



Neurodevelopmental Integrity and Substance Risk: A Developmental Public Health Model for Education, Risk Literacy, and Adult Autonomy

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Abstract

Modern substance discourse is often organized around legal, medical, and cultural labels: legal drugs, illegal drugs, prescription medicines, over-the-counter products, recreational substances, controlled substances, and commercially normalized stimulants. These labels are administratively useful, but they are not reliable indicators of neurodevelopmental safety. A developing brain responds to pharmacology, timing, dose, frequency, potency, route of administration, psychological vulnerability, setting, medical necessity, commercial context, and pharmacological interaction.

This paper advances *neurodevelopmental integrity* as a guiding concept for substance education, developmental risk literacy, and adult harm reduction. Neurodevelopmental integrity refers to the developing neural, psychological, behavioral, and bodily capacities that support attention, learning, memory, emotional regulation, impulse control, reward evaluation, bodily awareness, sleep regulation, and future autonomy. The concept is derived from three observations: important aspects of brain maturation continue into young adulthood; many substances affect systems involved in reward, inhibition, memory, mood, stress, sleep, pain, and perception; and inherited legal, medical, commercial, or cultural categories often fail to reflect developmental risk.

The paper uses selected substance categories as illustrative cases: alcohol, nicotine, highly caffeinated beverages and energy drinks, cannabis, opioids, benzodiazepines, stimulant medication, antidepressants, over-the-counter analgesics, party drugs, classic psychedelics, and interaction-related risks. These substances are not treated as equivalent. The model evaluates multidimensional exposure conditions rather than relying on binary moral, legal, or administrative classifications of substances. It asks how age, setting, dose, frequency, mental state, medical history, medication use, polydrug exposure, commercial normalization, sleep disruption, and interaction literacy shape risk.

The paper argues for a substance culture centered on education, proportionality, developmental honesty, behavioral skill-building, and accurate risk communication. For adolescents and emerging adults, substance education should emphasize neurodevelopmental awareness, risk literacy, interaction literacy, caffeine and sleep literacy, coping capacity, social decision-making, and informed delay of avoidable exposure. For mature adults, policy should give greater weight to informed autonomy, harm reduction, comparative risk assessment, and safe contexts. A mature substance culture does not normalize familiar

risks or demonize unfamiliar ones. It teaches how pharmacological effects change across age, context, vulnerability, purpose, setting, commercial environment, and interaction.

Keywords: neurodevelopmental integrity, adolescent brain development, substance education, developmental risk literacy, adult autonomy, harm reduction, alcohol, nicotine, caffeine, energy drinks, cannabis, psychedelics, opioids, benzodiazepines, attention-deficit/hyperactivity disorder medication, antidepressants, painkillers, drug interactions

1. Introduction

Substance education often begins with familiar labels. Alcohol and nicotine are legal consumer substances. Energy drinks and highly caffeinated beverages are commercially available stimulants. Cannabis may be commercialized, medicalized, decriminalized, or prohibited. Prescription stimulants, opioids, benzodiazepines, and antidepressants are treated as medicines. Paracetamol, ibuprofen, and related analgesics are sold over the counter. Methylenedioxymethamphetamine (MDMA), cocaine, ketamine, amphetamines, and many psychedelics are commonly framed through criminal or recreational categories. These labels do not define biological risk. A substance does not become safe because it is tolerated, prescribed, commercialized, legalized, or culturally normalized. The relevant question is how a pharmacologically active substance interacts with a person at a particular stage of brain and behavioral maturation, in a particular setting, and in combination with other substances, medications, commercial cues, or physiological stressors.

This is especially important for adolescents and emerging adults. A developing brain is not a smaller adult brain. It is an actively maturing system in which attention, memory, emotional regulation, impulse control, reward evaluation, bodily awareness, sleep regulation, and long-term decision-making are still being shaped [1–4]. Substances that influence these systems can therefore have different implications in developing individuals than in mature adults.

The central issue is not whether more substances should be prohibited. The central issue is whether public health, medicine, education, and law can communicate risk accurately. Socially tolerated substances should not be minimized. Commercially normalized stimulants should not be treated as developmentally neutral. Medicalized substances should not be treated as harmless merely because they are prescribed. Illegal substances should not be grouped into a single moral category without regard to age, dose, setting, vulnerability, and interaction risk.

Drug policy research has repeatedly shown that legal classification, social harm, individual harm, enforcement effects, market effects, and public health outcomes do not always align [5,6]. A developmental public health model should therefore educate before it punishes, differentiate before it moralizes, and inform before it normalizes.

This paper develops a model of *neurodevelopmental integrity* to support more accurate substance education. Its aim is not paternalistic protection, but informed developmental literacy.

2. Method, Scope, and Contribution

This paper is designed as a conceptual and normative analysis informed by developmental neuroscience, adolescent psychiatry, addiction medicine, harm reduction, public health education, drug policy research, and neuroethics. It clarifies how substance education and policy should be structured when legal, medical, commercial, and cultural categories fail to reflect developmental risk.

The paper uses selected substances as illustrative cases rather than as a comprehensive pharmacological review. These cases are not intended to provide a complete pharmacological account of each substance class. They are used as boundary examples to test whether legal, medical, commercial, and cultural categories reliably track developmental risk. Alcohol and nicotine illustrate socially tolerated substances. Energy drinks and highly caffeinated beverages illustrate commercial normalization of pharmacological stimulation. Prescription stimulants, benzodiazepines, opioids, and antidepressants illustrate medicalized substances. Over-the-counter analgesics illustrate commercial availability and false harmlessness. Party drugs illustrate setting, polydrug use, and acute contextual risk. Psychedelics illustrate the distinction between adult potential and developmentally informed caution. Interaction-related risks show why substance safety cannot be assessed by substance identity alone.

The analysis focuses on adolescents and emerging adults because this period includes continuing maturation of systems involved in autonomy, inhibition, reward evaluation, emotional regulation, learning, bodily awareness, sleep regulation, and risk assessment. Maturity varies between individuals and cannot be reduced to a single birthday.

The paper distinguishes medical use from casual normalization. Medication can be necessary, protective, and life-saving. Untreated pain, depression, attention-deficit/hyperactivity disorder (ADHD), anxiety, trauma, sleep disturbance, or psychiatric impairment can itself harm development. The relevant comparison is not medication versus no medication, but proportionate, diagnosis-based, monitored treatment versus poorly explained or casual pharmacological use.

The contribution is threefold. First, the paper reframes substance risk around developmental stage rather than legal status. Second, it integrates socially tolerated, commercially normalized, medicalized, recreational, over-the-counter, psychedelic, and interaction-related risks within one developmental public health model. Third, it distinguishes developmental risk literacy in young people from informed autonomy in mature adults.

3. Brain Maturation and Developmental Vulnerability

Legal systems require age thresholds, but these thresholds are not precise biological markers of brain maturity. Important aspects of brain maturation, especially in prefrontal and executive-control networks, continue into young adulthood and are commonly described as extending into the mid-to-late twenties [1–4]. For the purposes of this model, adolescence refers primarily to the period before legal adulthood, emerging adulthood refers operationally to approximately 18–25 years, and mature adulthood refers operationally to approximately 26 years and older. This does not imply that neurodevelopment is identical across individuals or completed at a single biological threshold; rather, it provides a practical developmental structure for distinguishing education, harm reduction, and autonomy across life stages.

Prefrontal and executive-control networks support planning, self-regulation, impulse control, emotional modulation, risk evaluation, and long-term decision-making. Sleep regulation is also developmentally important because sleep supports learning, memory consolidation, emotional regulation, metabolic regulation, and behavioral control. This matters because many substances act on systems that are still maturing. Substances affecting reward, inhibition, arousal, stress, sleep, memory, emotional learning, pain perception, perception itself, and bodily awareness may interact with ongoing development.

This does not mean that every exposure causes permanent damage. It means that developmental timing, frequency, dose, potency, route of administration, setting, interaction risk, and individual vulnerability are central variables for education and policy.

The model therefore treats developmental stage as a graded variable. For minors, substance education should be especially clear, developmentally specific, and oriented toward avoiding uninformed or unnecessary exposure. Emerging adults require a hybrid approach: legal autonomy should be respected, while risk communication, access conditions, setting-based regulation, and harm-reduction services should recognize that relevant neurodevelopmental and psychosocial capacities are still consolidating. Mature adults should receive greater weight for informed autonomy, while still receiving honest information about dependence, toxicity, interactions, psychological risks, sleep effects, and long-term harm.

4. Substance Effects and Developmental Systems

Alcohol affects intoxication, memory, learning, reward processing, executive control, emotional regulation, and risk behavior. In adolescents and emerging adults, these effects intersect with heightened reward sensitivity, social motivation, and still-developing inhibitory control [7,8]. In adults, alcohol remains biologically harmful despite cultural familiarity, with risks including dependence, liver disease, cancer, injury, violence, and social harm.

Nicotine and vaping products act on reward pathways and systems involved in attention, learning, mood, and impulse control. Youth exposure is concerning because nicotine can reinforce dependence during a period of heightened neurobiological sensitivity [9,10]. Vaping may reduce perceived risk through flavoring, technology, and social normalization.

Highly caffeinated beverages and energy drinks should also be included in developmental substance education. Although caffeine is socially normalized and legally available, it is a pharmacologically active stimulant that affects arousal, sleep, anxiety, cardiovascular activation, and reward-related consumption habits. Energy drinks are especially relevant because caffeine may be combined with sugar, taurine, guarana, branding, performance framing, gaming culture, sports imagery, and youth-oriented consumption contexts. Pediatric guidance has cautioned that stimulant-containing energy drinks are inappropriate for children and adolescents [11]. Caffeine safety assessments also emphasize dose, body weight, habitual intake, and interaction conditions, including physical exercise and other energy drink constituents [12]. In adolescents, energy drink consumption is particularly relevant because caffeine can disrupt sleep patterns, and sleep loss can impair learning, emotion regulation, impulse control, and stress tolerance [13].



Cannabis requires differentiated education. Early, frequent, daily, or high-potency use during adolescence is more concerning than occasional adult use. Relevant domains include attention, learning, memory, motivation, executive function, and psychiatric vulnerability [14,15]. For emerging adults, the issue is not only legality, but potency, frequency, age of initiation, driving, educational or occupational functioning, and psychiatric vulnerability.

Opioids are medically essential in severe pain, trauma, surgery, cancer care, and palliative contexts, but they can engage reward, tolerance, dependence, withdrawal, sedation, and respiratory-risk mechanisms [16]. The issue is not pain relief itself, but normalization without clear indication, duration awareness, monitoring, and education.

Benzodiazepines can reduce acute anxiety, panic, agitation, and insomnia, but they also carry risks of sedation, memory impairment, tolerance, dependence, withdrawal, and emotional avoidance. Repeated use may replace the development of distress tolerance with pharmacological suppression [17,18].

Prescription stimulants used for attention-deficit/hyperactivity disorder can be clinically valuable when diagnosis and impairment are clear. Amphetamine-based medications and methylphenidate both modulate catecholaminergic signaling, but they do so through different pharmacological mechanisms. Amphetamine-based medications act partly as monoamine-releasing agents and transporter modulators, whereas methylphenidate acts primarily as a dopamine and norepinephrine reuptake inhibitor through blockade of dopamine and norepinephrine transporters. Despite these distinct kinetic profiles, both medication classes influence dopaminergic and noradrenergic pathways involved in attention, motivation, arousal, and executive control during development [19]. These medicines should therefore not become ordinary responses to academic pressure, sleep deprivation, classroom inconvenience, or non-specific developmental difficulties, and clinical guidance should address misuse, diversion, nonmedical use, and unapproved routes [20].

Antidepressants can be necessary in moderate to severe depression, anxiety disorders, obsessive-compulsive disorder, severe functional impairment, and high-risk psychiatric conditions. For some young people, antidepressant treatment may be developmentally protective. Their use nevertheless requires monitoring for activation, worsening mood, suicidality, side effects, and discontinuation symptoms, especially during initiation and dose changes [21].

Over-the-counter analgesics are relevant less because of direct neurotoxicity than because of health literacy, bodily awareness, dosing competence, and self-medication habits. Paracetamol, ibuprofen, and aspirin are useful medical tools, but availability can create false harmlessness. Education should include dose limits, liver risk, gastrointestinal risk, kidney risk, drug interactions, and the difference between appropriate pain relief and habitual suppression of minor discomfort [22,23].

Party drugs such as methylenedioxymethamphetamine, amphetamines, cocaine, ketamine, synthetic cathinones, and related substances involve pharmacological and contextual risks. Sleep deprivation, overheating, dehydration, uncertain purity, unknown dosage, polydrug use, peer pressure, consent-related and sexual safety risks, impulsive behavior, and limited access to help can amplify harm [24].

Classic psychedelics require a distinct analysis. In this paper, “classic psychedelics” refers to serotonergic psychedelics such as psilocybin, lysergic acid diethylamide (LSD), N,N-dimethyltryptamine (DMT), and mescaline. Methylenedioxymethamphetamine and ketamine are discussed separately because their pharmacology and risk profiles differ. In carefully screened adults and controlled clinical or supportive settings, classic psychedelics are being investigated for therapeutic potential and are generally regarded as having comparatively low risk of classical physical dependence relative to alcohol, nicotine, opioids, and benzodiazepines [25,26]. Their main risks are psychological, contextual, and vulnerability-dependent. Adult evidence cannot be generalized to adolescents without adolescent-specific developmental, ethical, and safety research [27].

5. False Safety Signals

A central failure in substance education is the confusion between normalization and safety. Alcohol, nicotine, energy drinks, sedatives, stimulants, opioids, and painkillers can become normalized through law, advertising, prescribing, commerce, family culture, medical routine, school culture, sports culture, gaming culture, or habit. Normalization changes perception; it does not remove risk.

Alcohol is associated with celebration, relaxation, adulthood, and social bonding, yet it remains a major source of bodily, psychological, and social harm. Nicotine delivery systems differ in risk, but nicotine dependence remains central. Energy drinks are associated with performance, endurance, productivity, gaming, sport, and alertness, yet they remain pharmacologically active stimulant products whose developmental relevance may operate through sleep disruption, anxiety, cardiovascular activation, dose escalation, and commercial normalization. Prescription and over-the-counter status can create similar safety illusions. A medicine may be useful and necessary, but usefulness does not remove risk.

False safety signals are especially relevant for emerging adults. A substance may become newly accessible at the same time that social reward sensitivity, identity exploration, novelty seeking, performance pressure, sleep restriction, and peer belonging remain developmentally salient. For this group, the question is not whether autonomy exists, but whether autonomy is supported by realistic information, safe environments, and context-sensitive regulation.

Adult education matters as well. Adult autonomy is stronger when adults receive realistic information about dependence, toxicity, interactions, context, sleep effects, and long-term consequences. Autonomy is not strengthened by cultural denial.

6. Medicalized Substances and Therapeutic Legitimacy

Medical substances can be both necessary and risky. Therapeutic legitimacy should not be confused with developmental neutrality.

Attention-deficit/hyperactivity disorder stimulant medication illustrates this balance. In properly diagnosed cases, stimulants may improve attention, reduce impulsivity, support functioning, and reduce distress. The same medication category can also be misused as performance enhancement, diverted to peers, or prescribed too quickly in response to academic pressure. Responsible use requires diagnosis, assessment of sleep, nutrition, trauma, anxiety, family context, school environment, and behavioral

support, followed by monitoring of appetite, sleep, cardiovascular effects, mood, misuse risk, and ongoing necessity [19,20].

Benzodiazepines may be appropriate in acute, severe, or procedural contexts, but repeated use can produce tolerance, dependence, withdrawal, memory impairment, sedation, and avoidance learning [17,18]. In developing individuals, reducing anxiety pharmacologically without supporting emotional learning may weaken coping capacity.

Antidepressants are not intoxicants or addictive sedatives in the same sense as benzodiazepines or opioids, and they may be clinically appropriate. Their developmental use should involve careful diagnosis, informed consent, monitoring for activation or suicidality, assessment of side effects, and psychosocial support where appropriate [21].

Opioids may be ethically necessary for severe pain. Their developmental use should be limited by clear indication, dose awareness, duration control, dependence education, and monitoring [16].

Medical status justifies careful use, not casual normalization.

7. Pain, Analgesics, and Bodily Awareness

Pain treatment is medically and ethically necessary. A humane society should not glorify pain or deny effective analgesia. Yet pain medication in young people requires proportionality and health literacy.

Young people should learn to distinguish severe pain, inflammatory pain, injury-related pain, fatigue, dehydration, poor sleep, emotional distress expressed through the body, and minor discomfort. A culture that immediately pharmacologically silences every small discomfort may weaken bodily awareness and reduce opportunities for self-regulation.

Paracetamol, ibuprofen, aspirin, and related medications are useful, but they have dose limits, organ risks, contraindications, and interaction risks [22,23]. Analgesics are medical tools, not ordinary lifestyle reflexes.

8. Setting, Party Drugs, and Psychological Destabilization

Party-drug risk is often misunderstood because public debate focuses on the substance while ignoring the setting. Festivals, clubs, and parties may combine social pressure, sleep deprivation, intense stimulation, dehydration, overheating, uncertain purity, unknown dosage, polydrug use, consent-related and sexual safety risks, impulsive decision-making, and limited access to help [24].

Consent-related and sexual safety risks include impaired consent, boundary violation, unprotected sex, exploitation, or unsafe intimate situations under intoxication or impaired judgment.

Several substances carry setting-dependent psychological risks that are not captured by toxicity or dependence measures alone. Psychedelics, high-potency cannabis, ketamine, stimulants, and empathogens may produce acute anxiety, panic reactions, derealization, depersonalization, paranoia, confusion, or overwhelming emotional material when used in unstable, crowded, chaotic, overstimulating, or socially unsafe environments. In vulnerable individuals, such experiences may become subjectively traumatic or

may exacerbate pre-existing anxiety, mood instability, psychotic vulnerability, or unresolved psychological conflict.

A party or festival environment is not neutral. It can be a high-risk context for substances that intensify perception, dissolve ordinary self-boundaries, alter time perception, amplify emotional material, or increase suggestibility. For psychologically active substances, setting is safety-relevant because it shapes how the altered state is interpreted, regulated, and integrated.

For emerging adults, party-drug education should not rely on abstinence-only messaging. It should include context-specific risk literacy: hydration without overhydration, sleep recovery, avoiding polydrug combinations, recognizing panic and overheating, protecting consent, seeking help early, and understanding when a setting is unsuitable for psychologically destabilizing substances.

Honest harm-reduction education is necessary even where substances remain illegal. Silence does not protect young people; practical risk knowledge can prevent avoidable harm.

9. Substance Interactions and Information Deficits

Substance risk is rarely determined by one compound in isolation. Many adverse outcomes arise from interactions between substances, prescribed medication, over-the-counter medication, supplements, alcohol, sleep deprivation, dehydration, heat, fasting, physical exertion, and individual vulnerability.

Alcohol combined with opioids or benzodiazepines can increase sedation and respiratory risk. Stimulants combined with alcohol may mask intoxication and increase cardiovascular strain. Methylenedioxymethamphetamine combined with other stimulants may increase risks related to overheating, dehydration, cardiovascular strain, and serotonergic toxicity. Energy drinks and high caffeine intake may intensify anxiety, insomnia, cardiovascular activation, and stimulant burden, especially when combined with sleep deprivation, physical exertion, alcohol, or other stimulants. Psychedelics combined with stimulants, cannabis, ketamine, or certain psychiatric medications may alter psychological intensity, reduce or modify effects, or increase risks in vulnerable individuals depending on the medication and substance involved. Over-the-counter analgesics combined with alcohol, dehydration, fasting, or repeated dosing can increase liver, gastrointestinal, or kidney risk [22–24].

Medication interactions are particularly important. Antidepressants, stimulants, benzodiazepines, opioids, antipsychotics, sleep medications, antihistamines, and painkillers may alter the risk profile of recreational or non-medical substance use. The same applies to some supplements and herbal preparations.

Interaction literacy should therefore be a core part of substance education. Dose, setting, and substance identity are not enough. Safety also depends on what else is in the body, what medications are being taken, and whether the person is sleep-deprived, overstimulated, overheated, dehydrated, fasting, psychologically unstable, or physically strained.

10. Psychedelics: Adult Potential, Developmentally Informed Caution

Psychedelics show why legal categories are insufficient. Classic psychedelics remain prohibited in many jurisdictions, while adult clinical research investigates their therapeutic potential. Their risk profile differs from alcohol, nicotine, opioids, benzodiazepines, and many stimulants [25,26].

In adults, classic psychedelics appear to act primarily through psychological, perceptual, emotional, and neuroplastic mechanisms rather than through classical intoxication-reinforcement patterns. Their risks are strongly context-dependent. Screening, dose, preparation, setting, guide quality, psychological stability, medical contraindications, interaction risk, and integration matter. Panic, confusion, paranoia, overwhelming emotional material, unsafe behavior, psychosis risk in vulnerable individuals, mania risk, and persistent perceptual disturbances must be taken seriously [25–28].

For adolescents and emerging adults, the developmental context changes the evaluation. A substance that may increase psychological flexibility in a mature adult may destabilize an immature or vulnerable developmental system. Identity, emotional regulation, reality testing, autobiographical meaning, social belonging, and long-term self-structure are still forming. This justifies developmentally informed caution, not because psychedelics are equivalent to alcohol, nicotine, opioids, or benzodiazepines, but because they act deeply on consciousness, meaning, emotion, and plasticity.

For psychedelics, setting is a central safety condition. A party setting may increase risk because sensory overload, social unpredictability, sleep deprivation, intoxicated bystanders, lack of privacy, and absence of trusted support can intensify fear, confusion, panic, or destabilization. Adult clinical findings should not be generalized to adolescents without adolescent-specific safety data [27]. The limited adolescent evidence base should not be interpreted as evidence of safety; it indicates a need for caution, better research, and age-specific education.

This context-sensitive interpretation is also consistent with recent substance-specific models of psychedelic preparation and post-acute integration, which emphasize that psychedelic risk and benefit cannot be assessed through substance identity alone. Substance profile, psychological readiness, setting, interaction risk, memory, interpretation, aftercare, and integration all shape whether an altered state becomes clinically useful, neutral, or destabilizing [29,30].

11. Emerging Adults: Between Developmental Risk and Legal Autonomy

Emerging adults occupy the most difficult policy position in this model. They are often legally autonomous, but many developmental systems relevant to impulse control, risk evaluation, emotional regulation, social belonging, sleep regulation, performance pressure, and long-term planning are still consolidating. Treating this group as biologically identical to mature adults is inaccurate; treating them as minors is legally and ethically inappropriate.

A coherent model should therefore use a hybrid approach. For emerging adults, public policy should combine legal autonomy with enhanced risk literacy, harm-reduction access, context-specific safeguards, and higher thresholds for substances with strong dependence potential or high contextual risk. Such thresholds should not be understood as fixed biological claims. They are pragmatic tools that may vary across substances, jurisdictions, clinical contexts, and public health conditions.

This hybrid approach is especially relevant for cannabis, psychedelics, party drugs, high-caffeine stimulant products, and high-risk medical or recreational combinations. The regulatory goal is not indefinite paternalism, but a staged transition from developmental risk literacy toward mature autonomy. Emerging adults should not be treated as incapable; they should be treated as legally autonomous persons who require unusually clear information, safe contexts, and access to harm-reduction infrastructure.

12. Neurodevelopmental Integrity Model

The concept of neurodevelopmental integrity follows from the preceding analysis. Important brain and behavioral systems continue maturing into young adulthood; many substances affect those systems; common legal, medical, commercial, and cultural categories do not consistently track developmental risk; and interaction-related harms often arise when people lack adequate substance education.

Neurodevelopmental integrity refers to the developing capacities that support future autonomy: attention, learning, memory, emotional regulation, impulse control, reward evaluation, stress tolerance, sleep regulation, bodily awareness, pain interpretation, social judgment, and long-term decision-making. These capacities are not selected as abstract moral preferences, but because they are repeatedly implicated in developmental neuroscience, adolescent health, education, self-regulation, risk behavior, and later functional autonomy.

The model evaluates substance risk through multiple variables: developmental stage, substance mechanism, dose, potency, frequency, route of administration, medical necessity, dependence liability, acute toxicity, psychological vulnerability, setting, sensory load, sleep, stress, trauma, polydrug exposure, medication and supplement interactions, commercial normalization, marketing exposure, monitoring, health literacy, preparation, and integration.

Table 1. Neurodevelopmental Substance Risk Matrix: Substance Categories, Developmental Concerns, and Educational Implications

Substance category	Examples	Primary developmental or educational concern	Educational and policy implication
Socially tolerated legal substances	Alcohol, nicotine, vapes	Reward, dependence, learning, impulse control, bodily harm	Do not normalize as harmless; support informed delay of avoidable exposure; improve honest risk education
Highly caffeinated beverages	Energy drinks, caffeine shots, high-caffeine coffee drinks, stimulant powders	Sleep disruption, anxiety, arousal dysregulation, cardiovascular activation, dose escalation, normalization of	Include caffeine and sleep literacy in substance education; discourage energy drinks in children and adolescents; address dose limits, marketing, sports and gaming contexts, and emerging-adult overuse

Substance category	Examples	Primary developmental or educational concern	Educational and policy implication
		pharmacological self-stimulation	
Cannabis	High-potency products, daily or early use	Attention, memory, executive function, psychiatric vulnerability, impaired driving	Differentiate adolescent use, emerging-adult use, and mature adult use; use potency limits, driving education, context-specific regulation, and developmentally staged access safeguards where legally and contextually appropriate
Medical high-risk substances	Opioids, benzodiazepines	Dependence, withdrawal, sedation, emotional avoidance, respiratory risk	Strict indication, monitoring, shortest appropriate duration
Psychopharmacological developmental substances	Attention-deficit/hyperactivity disorder stimulants, antidepressants	Benefit-risk balance during development	Diagnosis-based use, monitoring, psychosocial support
Over-the-counter analgesics	Paracetamol, ibuprofen, aspirin	False harmlessness, dose errors, organ risks, bodily awareness, self-medication habits	Health literacy and proportional use
Party drugs	Methylenedioxymethamphetamine, amphetamines, cocaine, ketamine, synthetic drugs	Polydrug use, sleep deprivation, overheating, panic risk, impulse risk, consent-related and sexual safety risks	Harm-reduction education, emergency-response literacy, safer-setting design, and age-staged safeguards for emerging adults where legally and contextually appropriate
Classic psychedelics	Psilocybin, lysergic acid diethylamide, N,N-dimethyltryptamine, mescaline	Adult therapeutic potential but adolescent developmental uncertainty; setting-	Developmentally informed caution; for emerging adults, emphasize age-sensitive thresholds, screening, preparation, safe setting,

Substance category	Examples	Primary developmental or educational concern	Educational and policy implication
		dependent psychological risk	support, and integration before exposure
Substance interactions	Alcohol with opioids or benzodiazepines; stimulants with alcohol; energy drinks with alcohol, sleep deprivation, or other stimulants; methylenedioxymethamphetamine with stimulants; psychedelics with psychiatric medication; analgesics with alcohol or dehydration	Interaction-related toxicity, respiratory risk, cardiovascular strain, stimulant burden, serotonergic toxicity, panic, confusion, organ stress	Make interaction literacy a core component of substance education

13. Adult Autonomy and Education Before Punishment

A coherent approach distinguishes developmental risk literacy from adult autonomy. During adolescence and emerging adulthood, education should emphasize developmental vulnerability, interaction literacy, setting awareness, and informed delay of avoidable exposure. In mature adults, informed autonomy and harm reduction should receive greater weight.

This distinction avoids two errors. The first is permissive normalization: assuming that legal, prescribed, commercialized, or culturally accepted substances are developmentally safe. The second is moral prohibition: assuming that all illegal substances are equally dangerous in all contexts and for all adults.

Adult autonomy does not mean risk denial; it requires risk literacy. Adults should receive accurate comparative risk information. Alcohol and nicotine may produce greater population-level bodily harm and dependence than some substances that remain illegal, while psychedelics may carry lower risk of classical physical dependence but higher psychological and contextual sensitivity [5,6]. Energy drinks may be legally available and socially ordinary while still carrying dose-dependent risks through sleep disruption, anxiety, cardiovascular activation, and stimulant interactions. Opioids may be medically necessary but high-risk. Benzodiazepines may be useful acutely but problematic chronically.

Autonomy also has a cognitive dimension. Neuroethical accounts of cognitive liberty emphasize that self-regarding decisions concerning consciousness, cognition, and mental agency raise questions that cannot be reduced to criminal classification alone [31]. A developmental model therefore requires two principles

at once: greater developmental caution before maturity, and stronger respect for informed adult autonomy after maturity.

Education should come before punishment. Regulation, medical oversight, access control, advertising restrictions, age limits, labeling requirements, and harm-reduction services may all have legitimate roles. But legal classification without accurate education is insufficient.

14. Education Recommendations

Substance education should explain brain development concretely, but it should not be reduced to informational lectures. The failure of purely didactic drug-prevention models shows that knowledge alone rarely changes behavior when social belonging, stress, novelty seeking, peer pressure, trauma, or emotional dysregulation drive substance use [32]. Neurodevelopmental literacy must therefore be combined with behavioral, social, and emotional skill-building.

Effective substance education should include coping strategies, refusal skills, emotional regulation, stress management, help-seeking behavior, social pressure recognition, consent literacy, and practical decision-making in real settings [33,34]. A young person who understands the pharmacology of alcohol may still drink under peer pressure; a person who understands benzodiazepine dependence may still seek pharmacological relief if no coping skills are available. Education must therefore teach not only what substances do, but what alternative actions are available when stress, fear, shame, loneliness, pain, tiredness, or social pressure appear.

Alcohol, nicotine, and vaping should not be treated as biologically neutral because they are legal or culturally tolerated. Adult education should also address socially tolerated substances more honestly.

Energy drink education should become part of substance and health literacy. Adolescents and emerging adults should learn how caffeine dose, body weight, timing, sleep restriction, sugar content, stimulant combinations, physical exertion, anxiety, and marketing affect risk. Caffeine literacy should not be framed as moral panic, but as practical self-regulation: protecting sleep, avoiding stimulant escalation, recognizing anxiety and palpitations, avoiding energy drinks with alcohol or other stimulants, and distinguishing genuine rest needs from commercialized performance pressure.

Cannabis education should distinguish adult use from early, frequent, daily, or high-potency adolescent use. For emerging adults, education should also address potency, driving, anxiety, motivation, occupational functioning, and psychiatric vulnerability.

Attention-deficit/hyperactivity disorder medication should not be used as casual performance enhancement or as a substitute for sleep, nutrition, behavioral support, educational adaptation, trauma assessment, and psychological care. When clinically justified, it should be monitored.

Benzodiazepines should not be normalized as routine anxiety management. Education should include non-pharmacological coping skills, distress tolerance, sleep hygiene, and psychological support. Antidepressants should remain available when clinically indicated, with monitoring, informed consent, psychosocial support, and attention to activation, suicidality, side effects, and discontinuation symptoms.



Opioids should be used with clear indication, dose control, duration awareness, monitoring, and education about dependence and respiratory risks.

Over-the-counter painkillers should be included in health-literacy education, including dose limits, interaction risks, organ risks, and the distinction between appropriate pain relief and habitual discomfort suppression.

Party-drug education should include polydrug use, overheating, hydration, sleep deprivation, adulteration, dosage uncertainty, consent-related and sexual safety risks, panic reactions, emergency response, and realistic strategies for leaving unsafe settings.

Psychedelic education should distinguish adolescents, emerging adults, and mature adults. Use during adolescence and emerging adulthood requires developmentally informed caution because of uncertainty, psychological sensitivity, and setting-dependent risks. Adult use should be evaluated through screening, safe setting, preparation, supervision, integration, interaction literacy, and comparative risk.

Interaction literacy should become a core component of substance education. People should understand that substances can change risk profile when combined with medication, alcohol, supplements, caffeine, sleep deprivation, dehydration, heat, fasting, physical exertion, or psychological instability.

15. Limitations

Several limitations define the scope of this model. First, neurodevelopmental maturity cannot be reduced to a single biological threshold. Brain development varies between individuals, and legal systems require workable age categories even when biological maturation is gradual.

Second, the strength of evidence differs across substance categories. Alcohol, nicotine, cannabis, opioids, benzodiazepines, and prescription stimulants have substantial literature relevant to adolescent development and dependence risk. Psychedelic use in adolescents has a more limited evidence base; developmentally informed caution is therefore supported by uncertainty, psychological sensitivity, and the known importance of context. Evidence on energy drinks is stronger for sleep, cardiovascular activation, anxiety-like symptoms, and consumption patterns than for direct long-term neurodevelopmental outcomes; their relevance in this model therefore lies primarily in stimulation, sleep disruption, dose escalation, interaction risk, and commercial normalization rather than in claims of direct neurotoxicity.

Third, the purpose of the paper is conceptual and educational rather than quantitative. The model is intended to show why legal status, prescription status, over-the-counter availability, commercial normalization, and social tolerance are insufficient indicators of developmental safety. It should therefore be read as a structure for risk literacy, education, and policy analysis rather than as a numerical ranking of substances.

Fourth, appropriate medical treatment remains compatible with the model when it is evidence-based, monitored, proportionate, and clinically justified. In some cases, medication protects development more than non-treatment. The proper comparison is evidence-based, monitored treatment versus casual, poorly explained, or insufficiently supervised pharmacological normalization.

Finally, cultural, socioeconomic, familial, trauma-related, mental-health, structural, and commercial factors may strongly influence vulnerability. Substance exposure is not shaped only by individual knowledge or neurobiology, but also by poverty, educational opportunity, housing conditions, neighborhood environments, peer networks, healthcare access, advertising, product design, pricing, availability, platform marketing, and industry strategies that normalize or intensify consumption [35,36]. A neurodevelopmental model should therefore not be interpreted as an individual-responsibility model. It should be combined with public health equity, regulation of commercial risk environments, behavioral skill-building, and context-sensitive prevention.

16. Conclusion

Substance education should not be organized only around whether a substance is legal, illegal, prescribed, commercialized, tolerated, or freely available. These categories may be administratively useful, but they cannot substitute for developmental, contextual, and interaction-based risk assessment.

For adolescents and emerging adults, the central task is to build neurodevelopmental awareness and behavioral risk competence: accurate knowledge about how substances interact with a brain and body that are still maturing, combined with the emotional and social skills needed to act on that knowledge. This includes socially normalized and commercially marketed products such as alcohol, nicotine, high-caffeine beverages, and over-the-counter medicines, not only illegal or stigmatized substances.

Psychedelics illustrate the need for mature differentiation. They may require developmentally informed caution in adolescents because of uncertainty and psychological sensitivity, while showing therapeutic promise for carefully screened adults in safe and integrative settings. Energy drinks illustrate the same principle from the opposite direction: a substance category may be legal, familiar, and commercially ordinary while still being developmentally relevant through sleep disruption, stimulation, and interaction risk.

For mature adults, the balance shifts toward informed autonomy, harm reduction, accurate risk comparison, and context-sensitive regulation. A mature substance culture does not normalize familiar risks or demonize unfamiliar ones. It teaches how pharmacological effects change across age, context, vulnerability, purpose, setting, commercial environment, and interaction.

17. Conflict of Interest

The author declares no conflict of interest.

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