calculation of the effect of social factors on reducing an agent's decision to engage in deviant behavior (smoking).

Emergence: An outcome of modeling friend groups and peer-influences is the emergence of social networks. These networks exhibit trends in homophilous attributes. For instance, those who smoke and those who attend sports drift apart, even from the same friend group and form distinct friendships in the model where some agents smoke after school everyday, and others attend sports, ceasing to influence each other and maintaining these patterns throughout the simulation.

Adaptation: The adaptive behavior is the decision to smoke or not. Based on peer-influence, namely the number of peers in their vicinity and friend group that smoke. This decision is binary (to smoke or not), while the calculations for this decision are based on the social factors values (family, school, sports) and the amount of peers the agent perceives to be smoking. The decision to move to the sport club is also based on these factors, where the calculation that is conducted will determine if the agent participates in sports or not, smoking instead. See figure 3 for a diagram of agent decision making through each iteration.

Objectives: Agents will seek out cigarettes if their urge to smoke passes a critical threshold (an urge to smoke > 0.5). This seeking behavior will be calculated based on their current urge to smoke, plus the perceived peers smoking, against their aggregate social capital value. This is done to represent the decision-making process that occurs when deciding to engage in deviant behavior, between the current pressure from peers and their other social commitments and bonds.

Interaction: Agents interact through broadcasting their behaviors to one another. Other agents then perceive the deviant (smoking) peer(s) if they are within their friend group and within proximity. The perception of the smoking behavior is then calculated by the agent, who will then update their urge to smoke value accordingly. The rationale for this type of interaction is that adolescents who are in the presence of peers who engage in deviant behavior often feel a pressure to conform to the friend group, thus broadcasting the behavior of smoking to friends rather than a direct command from agent to agent to engage in smoking, which would be more akin to coercion than peer-influence.

Stochasticity: Stochasticity in the model is present in the variability of agent initial conditions, specifically their initial values of age, social capital (time spent with family, sports frequency, grades) and their urge to smoke. Which can be set to be initialized stochastically within a certain range.

Collectives: There is no set collective agent, though the agents' friend group size can be set, and further segregation and grouping can occur from this group. The group itself has no parameters of its own and is not considered an agent. An example of this would be when the friend group splits into two, as smokers will stay on the street and smoke after school, while those who do not want to smoke will go to sports. This trend will continue, thus eventually forming separate groups.

Observation: Output from the model includes the time of day that agents are currently in by showing the day and hour at the beginning of each tick. Each agent then lists its agent id (e.g. Agent 0, Agent 1, etc.), then outputs its current decision of moving locations or smoking while also providing its final numeric value for this decision (this would be the calculation of their urge to smoke and their social capital as well as any peer-influence they are perceiving). Agents then state what they have chosen to do, this can include moving to the sports club, school, street, store, to do nothing, acquire cigarettes, or consume cigarettes. Agents will also state what their current parameter values are at the start of each iteration, so that this value may be examined over time, making it possible to see the exact changes that occur and when, why, and by how much. Lastly, agents will also state who is in their friend group so that values of the whole group may be observed.

Initialization: Upon initialization, the agent population consists of 6 individual agents aged 14-16 years old with social capital parameters designed to replicate the domains of intervention that are targeted by the Icelandic Prevention Model. All agents were assigned to one friend group which consists of all 6 agents. In each different experimental condition, agents are randomly assigned a value within the low, medium, or high category of the experimental conditions table (see table 3 and the agent profile table of the validation test for full explanation). Friend group size and daily routine schedule remained the same throughout all experimental conditions while testing occurred. The values of low, medium, and high social capital and deviance were meant to represent a variety of possible friend groups combinations that can be present in real life adolescent friend groups.

5. Verification and Validation of the Peer-Influence Model

Prior to using the ABM for any real experimental testing, verification and validation had to take place in order to ensure that the model is functioning as intended and according to what would be expected from real world data and theory. After the verification process which required many days of debugging and running the model to ensure proper output with a member of the SocialInsight tech team, I began the validation process by running the simulation and ensuring that the macro level behavior (of the friend group) was correct according to the theoretically proposed outcomes based on the theories of social integration, control/bonding, and capital. This was done by testing the effects of the social capital parameters and ensuring they had the proper impact on the agents in the model (such as increased time spent with parents, sports participation and grades reducing their urge to smoke). Social integration and bonding/control would expect that the reduction in time spent with parents, grades, and sports would increase the agents' propensity to smoke. I performed a sensitivity analysis by reducing these parameters and raising them to extremes in order to ensure they are having the proper effects and working as intended. This was done once for each parameter where I reduced and increased one parameters weight and keeping the remaining parameters intact. Here I am looking for friend groups to behave according to homophily (similar friends influencing each other more than others), that their social capital is providing the protective effects that are described in the literature, and observing the model to ensure nothing abnormal is occurring during the iterations.

I will take this opportunity to explain how the results section will be presented and provide an explanation for each component. After conducting tests under different social capital and deviant peers (number of smoking peers in the friend group) conditions, the optimal number of agents for this test appeared to be six, representing the average friend group size, over 20 iterations (days). I found 20 iterations was suitable to represent one whole month of school days for adolescents, though I will note that I was limited in the amount of iterations I could perform due to model output becoming unmanageable after 20. This is a limitation in model development regarding output rather than a strict methodological consideration; therefore, 20 became the baseline number of iterations used in each experimental condition. When weighing the variables included in social capital, the

following values produced results that appeared to be most consistent with what would be expected based on the previous literature. These are by no means the absolute values that must be used every time, but for the purposes of my research they produced results that were acceptably close to the results of previous research. Time Spent with Parents (-0.5), Sports Frequency (-0.5), Grades (-0.06). These values are specifically related to model validation and not representative of any statistical data. What I am looking for most crucially, is model behavior, i.e. is the system behaving according to what the sociological theories (social integration, bonding/control, capital) would suggest? And does this behavior resemble real life observations of Icelandic adolescent behavior?

Agent Profile Table

This table (table 2) describes the attributes and parameters of agents at the beginning of the simulation. Each agent is assigned a number from 0-5 and is given a random value within the range of a given parameter (Urge to Smoke, Time Spent with Parents, Grades, Sports Frequency, and Child Age), see table 3 for ranges and their corresponding levels for each parameter. This table serves as a way to verify that the agent characteristics are appropriate for the experimental conditions in which they are being tested.

Table 2: Agent profile table for the validation test conducted before experimental conditions.

Agent	Urge To Smoke	Time Spent With Parents	Grades	Sports Frequency	Child Age
0	0.3	5.0	6.0	3.0	16.0
1	0.26	5.0	2.0	0.0	16.0
2	0.18	5.0	1.0	7.0	15.0
3	0.73	5.0	5.0	3.0	16.0
4	0.06	7.0	3.0	7.0	15.0
5	0.96	4.0	2.0	1.0	15.0

Each parameter's range will be manipulated for the specific experimental condition according to table 3, this table shows the ranges of each parameter (Family, Sports, Grades, Number of Deviant Peers in the Friend Group) depending on their experimental

condition. The low, medium and high-test conditions will correspond to the values within the table. For example: in the high social capital conditions, agents will be randomly generating a Grades value only between 8 and 10, and so on for the other parameters in the high social capital condition. From this table it is possible to see the profile before peer-influence and social capital come into effect, and then compare their initial conditions to the outcomes.

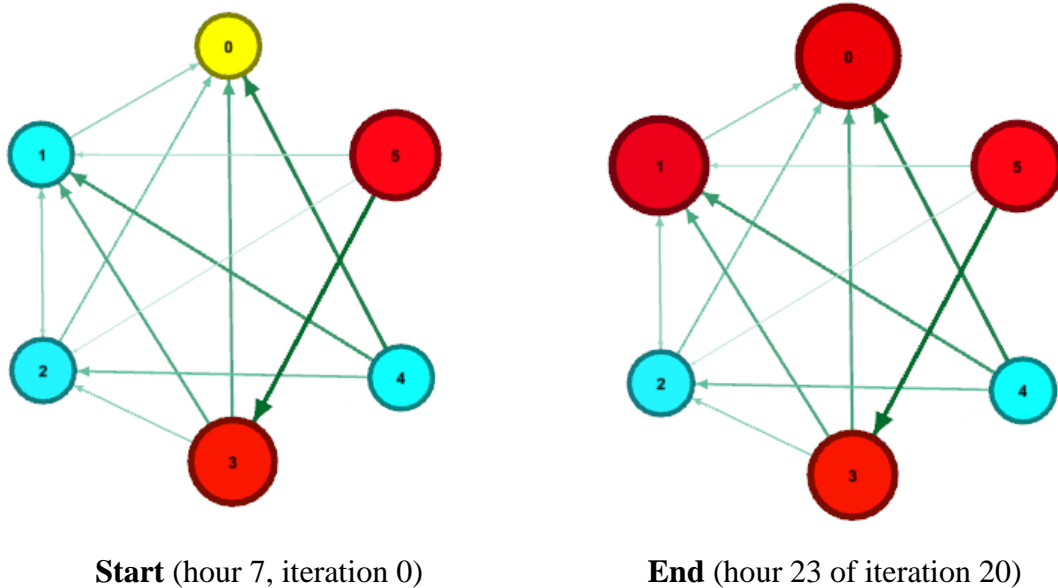
Table 3: Possible ranges of parameters for agents in the experimental conditions.

	Low	Medium	High
Urge to Smoke	0.00-0.29	0.30-0.40	0.50 +
Family	0-3	4-5	6-7
Grades	1-4	5-7	8-10
Sports	0-2	3-5	6-7
Number of Deviant Peers in Friend Group	0-1	2-3	4-6

Peer-Group Networks

Below are the network graphs of the friendship group generated for the validation test based on the agent profile table above. All six agents are present in the group ranging from agents 0-5 (these are the same agents from table 2). The colors indicate the level of their urge to smoke parameter. Blue indicates *low*, yellow indicates *medium*, and red indicates a *high* urge to smoke. The darkness of the arrows in the network represents the strength of the influence one agent is having on another. The size of the circle represents their smoking behavior, where a larger circle means the agent is smoking. Looking at the Start network, which is the network at the very beginning of the simulation (hour 7 of iteration 0), Agent 5 is having a strong influence on Agent 3, and also a weaker influence on Agent 1 and an even weaker influence on Agent 2. You may also notice Agent 0, 1, and 2 at the start are receiving a lot of peer-influence from other agents, likely due to their lower overall social capital that can be seen in the agent profile table. When looking at Agent 0 and 1 in the End network (hour 23 of iteration 20), both agents ended up smoking due to the heavy influence of peers and the low protective effects of their cumulative social capital, but Agent 2 was low enough in their urge to smoke that (deviance) and had enough social

capital to prevent them from smoking. This is how I will present the results of the experimental conditions testing peer-influences on substance-use in the results section.



Description of Outcomes

I will also give a description of the outcomes observed in the experimental condition. In this validation test, the agents were randomly generated within the maximum ranges for all parameters, so I do not expect any uniformity, though the final outcome of this friend group is what I would expect to see based on previous research. Namely, that agents with lower social capital will be more influenced by their peers than those with high social capital. Agent 0, 1, 3, and 5 all smoked within the first day of the simulation. 3 and 5 were both above the threshold for deviance at the start of the simulation. Agents 2 and 4 were among the highest in time spent with parents and sports frequency, with a low level of urge to smoke. Agents 2 and 4 alone ended up attending the sports club every day after school while the remainder of the friend group (0, 1, 3, 5) all skipped sports, stayed on the street to smoked instead. This difference split the group into two, specifically after school each day.

6. Models

From examining the previous Icelandic research into adolescent substance-use, peer-influences, and social capital, I created a straightforward formula to describe the function of the social environment on adolescent behavior.

$$P = f (SC = \sum (w \cdot F + w \cdot S + w \cdot Sp + w \cdot P))$$

In this formula, P represents the overall protective effect from substance-use (or deviance) that adolescents benefit from as a function of the \sum of their cumulative social capital (SC). Within their social capital lies the domains of intervention that play a major role in the lives of adolescence, namely their family (F), commitment to school (S), their organized leisure activities - usually sports (Sp) and their peers (P). Each of these domains of social capital may vary by the individual adolescent and by community. This is represented by the weight (w) of their given social capital generating domain. In this model, the weighting will be an arbitrary value that calibrates the model well enough to give expected results. I am more concerned with accurately modeling system dynamics at this time, though future research should include the inputting of raw data when those capabilities are developed.

Within SocialInsight, this equation will be used to calculate the individual agent's behavior based on their social capital measured against their urge to smoke. The peer-group will not be numerically calculated, rather it will serve as the dynamic social environment in the simulation, being the number of deviant (smoking) peers in the friend group. Each agent will have a certain level of urge to smoke which will range from 0-1. This is an abstraction to account for the diversity in adolescent behaviors and serves to represent an adolescent's risk-taking behavior. The simplified computational process that prevents smoking (0) or leads to smoking (1) within the simulation is as follows:

$$\begin{cases} 0 & \text{if } \sum(SC) > UtS \\ 1 & \text{if } \sum(SC) < UtS \end{cases}$$

The outcome will be based on a calculated of the \sum of the SC value and measured against the agent's urge to smoke. If the value of their urge to smoke is greater than their SC value, then the agent will smoke as soon as their urge to smoke value passes the threshold of 0.5. When peer smoking is perceived by the agent, this calculation takes place again, but against the influence of their peers being applied to the calculation as well. This will occur within the Perception and Decision-Making process of the agents each iteration which is described in figure 3.

3.2 Social Network Analysis and Friend Group Dynamics

I also use social network analysis (SNA) to explore the interconnections among agents in the friend group and examine how they influence each other. Social network analysis is particularly useful in studying adolescent substance-use as it enables the analysis of complex relations between individuals and the structural properties of their social networks (Ennett et al., 2006; Henneberger et al., 2021). Multiple attributes within adolescent social networks have been identified as relevant factors that can contribute to substance-use (Ennett et al., 2006). This includes social status, social embeddedness within a peer group, and proximity to other adolescents who use substances. This effect is not unidirectional though, showing that there are likewise protective effects to the network depending on one's relationships and placement within it. SNA has also been noted as an effective method to link with ABM research (Will et al., 2020). Modeling these relationships in SocialInsight allows for the examination of how these relationships, when tested under differing parameters and levels of social capital, influence individual agents and the network as a whole within the simulation. This offers a meso-level perspective on how substance-use can be influenced by one's position within their social network and friend group. I do this by noting the initial conditions of the agents at the very start of the simulation. In particular their values for their social capital (time spent with parents, age, grades, sport frequency) and the level of their urge to smoke. Then, I proceeded to measure the amount of influence that they received based on their exposure to friends who smoke, this is represented by a numerical value and the calculation for the updating of their urge to smoke based on peer-influence is then used as a weight for the directional influence (the arrows in the network graph) from one agent to another.

3.3 Experimental Conditions – Levels of Social Capital and Peer-Smoking

The following experimental conditions were conducted. In each condition, the values of the social capital parameters or the amount of smoking peers in the group was altered to test how the individual agents smoking behavior was influenced by the different friend group compositions, and how social capital would impact an agent's decision-making regarding smoking behavior and peer-influences:

- 1) **High Social Capital & Low Smoking Peers:** Agents with high social capital and minimal exposure to peers engaging in smoking.

- 2) **Low Social Capital & Low Smoking Peers:** Agents with low social capital and minimal exposure to peers engaging in smoking.
- 3) **High Social Capital & Medium Smoking Peers:** Agents with high social capital and medium exposure to peers engaging in smoking.
- 4) **Low Social Capital & Medium Smoking Peers:** Agents with low social capital and medium exposure to peers engaging in smoking.
- 5) **High Social Capital & High Smoking Peers:** Agents with high social capital with high exposure to peers engaging in smoking.
- 6) **Low Social Capital & High Smoking Peers:** Agents with low social capital and high exposure to peers engaging in smoking.

These conditions are chosen on the basis of testing if the model can give realistic results when compared to previous research on peer influences and substance-use in Iceland. These six conditions encompass the lowest to highest values to cover the range of possible friend groups that could exist in a given adolescent friend group. Although other friend group sizes could be simulated, due to constraints in model development, six was most manageable to create a group network with proper simulation output. Each agent can perceive their neighboring agents and be influenced by their smoking behavior. Agents will run for 20 iterations, representing 20 school days in a month. This will only include school days and not consider adolescent weekend behavior.

4. Results

This model of peer-influence appeared to capture the dynamics I expected to find according to the existing Icelandic sociological and criminological research. The model revealed social networks and differing group outcomes depending on initial conditions and levels of social capital compared to smoking (deviance) in the group. Groups with the lowest levels of social capital appeared to be most influenced by their deviant peers. However, those agents with the highest social capital observed the greatest protective

effect against their own and others deviant behavior. Interestingly, the groups with high and low social capital compared with medium levels of deviance (conditions 2a and 2b) saw a more drastic outcome based on initial conditions (levels of deviance and levels of social capital) than other conditions. The only changes that occurred between the six experimental conditions were the ranges of the social parameters (time spent with parents, sport frequency, age, and school grades), and the number of smoking peers within the friend group.

4.1 1a - High Social Capital & Low Smoking Peers:

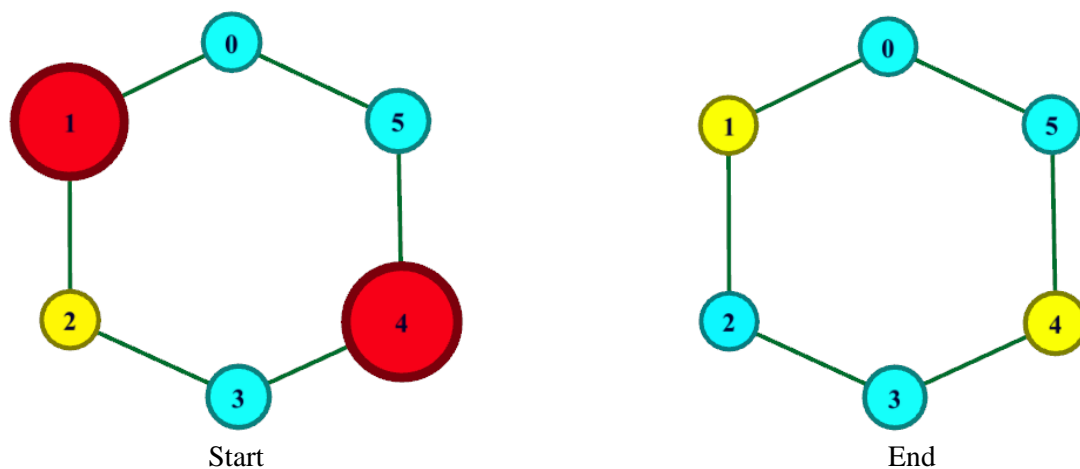


Figure 4: Start and end state of agents in test condition 1a (high social capital and low smoking peers). Blue, yellow, red indicate low, medium, and high urge to smoke, respectively. Larger circles indicate smoking behavior.

Table 4: Agents Generated in Experimental Condition 1a.

Agent	Urge To Smoke	Time Spent With Parents	Grades	Sports Frequency	Child Age
0	0.22	7.0	8.0	6.0	15.0
1	0.65	7.0	10.0	7.0	15.0
2	0.39	7.0	9.0	7.0	14.0
3	0.04	7.0	9.0	7.0	14.0
4	0.91	5.0	8.0	7.0	16.0

5	0.31	5.0	8.0	7.0	14.0
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The analysis of condition 1a, High Social Capital & Low Smoking Peers, shows an undirected network, where no influence to smoke occurred. After calculation of social capital to the agents, all agents were below the threshold to smoke. Agents 1 and 4 exhibited deviant attribute profiles compared to others at the beginning of the simulation, though after social capital had been calculated in the first iteration, all agents were reduced below the threshold of smoking. Degree centrality measures indicated uniformity among the agents, each having a degree centrality of 2, suggesting an evenly distributed network. Despite variations in individual attribute profiles, no distinct clusters or communities were evident within the network due to a lack of peer-influence to smoke. All agents followed the scheduled daily routine.

4.2 1b - Low Social Capital & Low Smoking Peers

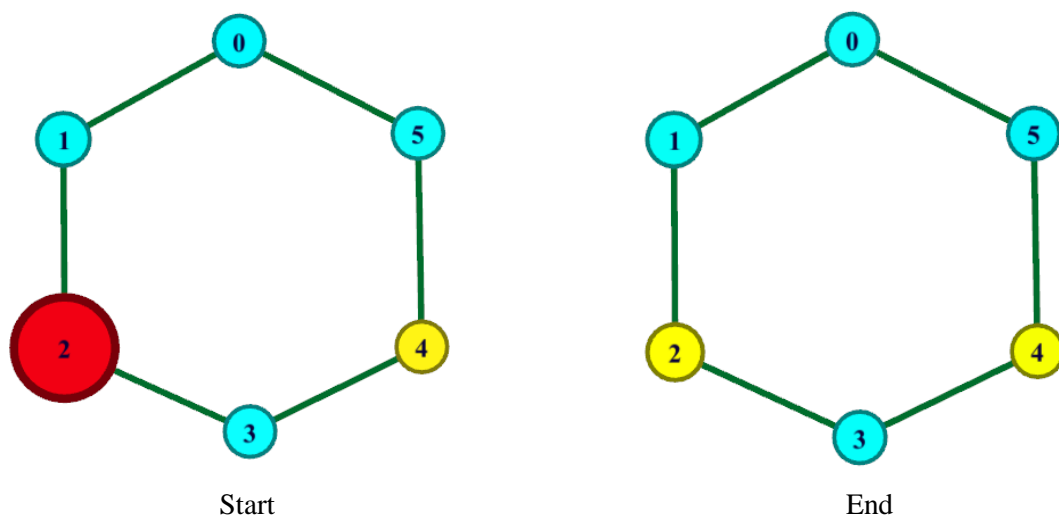


Figure 5: Start and end state of agents in test condition 1b (low social capital and low smoking peers). Blue, yellow, red indicate low, medium, and high urge to smoke, respectively. Larger circles indicate smoking behavior.

Table 5: Agents Generated in Experimental Condition 1b.

Agent	Urge To Smoke	Time Spent With Parents	Grades	Sports Frequency	Child Age
0	0.15	3.0	1.0	2.0	15.0
1	0.18	2.0	2.0	2.0	14.0
2	0.56	3.0	3.0	0.0	15.0
3	0.22	3.0	1.0	1.0	15.0
4	0.44	3.0	3.0	2.0	14.0
5	0.21	1.0	3.0	2.0	14.0

The analysis of condition 1b, low social capital and low peer smoking, Agent 2 exhibited deviant attributes compared to others, displaying a higher urge to smoke (0.56) and no engagement in sports. Despite these differences, all agents possessed low levels of grades, sports frequency, and time with parents. Degree centrality measures indicated uniformity among the agents in a non-directed network due to a lack of peer-influence on smoking. Visual representation of the network graph revealed a uniformly connected structure without prominent groupings or patterns. Agent 2, who surpassed the threshold for deviance (0.56), was brought down to an overall urge to smoke of 0.44 after calculation of social capital. Even with very low social capital, it brought the overall value of smoking just below the threshold with a very small protective effect, likely due to 0.56 being just above the threshold. Agent 2's social capital was significant enough to results in not smoking. No agents ended up smoking while having low social capital and low smoking peers.

4.3 2a - High Social Capital & Medium Smoking Peers:

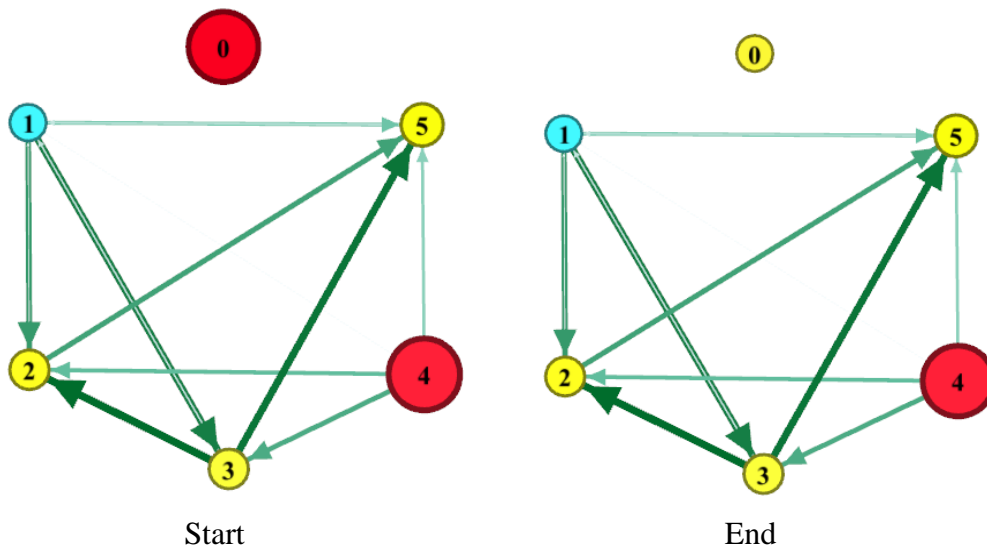


Figure 6: Start and end state of agents in test condition 2a (high social capital and medium smoking peers). Blue, yellow, red indicate low, medium, and high urge to smoke, respectively. Larger circles indicate smoking behavior.

Table 6: Agents Generated in Experimental Condition 2a.

Agent	Urge To Smoke	Time Spent With Parents	Grades	Sports Frequency	Child Age
0	0.86	6.0	9.0	6.0	15.0
1	0.08	6.0	8.0	7.0	14.0
2	0.41	7.0	8.0	7.0	16.0
3	0.49	6.0	9.0	7.0	14.0
4	0.97	5.0	9.0	6.0	14.0
5	0.3	7.0	9.0	7.0	16.0

The analysis of condition 2a, characterized by high social capital and medium peer smoking. Agents 0 and 4 demonstrated deviant behavior with a high urge to smoke, 0.86 and 0.97 respectively, despite having high social capital in the other domains. Once the social capital was calculated, Agent 0's urge to smoke was reduced below the threshold.

The peer-group demonstrated a directed network, showing strength and direction of the influence from agent to agent. Degree centrality for the network measured an average of 2.7, with Agent 4 having the most out-degrees of influence at 4. Likewise, Agent 1 and 3 both had degrees of 3 and weighted out-degrees of influences of 0.46, slightly higher than Agent 4's weighted out-degree of 0.37. While there was a smoking peer in the friend-group (Agent 4), the high social capital reduced the amount of influence received by other agents, despite a well-connected network. This left Agent 4 as the only smoker in the friend-group at the end of the simulation.

4.4 2b - Low Social Capital & Medium Smoking Peers

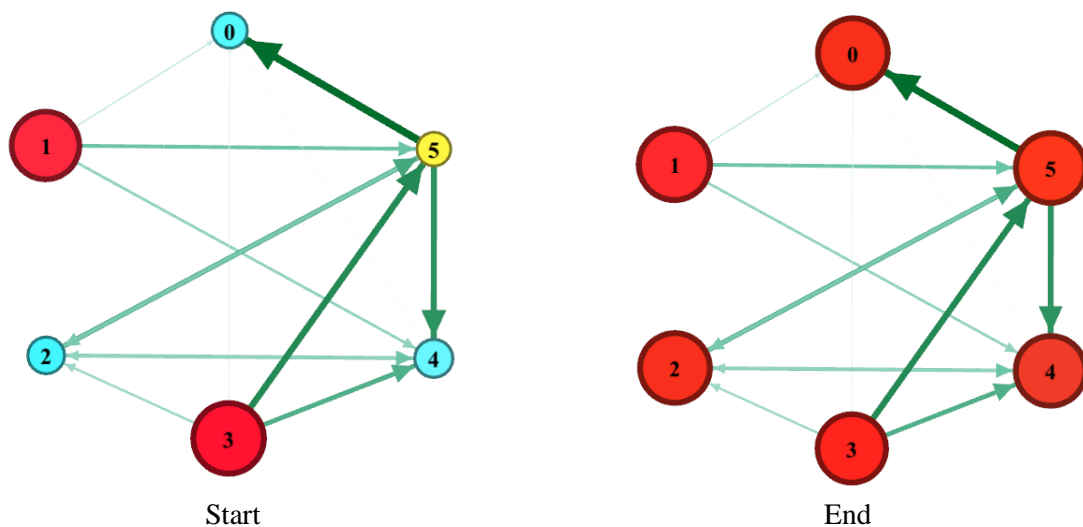


Figure 7: Start and end state of agents in test condition 2b (low social capital and medium smoking peers). Blue, yellow, red indicate low, medium, and high urge to smoke, respectively. Larger circles indicate smoking behavior.

Table 7: Agents Generated in Experimental Condition 2b.

Agent	Urge To Smoke	Time Spent With Parents	Grades	Sports Frequency	Child Age
0	0.03	0.0	3.0	2.0	16.0
1	0.96	1.0	1.0	1.0	15.0
2	0.16	0.0	2.0	0.0	16.0
3	0.84	3.0	2.0	2.0	16.0
4	0.28	1.0	1.0	2.0	15.0
5	0.38	1.0	1.0	2.0	16.0

The analysis of condition 2b, characterized by low social capital and medium smoking peers. This network was highly connected, Agent 4 and 5, with their moderate urge to smoke, were influenced most heavily while having in-degrees of 4 and 3 respectively and having the highest weighted in-degrees of 0.51 and 0.45, meaning they were heavily influenced. The majority of this influence came from Agents 1 and 3 who had the highest urge to smoke and interestingly who both had an in-degree of 0, meaning they were not being influenced by the other agents, but had out-degrees of 3 and 4. Agent 0, who had a low urge to smoke at first (0.03) and did not engage in smoking at the beginning of the simulation, had the highest in-degree of 5, meaning all other agents had an influence on Agent 0. Notably, Agent 0 had no time spent with parents, and was the most influenced in the group. At the end of the simulation, Agent 0 had perceived all other friends engaging in smoking, Agent 0's urge to smoke had reached 0.81, resulting in smoking.

4.4 3a - High Social Capital & High Smoking Peers

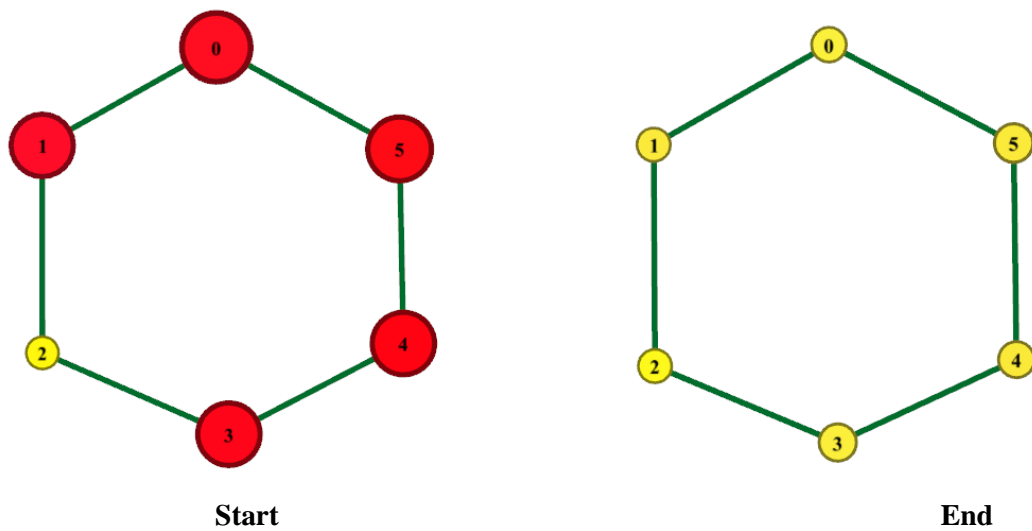


Figure 8: Start and end state of agents in test condition 3a (high social capital and high smoking peers). Blue, yellow, red indicate low, medium and high urge to smoke, respectively. Larger circles indicate smoking behavior.

Table 8: Agents Generated in Experimental Condition 3a.

Agent	Urge To Smoke	Time Spent With Parents	Grades	Sports Frequency	Child Age
0	0.7	5.0	8.0	7.0	15.0
1	0.85	5.0	10.0	6.0	15.0
2	0.35	6.0	8.0	7.0	16.0
3	0.76	5.0	10.0	6.0	15.0
4	0.82	7.0	9.0	6.0	14.0
5	0.73	7.0	10.0	6.0	15.0

The analysis of condition 3a, characterized by high social capital and high peer smoking. All but Agent 2 in this network displayed a high urge to smoke passing the threshold before the application of social capital to the agents. After social capital was calculated and applied, all agents fell below the threshold into the medium range for urge to smoke. The network did not demonstrate a directed structure due to a lack of smoking behavior from agents. Despite 5 out of 6 agents having a high urge to smoke at the start, after calculation

of high social capital values, no smoking occurred in the friend group, all agents attended the regular schedule of moving to school, sports and home.

4.5 3b - Low Social Capital & High Smoking Peers

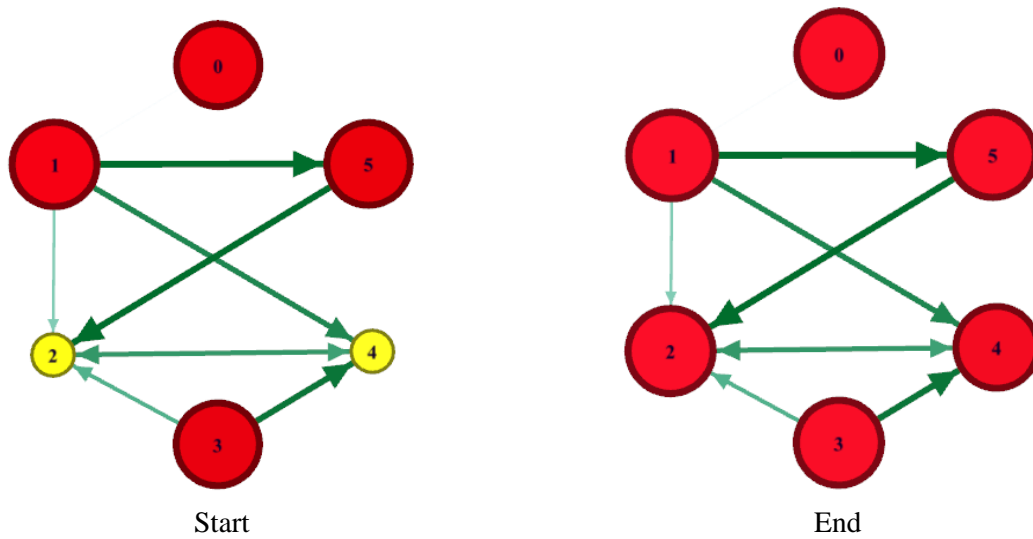


Figure 9: Start and end state of agents in test condition 3b (low social capital and high smoking peers). Blue, yellow, red indicate low, medium and high urge to smoke, respectively. Larger circles indicate smoking behavior.

Table 9: Agents Generated in Experimental Condition 3b.

Agent	Urge To Smoke	Time Spent With Parents	Grades	Sports Frequency	Child Age
0	0.98	1.0	3.0	1.0	16.0
1	0.84	0.0	2.0	0.0	14.0
2	0.32	2.0	3.0	0.0	14.0
3	0.93	1.0	3.0	1.0	14.0
4	0.4	2.0	3.0	0.0	16.0
5	0.71	0.0	1.0	2.0	15.0

The analysis of condition 3b, characterized by low social capital and high peer smoking. All agents were in the low social capital brackets, with 4 out of 6 agents having an urge to smoke above the threshold. The network demonstrated a directed network structure. Degree centrality measures an average of 1.5. The low social capital parameters had almost no protective effect on the final value of agents' urge to smoke. Both agents who were not smoking at the start of the simulation (Agents 2 and 4) received the most in-degrees (4 and 3) and due to already moderate levels of urge to smoke and began smoking within 2 ticks (2 hours) of the first iteration.

5. Discussion

Given the behavior of the agents and the outcomes of the model, SocialInsight was successful in creating a model of peer-influence that portrayed normative and expected system dynamics regarding adolescent peer-influence and substance-use. Likewise, the additional protective calculations of social capital proved reliable in modeling how social capital can provide protection against negative peer-influence. The Icelandic sociological data and research that informed this model was also successfully implemented, though refinement of the peer-influence model and the calculation of social capital will be an ongoing process as the ABM is developed further in its capabilities.

Both hypotheses (H1: Agents with higher social capital will be less likely to engage in substance use, regardless of the presence of deviant peers, due to the influence of strong social capital, and H2: The presence of deviant peers will increase the likelihood of substance use among agents, particularly those with lower social capital, as they may be more susceptible to peer-influence and less inclined to resist deviant behavior) were supported by these findings. This is encouraging since this is the behavior that was generally seen in the empirical research. Although the ABM is not at the stage of predictive analytical quality or to use empirical data directly, the theoretical base for the model seemed to correspond to the results of the empirical research in a way that demonstrated that the rules of the agents and the model's behavior are theoretically sound. This is particularly interesting given that there are no lurking variables in the ABM; only the rules based off the theory and the behavioral rules of agents that are described in the diagrams earlier in the methodology section are at play. In addition, although mathematical calculations are being used to represent social capital and peer-influence in the model, they are serving as representations of how the theories of social order, control/bonding, and capital may mechanistically function. This thesis was not meant to directly research the mechanistic nature of these theories, but I find the implications of making these theories explicitly modeled in calculations and to serve as a rule-base for agents to be an exciting avenue to explore the theories more mechanistically. For the remainder of the discussion will be focused on the behavior of the agents under their specific testing conditions as well as model behavior and areas for improvement and future research.

5.1 Initial Conditions and Social Capital's Protective Effects

The initial conditions of each test had a drastic impact on the end results of each of the simulations. While this showed the deterministic nature of the simulation, it also showed how previous social factors influenced agent outcomes before having any peer-influence. This is observed in how an agent's level of urge to smoke, which likewise can serve as a representation for adolescent risk taking, drastically predicted their smoking behavior and the influence that their peers had on their own smoking behavior, notably making them more susceptible. In the context of the IPM, I believe this supports its main endeavors in promoting high social closure and community involvement. I noticed this particularly in the way agents in the high social capital conditions rarely smoked, save one agent in the medium peer smoking condition (2a) who is somewhat of an outlier. These results echo

the findings of previous Icelandic research that found community structure and the inclusion of high quality activities for adolescents reduces their likelihood of engaging in substance-use (Kristjansson et al., 2010; Thorlindsson et al., 2012; Thorlindsson & Bernburg, 2004, 2006). This would also imply that communities with minimal youth involvement in high quality community endeavors, would see less protection against adolescent substance-use and deviant behavior, which is exactly what has been observed in Icelandic communities who did not adopt the community based prevention measures (Kristjansson et al., 2010). In alignment with the notion that higher social capital reduces the chances of adolescent substance-use, Kristjansson et al (2010) showed that those communities who did not adopt the community-based prevention programs of increased parental monitoring and high-quality leisure activities did not see a significant reduction in adolescent substance-use compared to those who did. Despite high peer-influences in the simulation, if social capital was high enough, then this appeared to be enough to guard against smoking behavior of the individual agent, even at the outset of test conditions such as 1a, 1b and 3b, where social capital brought all agents into moderate or low levels of urge to smoke and avoiding substance-use altogether.

5.2 Social Capital and Peer-Influence

Given Thorlindsson and Bernberg's (2004) findings indicating that there remains significant difference in substance-use outcomes between those adolescents who have delinquent friends and those who do not, the ABM seems to properly replicate these results in the six-agent friend group. When looking at the results of all test conditions save 3a (high social capital & high smoking) the results indicate that the impact of deviant peer-influence, particularly if the agents have low social capital, have a strong effect on the agents, usually with the majority of the group adopting smoking behavior. Furthermore, tests 2b (low social capital & medium smoking) and 3b (low social capital & high smoking) which both measured low social capital clearly demonstrated this type of outcome. Likewise, test 1b (low social capital & low smoking), where group smoking was not seen due to low levels of deviance in the group, also showed that despite low social capital, and by all measures poorly integrated agents, smoking did not occur due to a general lack of deviance in the network. This echoes the findings from past research into group association, indicating that those friend groups with substance-using peers tend to use more

substances, and those with fewer or no substance-use tend to not engaging in the behavior (Kristjansson et al., 2010; Meyers et al., 2023).

Another finding that caught my attention was test 3a (high social capital & high smoking), which did not see group smoking, and instead saw the protective effects of social capital reduce five out of six agents who were above the threshold at the start of the simulation, to levels below the threshold once it began. Peer-influences in this group remained stable yet smoking did not occur. This also confirms the findings from Thorlindsson and Bernburg (2004; 2007) and the claims of Kristjansson (2010) and Sigfúsdóttir (2009) that high social integration and social involvement proved protective, despite having deviant peers in the friend group. This is directly related to the theoretical perspective of social integration, showing that agents who were more socially integrated (via the measure of social capital) acquired an overall protective effect from their deviant peers and a social network of non-deviant friends likewise prevented any substance-use.

Experiment 2b was also interesting as it tested the effects of social capital and its protective effects when it came to having a single deviant peer in the group (Agent 4 who continued to smoke despite all other agents not smoking). Agent 4 had a decently large influence with a high out-degree, meaning it was influencing other agents, but this was still not enough to cause other agents to smoke due to their high levels of social capital and interconnectedness amongst the friend group. Agent 4 also splits from the friend group when it came to after school schedule, instead of sports, Agent 4 remained alone, smoking on the street. I also expected Agent 2 to be more susceptible than agent 0 to the amount of peer-influence received given Agent 2 actually has a lower social capital score than Agent 0. This may indicate that the placement of friends within a group (the friends they are closer with or the position that they occupy in the friend group) plays a role in susceptibility to influence. This seems generally supported by the research into networks of adolescent substance-use (Ennett et al., 2006), where proximity to other substance-users in the friend group also significantly increased that friends likelihood of also using substances.

5.3 Model Behavior

Homophily

Homophily occurred within the validation test (random social capital and random peer smoking) as well as test 2a (high social capital and medium smoking peers), as friend

groups split into two groups once part of the group started smoking and the other remained consistent with their routine schedule. The two groups never rejoined and remained distinct, despite being part of the same friend group. Homophily is a typical characteristic associated with group affiliation and friend choice, particularly in the case where there are shared characteristics (Ennett et al., 2006). In all conditions where the whole friend group ended up smoking (tests 2b and 3b) the group remained consistent in their behavior, where they eventually all ended up sharing the same schedule. In conditions where only some agents ended up as smokers, which was only 2a (high social capital and medium peer smoking), this condition had the most variability among agent profiles, therefore it was not surprising that the group was not as homophilous as other conditions which shared more closely in their social capital and levels of urge to smoke. Most groups, save 2a, appeared to conform to either smoking or abstaining from smoking by the end of the simulation, showing the tendency for those who are already friends to conform and eventually produce homophilous group behavior.

Feedback Loops

Within the simulation, there appeared to be a positive feedback loop where agents who smoked and were eventually influenced enough to smoke, did not stop. I noticed this in the calculation of the updating to the urge to smoke parameter, which remained stable after the initial pass of the 0.5 threshold, which would result in smoking. While this is also a point to consider for future model improvements, it also demonstrates addiction, though addiction is not likely to occur after a first exposure, this model seemed to behave in this way. Similarly, but in a more theoretical light, the model also showed how friends may serve as positive or negative feedback mechanisms in the social environment, encouraging pro-social or deviant behavior due to their influences. This was clearly seen in each model where agents received influence from peers in the friend group, resulting in stability or group conformity.

5.4 Organized vs. Unsupervised Leisure Activities

When examining sport attendance, I noticed those agents who engaged in smoking did not participate in organized leisure activities (sports) at all. This created a friend group with high substance-use based on the results from experiments 2b and 3b where social capital in the group was low and smoking was medium to high. This outcome is supported

empirically by a variety of research on this topic of adolescent society (Coleman, 1988; Thorlindsson & Vilhjalmsson, 1991), where adolescents who were thoroughly integrated into adolescent society, characterized by lack of supervision and high peer-dynamics with a sub-culture of their own, saw lower grades, higher substance-use and less community participation. The addition of adult supervision (time with parents) seems to offer a protective level of social control for the adolescents. This would be compounded if the parents are also highly connected and have a high level of social closure. One consideration of this model is the fact that the time spent with family parameters is assumed to be a factor in producing high social capital with intergenerational closure. This, of course, is not always the case. Parental households, as well as communities that do not promote educational success, pro-social attitude and behaviors would work in the opposite way that this model considers parental involvement to function. This corresponds to Hirschi's and Coleman's notions that the quality of bonds and social control in the community and family have a significant impact on adolescent behavioral outcomes, which depends on the familial and communal norms.

Agents who followed norms of school attendance and sport engagement had significantly lower levels smoking behavior among the group. This demonstrated something of a resource depletion, namely that of time. If the time of agents is used up through prosocial and organized leisure activity, then there is less time to engage in deviant behavior with deviant peers in general. This is a very simple observation, though I believe it holds true that keeping adolescents occupied with pro-social activities reduces their opportunity to engage in other activities. This is also observed in past research, some noting that social bonds forged at sport centers are protective against deviance, even in the presence of deviant peers (Thorlindsson & Bernburg, 2006). Similarly, others have observed the reduction in unsupervised free-time that adolescents have within the day reduces their opportunity to engage in deviant behavior or substance-use (Kristjansson et al., 2021; Sigfúsdóttir et al., 2009). This ABM, while offering insights in the social capital and peer-influence regarding substance-use, also demonstrated that the environment and daily structure of adolescents may play a role in their ability to engage in deviant behavior, as well as reduce their opportunity to even consider engaging in such activities. As the old saying goes, "the devil finds work for idle hands," thankfully high-quality organized leisure activities, school, and familial involvement can ensure that idle time remains at a minimum.

6. Future Direction

This model was quite ambitious, and while it aimed to simulate a holistic social environment, there were some factors that could not be included due to time or developmental (technological) constraints. Firstly, cultural norms and traditional substance-use customs were not included. This can be critical as legalization and promotion of certain substances within a culture could drastically change the dynamics of how adolescents interact and use substances. This may also prove to be substance-specific, such as towards nicotine pouches which are becoming more commonly used. Similarly, other cultural norms could drastically alter the type of social capital that is produced in any given domain of intervention. For instance, if alcohol consumption is usually coupled with sports participation in a certain community, then sport would no longer serve as a protective factor and instead would be a risk factor for substance-use. This should be considered for future models, specifically when seeking to model specific location characteristics of friend groups. Likewise, I used social capital as a cumulative variable, therefore I can only deduce that the cumulative effects protect against substance-use, and can not yet comment on each domain separately, although this can be done in future research with this model.

Community factors and neighborhood composition is another component that was not modeled in the simulation. This may influence many of the social norms associated with peer-groups, parental behavior (including monitoring, social and intergenerational closure), and substance-use norms. Parental networks are not accounted for in this model; therefore, the community level effects are not accurately modeled either. Further research may consider creating full parental networks of single and double parent households to accurately recreate the entire community structure of interest. Incorporating single and two-parent households would be beneficial to further model how parental dynamics unfold and subsequently impact adolescent behavior. Given that single parents have less time to devote to their child's endeavors, including this in future models, based on quantitative and qualitative research of household composition would be beneficial.

Similarly, weekend behavior was also not modeled in this simulation. This particular model only demonstrates behavior on a school weekday. Party behavior and attendance should be looked at in future models in order to more accurately simulate a full week to better understand how the spread of peer-influence may proliferate and decay over a

month. Given technological develop, the number of agents was limited to six, although this was still a reasonable peer-group size. The option to have larger groups and a multitude of groups interacting would be beneficial when seeking to model entire communities (e.g. schools) and how peer-dynamics play out in this environment. Currently, only smoking behavior is perceivable by agents, in future peer-dynamics research, positive behaviors should also be perceivable by agents to account for the benefits of peer-influence. This model offers some insight into the dynamics of peer-influence on substance-use but remains incomplete without the balancing aspects of prosocial behavior and its impact on adolescent substance-use. Nevertheless, this model was successful in producing a computational model of social theory and the potential mechanisms of peer-influence and decision making when it comes to social pressures, which in and of itself offers a novel way of looking at the phenomenon from a mathematical and networked perspective.

As the ontologies within SocialInsight are further developed, the inclusion of the psychological and biological level may be layered in the substance-use ontology and the peer-influence model. This would offer a more complex and interdisciplinary observation of system dynamics of social phenomenon where multiple levels of detail are incorporated into the mix. This would be an ideal model for my research interest, which would be to create a model that transcends multiple levels of analysis to test the factors that produce the greatest impact with the minimum amount of change. As there are still limitations in the model at this time in its development, future modeling should include statistically accurate friend groups according to location specific demographic and network data, which may be done to test different policy interventions and how these may impact population and individual level behavior. Future research may also seek to provide simulation-based policy design. By using SocialInsight to create a validated and calibrated model with the addition of community specific data, the ABM may be used to test viable intervention options to help refine the planning and implementation process. And from a theoretical perspective, micro, meso, and macro level social theories can be tested computationally, offering the next steps in refining our understanding of how these theories function mechanistically.

6.1 Conclusion and Final Words

Given the results of the experimental conditions tested in this thesis, the model seems to accurately simulate the social dynamics that are seen in empirical research. This is my first

step in understanding social phenomena from a computational and complexity-based perspective with Icelandic data. For me, these models have offered a unique glance into the theoretical underlying social mechanisms that are at play in adolescent group dynamics. What is most interesting from this research in my view, is that it was impossible for me to program the outcomes of the friend groups' smoking behavior, I could only change the parameters of the adolescents within the groups, and then the group dynamics ensued to produce the overall individual and group behavior. This is an essential feature in the complex and interconnected nature of group dynamics. Namely, that these dynamics and social phenomenon emerge from the interactions of individuals and are their products. I believe this is something to consider when trying to influence adolescent behavior. Rather than dealing with the end process (or even a macro process) such as substance-use or deviant behavior, the lower-level (micro) social components of the system (e.g. community social capital) should be targeted instead. From this research, I have gained a more systems-oriented and mathematical understanding of how such social processes may function, and I plan to take this perspective with me as I continue to study social phenomenon from the perspective of complexity theory and system dynamics in the future.

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Appendix

Full tech report on SocialInsight: https://www.iiim.is/wp/wp-content/uploads/2024/04/SocialInsight_Tech_Report_1_0.pdf

Table of Terms and Concepts

Term	Definition
Agent	A discrete entity with its own characteristics, behaviors, and rules governing interactions within the model.
Agent-based model	A computational model composed of autonomous agents that interact with each other and the environment.
Environment	The space in which agents operate and interact, typically represented as a grid, network, or continuous landscape.
State	The current condition or configuration of an agent or the environment.
Behavior	The actions or decisions made by an agent based on its internal state and the information it receives from the environment.
Interaction	The exchange of information, resources, or influence between agents or between agents and the environment.
Rule	A predefined guideline or condition that governs an agent's behavior or interaction within the model.

Simulation	The process of running an agent-based model to observe the emergent properties and dynamics of the system.
Emergence	The phenomenon where complex patterns or behaviors arise from the interactions of simpler components (agents).
Heterogeneity	The diversity or variability among agents in terms of attributes, behaviors, or rules.
Spatial	Pertaining to the arrangement or distribution of agents and their interactions within the environment.
Feedback	Information returned to an agent based on its actions or interactions, influencing its future behavior.
Calibration	The process of adjusting model parameters to better match observed data or real-world phenomena.
Validation	Assessing the accuracy and reliability of a model by comparing its outputs to empirical data or expert knowledge.
Sensitivity Analysis	Examining how changes in model inputs or parameters affect model outputs and behaviors.
Complexity	The degree of intricacy or interconnectedness within an agent-based model, often characterized by nonlinear dynamics.

