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ORIGINAL RESEARCH/SCHOLARSHIP

Acceptability of Neuroscientific Interventions in Education

A. Schmied[1] · S. Varma[2] · J. M. Dubinsky[3]

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Abstract
Researchers are increasingly applying neuroscience technologies that probe or manipulate the brain to improve educational outcomes. However, their use remains fraught with ethical controversies. Here, we investigate the acceptability of neuroscience applications to educational practice in two groups of young adults: those studying bioscience who will be driving future basic neuroscience research and technology transfer, and those studying education who will be choosing among neuroscience-derived applications for their students. Respondents rated the acceptability of six scenarios describing neuroscience applications to education spanning multiple methodologies, from neuroimaging to neuroactive drugs to brain stimulation. They did so from two perspectives (student, teacher) and for three recipient populations (low-achieving, high-achieving students, students with learning disabilities). Overall, the biosciences students were more favorable to all neuroscience applications than the education students. Scenarios that measured brain activity (i.e., EEG or fMRI) to assess or predict intellectual abilities were deemed more acceptable than manipulations of mental activity by drug use or stimulation techniques, which may violate body integrity. Enhancement up to the norm for low-achieving students and especially students with learning disabilities was more favorably viewed than enhancement beyond the norm for high-achieving students. Finally, respondents rated neuroscientific applications to be less acceptable when adopting the perspective of a teacher than that of a student. Future studies should go beyond the acceptability ratings collected here to delineate the role that concepts of access, equity, authenticity, agency and personal choice play in guiding respondents' reasoning.

Keywords Neuroethics · Cognitive enhancement · tCDS · Neuroeducation · Educational neuroscience

✉ J. M. Dubinsky
Dubin001@umn.edu

[1] Department of Educational Psychology, University of Minnesota, Minneapolis, MN, USA

[2] School of Interactive Computing, College of Computing & School of Psychology, College of Sciences, Georgia Institute of Technology, Atlanta, GA, USA

[3] Department of Neuroscience, University of Minnesota, 6-145 Jackson Hall, 321 Church St SE, Minneapolis, MN 55455, USA

Introduction

An essential set of neuroethical questions has been identified by the 2018 Global Neuroethics Summit for national brain research initiatives to address while unraveling the inner workings of the brain (Rommelfanger et al., 2018). Their last question focuses upon recognizing the cultural contexts in which novel neurotechnologies or innovations may be deployed, raising issues of proper vs improper use, equity of access, and considerations for all stakeholders (Rommelfanger et al., 2018). While this body was envisioning medical applications, education provides a potential setting in which neuroscience-derived technologies or innovations could also be productively and readily applied. A further ethical issue is that of using brain research as a justification for applying a proposed intervention in a classroom (Zocchi & Pollack, 2013). The dangers here include validity (i.e., the original research was exploratory and not definitive), generalizability (i.e., the original research was laboratory- and not classroom-based, limited by sample population characteristics, and applicable to groups, not individuals) and pragmatics (i.e., the proposed intervention has been overly popularized) (Zocchi & Pollack, 2013). Such limitations may not be appreciated or deeply understood by administrators, teachers, parents or students. Thus national and international policies have encouraged neuroscience application to education with caution, in an evidence-based manner (Ansari et al., 2017; Royal Society, 2011).

Practically, neuroscientific methodologies may become integrated into classrooms for either research or evaluative purposes, with the goal of attempting to optimize students' educational experiences. As the demand for evidence-based interventions increases, researchers are applying medical technologies that probe or manipulate the brain (drugs, EEG, fMRI, tDCS, etc.) to human behaviors related to education. Utilization of physiological measures during classroom activity furthers the neuroscience research agenda (Dikker et al., 2017) but may not provide readily usable feedback for students or teachers. While the applicability of such research interventions may be limited in real world classrooms, the shift from research to common application can be swift when driven by commercial interests which act as vectors for disseminating educational innovations. Indeed, the fast pace of neuroscience research, discovery and innovation has been likened to a 'speedway' (Giordano, 2017). The rush to apply and market neuroscience ideas and techniques to educators has resulted in creation of neuromyths (Geake, 2013; Im et al., 2018). Therefore, determining the ethical acceptability of proposed neuroscience applications by educational stakeholders becomes paramount for initiating discussions around their use.

While the benefits of incorporating neuroscience concepts into teacher education and pedagogical practice are apparent (Coch, 2018), how individual measurements and interventions derived from neuroscience might directly be used in a classroom setting remains fraught with ethical controversies. A common theme among neuroscience educational applications is the idea of increasing student learning, outcomes, or performance—in other words, enhancement. Addressing the attentional control problems of students with ADHD by neuroactive drugs such as methylphenidate remains an established practice. By improving impulse control, students focus better and achieve according to their own potential (Rajala et al., 2012; Sprague & Sleator, 1977). However, students without ADHD also use these drugs to enhance their performance, raising issues of authenticity, personhood, fairness in testing, and equal access to the drugs (de Jongh et al., 2008). Novel approaches like transcranial direct current stimulation (tDCS) also promise cognitive enhancement with do-it-yourself technology (Landhuis, 2017). Such devices raise ethical issues around safety and efficacy.

Other advances with potential to predict and measure learning are under investigation for transfer to education. Assessment of individual learning or learning capacity becomes a corollary to the theme of enhancement. Techniques such as EEG or fMRI have been proposed for assessment or diagnosis of impairments in cognitive skills (Allen & Fong, 2008; Volkmer & Schulte-Korne, 2018); (Cetron et al., 2019; Seghier et al., 2019). They can be used to predict dyslexia in infants (Langer et al., 2017; Volkmer & Schulte-Korne, 2018) and developmental dyscalculia in children (Peters & De Smedt, 2018; Butterworth et al., 2011). These predictive technologies bring the advantage of being able to tailor instructional strategies to individual needs but also raise the possibility that stigmatization may result from diagnosing learning disabilities (Ball & Wolbring, 2014; Illes & Raffin, 2005). Additionally, pharmaceuticals and imaging technologies raise ethical questions concerning consent, privacy and incidental findings (Lalancette & Campbell, 2012; Maxwell & Racine, 2016).

More invasive, futuristic applications of neuroscientific devices involve use of surgically implanted neuroprostheses for cognitive enhancement. Memory enhancement has been demonstrated with both hippocampal and non-hippocampal depth electrode placements (Deadwyler et al., 2017; Hampson et al., 2018; Widge et al., 2019) like those currently used for treatment of Parkinson's Disease, dystonia and other psychiatric or neurological illnesses (Suthana et al., 2018). To date, improvement in specific aspects of memory have been reported, but so have failures to enhance, indicative of the early stages of such research and imprecisions in understanding of the multiple networks contributing to memory encoding and retrieval (Clausen et al., 2017; Jacobs et al., 2016; Suthana & Fried, 2014; Suthana et al., 2018). In addition, implanted electronic circuitry mimicking hippocampal function can improve visual identification memory in epileptic patients, opening the door for both correcting memory loss and enhancing memory function through brain-machine interfaces (Hampson et al., 2018). While the hope is that precision electrode placement will provide better results than pharmacological global enhancement, the ethical issues of safety, tolerability, longevity, off-target effects, security and privacy conflate the issue of enhancement alone (Clausen et al., 2017; Ragan et al., 2013). With respect to education, these devices could be used to induce learning in students' brain, boosting the cerebral functions beyond the natural capacities.

Research Questions

As a first step, we investigate here the acceptability of applying such methodologies, measurements, and treatments arising from the field of neuroscience to educational practice. Whether considering individual diagnoses, educational interventions, or assessments of learning, the ultimate goal is to improve student experiences and achievement. Determining attitudes towards the ethics of such applications now will guide their future development, implementation, and uptake. To determine the readiness of the next generation to deal with these transitions, we surveyed young adults with differing but relevant backgrounds: those studying bioscience, who will be driving the basic neuroscience research and technology transfer, and those studying education, who will be selecting among various available neuroscience-based assessments and interventions, and administering these to students. These study populations will be faced with making such decisions as they enter the workforce or choose to start families in the first half of the 21st century.

The current study evaluated four research questions:

1. Do students in the biosciences and in education differ in their judgments of the acceptability of applying neuroscience findings to improve student learning?
2. Do the two groups differ in their judgments based on the scenario—whether the application is non-invasive, pharmacological, or involves physical hardware?
3. Do the two groups differ in their judgments based on the perspective they adopt—that of a student receiving the application or a teacher approving it?
4. Do the two groups differ in their judgments based on the recipient population—high-achieving students, low-achieving student, or students with learning disabilities?

Public approval of what constitutes a benefit from cognitive enhancement, and by extension more invasive technologies, may be context-dependent (Shook et al., 2014). Opinions were gathered on six different scenarios addressing interventions or assessments derived from neuroscience as applied to education. These scenarios cross a number of dimensions, from already in use to highly experimental, from diagnostic to invasive. They also span multiple methodologies, from neuroimaging to neuroactive drugs to brain stimulation. Realizing that acceptability of proposed applications may vary depending upon the school population involved, the survey specifically included applicability to students performing at different levels. To uncover how participants' opinions might change as they transition from student into working adult, the survey asked them to take the perspective of distinct actors in educational settings: themselves as a student or that of a teacher. Thus respondents were asked to project how they expected each of these actors to rate the acceptability of the proposed scenarios for each of the school populations.

Methods

Participants

The questionnaire and methodology for this study was approved by the University of Minnesota Institutional Review Board (protocol 1503P66601). All participants gave their informed consent prior to taking the survey.

The participants were students in two undergraduate courses at a large public university in the American Midwest. The original sample of 183 students completed an online survey. A Survey Response Time analysis determined the subset of data for further analysis; those who completed the survey in less than 8 min were excluded from future consideration. The final sample consisted of 166 participants. Biosciences students (82) were enrolled in a capstone course for undergraduate Neuroscience majors and minors.[1] Many were also majoring or minoring in other biological sciences or in psychology. Education students (84) were enrolled in the core educational psychology course for trainee teachers.[2] Many were majoring in elementary education.[3] Demographic data about both groups are presented in the Results section.

Design

The study adopted a factorial design with four factors that were varied orthogonally. Respondent Group (biosciences, education) was a between-subjects factor, whereas Scenario (non-invasive, pharmacological, physical hardware), Perspective (student, teacher), and recipient Population (high ability students/HAS, low ability students/LAS, students with learning disabilities/SLD) were within-subjects factors. The dependent variable was acceptability rating. The within-subjects factors and the dependent variable were embedded in the structure of the materials, as described next.

Instrument

The materials consisted of a new instrument (see the supplementary materials) conceptually divided into two parts. The first part consisted of background questions. The second part contained the six scenarios that participants read about neuroscience applications to improve educational outcomes, and the six items they rated for each scenario.

[1] The Biosciences students completed the survey as a course assignment. Their data was then summarized and used as the basis for a class discussion led by the research team.

[2] The Education students completed the survey for extra credit on their next exam.

[3] Note that few if any of the Education students were training to be science or mathematics teachers. Those students take the educational psychology course during the summer session, whereas the current participants were recruited during the academic year.

Background questions

The background questions concerned demographics (i.e., age and gender), prior coursework taken (i.e., neuroscience, other natural sciences, psychology), educational attainment, parent status, and prior experience with neuroscience applications for improving learning.

Scenarios

Participants read six scenarios about the application of neuroscience findings to improve educational outcomes – two that were non-invasive, two that were pharmacological, and two that involved physical hardware (Table 1).

The following applications were selected from a broader set of applications that are widely discussed in the educational neuroscience literature.

- *EEG* (electroencephalography) is a spatially coarse measure of filtered electrical activity from the underlying brain, aggregated over many independent neural events, that is recorded with fine temporal precision. Aberrant EEG responses to auditory word stimuli in infants predict later reading disabilities upon entering school (Molfese, 2000). In educational settings, students could wear EEG caps to provide real-time information about their attention during learning from instruction (Gamez, 2018; Kuo et al., 2017).
- *fMRI* (functional magnetic resonance imaging) measures local blood flow as a proxy for neural activity. Its combination of moderate spatial resolution and moderate temporal resolution makes it an effective tool for investigating mathematical thinking and scientific reasoning (Mason & Just, 2015; Butterworth et al., 2011) and also language understanding (Richards et al., 2017, 2018). In educational settings, fMRI could potentially be used to identify which students might struggle with new content and why, and to evaluate the effects of new instruction for resolving these struggles (Varma et al., 2008).
- *Adderall* is a mixed amphetamine salt currently prescribed as a first-line pharmacotherapy for impulsivity reduction in ADHD (de Jongh et al., 2008). Cognitive enhancement may result from increased attention at low doses but this may be lost when doses increase to the point of controlling excessive motor behavior in affected individuals (Rajala et al., 2012; Sprague & Sleator, 1977). The perception that Adderall generally enhances cognition has resulted in a black market on college campuses (Benson et al., 2015; Colaneri et al., 2018; Smith & Farah, 2011). Teachers' inputs are important components of recognizing effective ADHD treatments (MTA Cooperative Group, 1999).
- *Oxytocin*, a brain peptide, has been found to play multiple roles in regulating human prosocial behaviors (Dolen, 2015). As a result, it becomes a possible target for interventions with people with emotional and social impairments (Parker et al., 2017). Oxytocin is available as a nasal spray. In educational settings, oxytocin can *potentially* be used to minimize students' misbehavior and to facilitate peer interaction and group work (Hyman, 2011).

Table 1 The six scenarios that participants read

Scenario	Level	Summary
EEG	Non-invasive	Measurement of the brain's electrical signals can predict future academic disabilities and can monitor learning during instruction
fMRI	Non-invasive	Indirect measurement of blood flow to different brain areas can be used to predict ability, to diagnose academic disabilities and to assess learning after instruction
Adderall	Pharmacological	Pharmacological stimulation of normal brain chemicals is currently used to decrease impulsivity and improve attention in children with ADHD. These cognitive enhancing effects may extend to others to improve educational outcomes
Oxytocin	Pharmacological	Introducing oxytocin as a nasal or air spray can *potentially* be used to improve cooperation and to facilitate peer interaction and group work
tDCS	Physical hardware	Application of electrical current to the scalp during instruction can *potentially* be used to improve learning and memory
Neuroprosthesis	Physical hardware	Stimulation through embedding electrodes in the brain can *potentially* be used to improve learning and memory during instruction

- *tDCS* (anodal transcranial Direct Current Stimulation) passes a weak electrical current through electrodes placed on the scalp, creating a circuit that may influence the activity of underlying brain regions. tDCS has been shown to improve mathematical performance (Cohen Kadosh et al., 2010) and creative problem solving (Ruggiero et al., 2018), although overall the results are mixed (Axelrod et al., 2015; Westwood & Romani, 2017). tDCS can *potentially* be used in educational settings because it requires inexpensive, portable equipment (Landhuis, 2017). However, such applications are in their infancy and will require regulatory control given their possible adverse effects on children (Cohen Kadosh et al., 2012; Fitz & Reiner, 2015).
- *Neuroprosthesis* refers to surgically implanted depth electrodes for stimulating specific brain regions. Originally developed for clinical applications (e.g., treating Parkinson's), this technique has been recently applied to improving cognitive abilities, albeit with mixed success (Jacobs et al., 2016; Suthana & Fried, 2014). The invasiveness of neuroprosthesis and the safety and ethical issues that surround its use likely limit its educational applicability (Clausen et al., 2017). However, technological breakthroughs are difficult to forecast, and could *potentially* lead to broader deployment (Hampson et al., 2018).

The scenarios were written following the Contrastive Vignette Technique (Burstin et al., 1980). This technique systematically organizes keywords and text structures so that readers can better identify the key informational elements. See Table 2 for the organization used across all scenarios and its instantiation for the EEG scenario.

Six selected-response items immediately followed each scenario. Each asked participants to rate the acceptability of the neuroscience application on a seven-point rating scale ranging from "Unacceptable (1)" to "Acceptable (7)". The items crossed the two levels of Perspectives factor and the three levels of the recipient Populations factor.[4] See Table 3 for the six items for the Adderall scenario. The terms "ethics" and "ethical" were avoided because people do not necessarily know or agree on their definitions (e.g., (Ball & Wolbring, 2014)).

Procedure

The study was implemented electronically using the Qualtrics tool. Participants received an email invitation providing a link to the online survey. The first screen was the consent form. After reading each scenario in turn, they made six acceptability ratings. Finally, the participants answered the background questions. Time-to-completion was recorded.

[4] Note that participants actually rated four Perspectives: student, classmate, teacher, and parent. The classmate and parent data are omitted here; the former added little beyond the student perspective and the latter was too hypothetical because participants were 20 years old on average and very few were parents. See (Schmied 2017) for the complete data set.

Table 2 The Contrastive Vignette Technique as applied in the EEG scenario

Structure	Scenario
Title	Electroencephalography (EEG)
Current use in medicine	EEG has been used to diagnose the cause of seizures in people with epilepsy
Stage of development and technical description	EEG is an approved technique that measures electrical activity coming from the brain using electrodes placed on the scalp
Transition to education and current or potential use	Recent research suggests that EEG might also be useful for predicting the verbal ability of children and adults without epilepsy
Extent of applicability	Thus, in the field of education, EEG could be indirectly applied to improve student learning
Specific example for use in education	For example, EEG might be used to identify infants who are at-risk for future reading difficulties when they enter school, so that they can benefit from early intervention programs
Precaution in translating the finding	However, at the present time, the potential of using EEG to improve educational outcomes is still unclear Additional research is needed to establish whether or not using EEG improves educational outcomes for students who do not have epilepsy
Level of invasiveness and short-term side effects	So far, the most known common side effect of EEG is irritation of the skin where the electrodes are placed
Long-term side effects	However, its potential long-term effects are unknown

Results

Comparison of Biosciences and Education Students

The biosciences and education groups were largely comparable on a number of variables measured by the background questions (Table 4).

With respect to the demographic variables, the bioscience and education students were comparable in age ($t(92.58) = -1.44$, $d = 0.22$, $p = 0.152$).[5] There was an association between group and gender, with the biosciences group having a larger proportion of male students than the education group ($X^2(1) = 14.54$, $p < 0.001$).[6]

With respect to the educational variables, the highest level of educational attainment in the two groups was comparable, with most students having earned high school degrees (i.e., were currently enrolled as undergraduates). A X^2 test to evaluate

5 Fractional degrees of freedom on *t*-tests indicate that the Levene's test for equal variances was not passed, and a correction was applied.

6 The Yates correction for continuity was applied to all 2×2 X^2 tests.

Table 3 The six items for the Adderall scenario

Perspective	Population	Item
Student		How acceptable would it be for you to use Adderall…
	HAS	…if you are performing well in class, but want to be the best?
	LAS	…if you are performing poorly in class, and want to perform better?
	SLD	…if you have been diagnosed with a learning difficulty, and want to perform as well as other students?
Teacher		If you are a teacher, how acceptable would it be for your student to use Adderall…
	HAS	…if your student is performing well in class, but you want him or her to be the best?
	LAS	…if your student is performing poorly in class, and you want him or her to perform better?
	SLD	… if your student has been diagnosed with a learning difficulty, and you want him or her to perform as well as other students?

Table 4 Comparison of the biosciences and education groups on a broad set of variables, *M* (*SD*)

Variable	Biosciences	Education
N	82	84
Age (years)	19.83 (.96)	20.49 (4.06)
Gender	53 F, 29 M	76 F, 8 M
Highest education level attained	72 high school, 10 college, 0 graduate	67 high school, 13 college, 4 graduate
Neuroscience courses	2.74 (.85)	1.31 (.71)
Other natural science courses	4.28 (1.63)	2.32 (.74)
Psychology courses	3.49 (1.75)	3.29 (1.29)
Parental status	1 yes, 81 no	5 yes, 79 no
Prescribed drug to improve learning	35 yes, 47 no	44 yes, 40 no
Prescribed brain stimulation to improve learning	3 yes, 79 no	15 yes, 69 no

the association between group and education level could not be performed because the expected count in two cells was fewer than 5. As expected, the biosciences students had taken more neuroscience courses ($t(157.10) = 11.71$, $d = 1.81$, $p < 0.001$) and more courses in the other natural sciences ($t(112.80) = 9.88$, $d = 1.54$, $p < 0.001$) than the education students. The two groups had comparable coursework in psychology ($t(148.75) = 0.842$, $d = 0.12$, $p = 0.401$).

We also measured several variables relevant to participants' reasoning about the scenarios. The first was parental status. Parents might reason differently about their own children, and thus about all students, then non-parents. However, very few students were parents—too few students, in fact, to evaluate the association between group and parental status using a X^2 test because the expected count in two cells was fewer than 5. The second variable was whether participants had been prescribed a drug (e.g., Adderall) that might improve their educational achievement. A high proportion of participants responded that they had been prescribed such drugs, although there was no association between this variable and group membership ($X^2(1) = 1.20$, $p = 0.273$). The final variable was whether participants had experienced brain stimulation for the purpose of improving educational achievement. A number of participants had, and this was more frequently the case for education students ($X^2(1) = 7.24$, $p = 0.007$).

We note that all observed differences between the two groups on the background questions should be interpreted with caution. This is because all responses were self-reports, and we did not collect independent and corroborating evidence for reasons of practicality and confidentiality. We return to this limitation in the Discussion.

Acceptability Ratings

The research questions were addressed in a four-way repeated measures ANOVA of the acceptability ratings with between-subjects factor Group (biosciences, education) and with within-subjects factors Scenario (non-invasive, pharmacological,

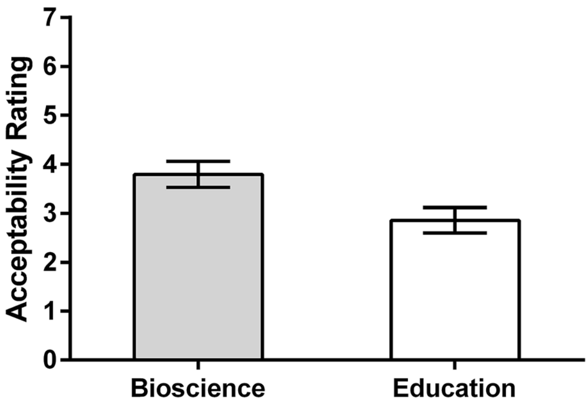

Fig. 1 Acceptability judgments for the two respondent groups. Error bars represent 95% CIs

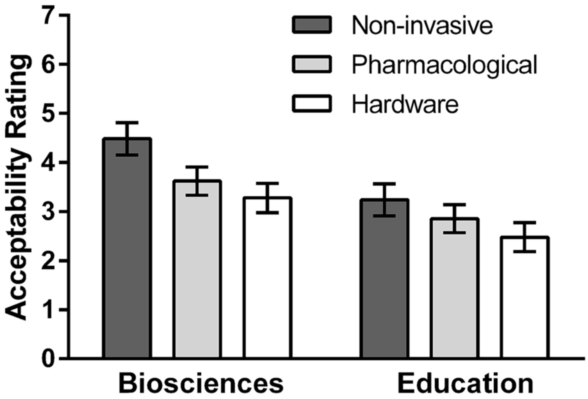

Fig. 2 Acceptability judgments for the different scenarios for the two respondent groups. Error bars represent 95% CIs

hardware), Perspective (student, teacher), and recipient Population (HAS, LAS, SLD). Where the sphericity assumption was violated, the Greenhouse–Geisser correction was applied and the *F* values reported with fractional degrees of freedom.

There was a main effect of Group ($F(1,164)=24.61$, $MSE=72.37$, $p<0.001$, $\eta_p^2=0.13$, Fig. 1). Biosciences students ($M=3.79$, $SE=0.13$) judged neuroscience applications to be more acceptable than education students ($M=2.85$, $SE=0.1$). Thus, with respect to the first research question, the two groups reasoned differently, with biosciences students more accepting of applying neuroscience treatments and interventions to improve student learning.

There was a main effect of Scenario ($F(1.81, 297.94)=55.47$, $MSE=270.41$, $p<0.001$, $\eta_p^2=0.25$, Fig. 2). An embedded contrast found that non-invasive scenarios ($M=3.85$, $SE=0.11$) were judged more acceptable than pharmacological scenarios ($M=3.23$, $SE=0.10$) ($F(1, 164)=40.86$, $MSE=128.57$, $p<0.001$, $\eta_p^2=0.19$), which were judged more acceptable than hardware scenarios ($M=2.87$, $SE=0.10$) ($F(1,164)=20.79$, $MSE=42.84$, $p<0.001$, $\eta_p^2=0.11$). This main effect was qualified by a significant Scenario x Group interaction

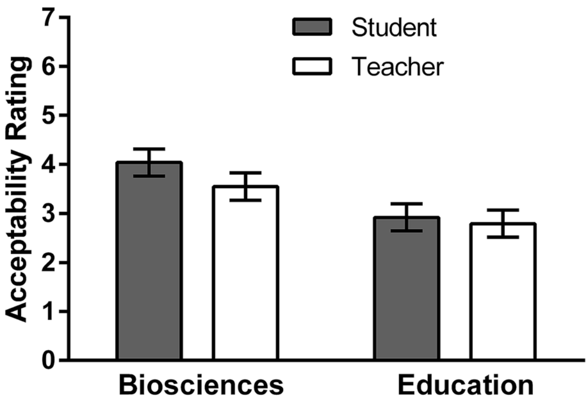

Fig. 3 Acceptability judgments for the different perspectives for the two respondent groups. Error bars represent 95% CIs

($F(2,328) = 4.03$, $MSE = 17.86$, $p = 0.019$, $\eta_p^2 = 0.024$). Biosciences students judged neuroscience applications more acceptable than education students, a difference that was larger for the non-invasive scenarios ($t(164) = 5.31$, $d = 0.82$, $p < 0.001$) than for the pharmacological ($t(164) = 3.71$, $d = 0.57$, $p < 0.001$) and hardware ($t(164) = 3.76$, $d = 0.58$, $p < 0.001$) scenarios. Thus, with respect to the second research question, the two groups reasoned differently based on the scenario, with bioscience students more accepting of non-invasive applications such as using EEG and fMRI to detect impaired cognitive function.

Both groups rated the hardware scenarios as least acceptable. A follow-up analysis evaluated the prediction that tDCS is more acceptable than neuroprosthesis because the former has been widely promoted for improving student learning whereas the latter has been largely limited to clinical applications. This prediction was tested in a two-way ANOVA with between-subjects factor Group and repeated measure Scenario (tDCS, Neuroprosthesis). As predicted, there was a main effect of Scenario ($F(1,164) = 68.23$, $MSE = 57.41$, $p < 0.001$, $\eta_p^2 = 0.29$), with tDCS more acceptable ($M = 03.29$, $SE = 0.12$) than neuroprosthesis ($M = 2.46$, $SE = 0.11$). However, this effect was comparable across groups and not driven, for example, by the biosciences students, as revealed by the non-significant interaction ($F(1,164) = 1.31$, $MSE = 1.11$, $p = 0.253$, $\eta_p^2 = 0.01$).

There was a main effect of Perspective ($F(1,164) = 24.85$, $MSE = 72.60$, $p < 0.001$, $\eta_p^2 = 0.13$). Neuroscience applications were more acceptable when taking the perspective of students ($M = 3.48$, $SE = 0.09$) than that of teachers ($M = 3.16$, $SW = 0.10$). This main effect was qualified by a significant Perspective x Group interaction ($F(1,164) = 8.67$, $MSE = 22.37$, $p = 0.004$, $\eta_p^2 = 0.05$, Fig. 3). The interaction indicates that the main effect of Perspective was driven by the biosciences students: the effect of Perspective was larger for them ($t(81) = 4.45$, $d = 0.49$, $p < 0.001$) than for the education students ($t(83) = 2.176$, $d = 0.24$, $p = 0.032$). Thus, with respect to the third research question, the two groups reasoned differently based on perspective, with the bioscience students more accepting of neuroscience applications when taking the perspective of students.

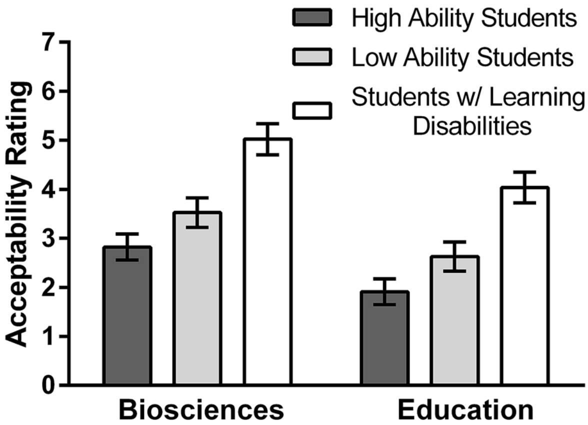

Fig. 4 Acceptability judgments for the different receiving populations for the two respondent groups. Error bars represent 95% CIs

There was a main effect of the recipient Population (F(1.49, 244.37) = 363.81, MSE = 1626.96, p < 0.001, η_p^2 = 0.68). An embedded contrast found that neuroscience applications were judged more acceptable for students with learning disabilities (M = 4.53, SE = 0.11) than for low-achieving students (M = 3.07, SE = 0.10) (F(1,164) = 314.00, MSE = 702.62, p < 0.001, η_p^2 = 0.65), which were judged more acceptable than for high-achieving students (M = 2.36, SE = 0.09; F(1,164) = 153.51, MSE = 166.98, p < 0.001, η_p^2 = 0.48). Note that the Population x Group interaction was *not* significant (F(2,328) = 0.18, MSE = 0.61, p = 0.831, η_p^2 = 0.001; Fig. 4). Thus, with respect to the fourth research question, the two groups reasoned comparably about the acceptability of neuroscience applications for different responding populations.

There was also a Scenario x Population interaction (F(4,656) = 11.78, MSE = 9.16, p < 0.001, η_p^2 = 0.06), and it was qualified by a Scenario x Population x Perspective interaction (F(4,656) = 3.04, MSE = 0.357, p = 0.017, η_p^2 = 0.018). The three-way interaction suggests that participants judged pharmacological interventions for HAS and LAS students to be more unacceptable than for SLD students, and this was particularly true when they adopted a teacher (vs. student) perspective. Although these interactions are sensible, they were not predicted a priori and are small in size. We therefore treat them as exploratory.

Discussion

A major finding was that across all scenarios, the bioscience students favored the use of neuroscience-derived enhancers or measures in education more than the education students. From non-invasive diagnostic techniques to predict use of individualized instruction to pharmacological interventions to brain stimulation, the education students were much more cautious in their acceptability ratings than the bioscience students. Another notable finding is that, consistent with previous determinations regarding who should receive cognitive enhancing treatments (Cabrera et al., 2015a; Wagner et al., 2018), respondents rated enhancements for students with learning disabilities to be more acceptable than those for low performing students; high performing students were the least deserving of intervention or cognitive enhancement. Interestingly, respondents rated neuroscientific applications to be less acceptable when adopting the perspective of a teacher compared with that of a student.

Notably, most participants responded with ratings in the lower half of the rating scale. The only scenario receiving a midrange acceptability rating was the use of non-invasive measurements for SLD when viewed from the students' point of view; this was marginally the case for education respondents and decisive only for biosciences students. The overall low acceptability ratings are in line with previous reports comparing acceptability for cognitive enhancement to or above the norm (Cabrera et al., 2015a, 2015b) but less than the reported acceptability ratings favoring enhancement in work over educational contexts (Dinh et al., 2020). Ambivalence towards the use of pharmacological cognitive enhancers has been noted previously among university students, their parents and health care providers (Cynthia Forlini & Racine, 2012). The current study probed a variety of different forms of cognitive enhancement whereas these prior studies focused solely on pharmacological enhancement. Teachers in England did not agree with the statement that grades achieved with cognitive enhancers should be valued as much as those achieved without (Howard-Jones & Fenton, 2012).

We can only speculate upon the reasons why the overall acceptability ratings were not higher. In one sense, this is an encouragingly cautious sign that authenticity was widely valued by respondents. Information sharing regarding 'study drugs' on social media platforms such as Instagram is often overly positive. Posts contain positive sentiments 4 to 34 times more often than negative evaluations depending upon their category (information vs motivational quotes) (Petersen et al., 2021). Fear of the consequences of the various enhancement strategies presented in the vignettes may be responsible for the low overall acceptability ratings observed here. Youth and young adults report choosing not to use illicit drugs due to fear of their long and short term effects or lack of interest altogether (Fountain et al., 1999). Note that the low ratings do not mean that people would not adopt some of the neuroscience applications considered here. Users of 'study drugs' recognize side effects and possible lack of positive effects yet persist pursuing personal optimization despite expressing uncertainty (Petersen et al., 2019).

An additional reason for respondents to be cautious is the possibility that enhancement of one cognitive domain may come at the expense of performance in another domain (Brem et al., 2014). The neurological tradeoffs or harms associated with cognitive enhancement are becoming more recognized and openly discussed (Davis, 2017). Pharmacologically enhanced chess players improved the quality of their decision making, but at the expense of increasing their deliberation time; the net result was *negative*, with the enhanced players losing more games on the basis of time (Franke et al., 2017). tDCS of one part of cortex enhanced learning a novel numerical task but automaticity was impaired, whereas tDCS of another area produced the opposite effect (Iuculano & Cohen Kadosh, 2013). Similarly, tDCS of same brain area in people with low or high math anxiety increased or decreased reaction times on simple arithmetic tasks, respectively, suggesting individual traits or brain states may influence enhancement outcomes (Sarkar et al., 2014). Fewer parents were willing to use tDCS to enhance a child's long term factual memory if the scenario included the possibility of a slight reduction in working memory (Wagner et al., 2018). Thus the skepticism reflected in the low acceptability ratings in this survey may well be warranted.

Future Scientists versus Future Teachers

Overall, the bioscience students appeared more favorable to all interventions than the education students. Educational attainment and age did not differ between the responding groups, thus their different attitudes could not generally be ascribed to demographic variables (though see Limitations). Several factors may have contributed to this result. First, this predisposition towards accepting neuroscientific-based interventions may stem from their knowledge of (neuro)scientific mechanisms or, less positively, a belief that biologically-based practices are inherently good. As neuroscience students, they may have been unduly influenced by the neuroscience covered in the course (McCabe & Caster, 2008; Weisberg et al., 2008). Second, education students may value authenticity (versus technical mediation) more than bioscientists, as authenticity is a critical characteristic of teachers and their instruction (De Bruyckere & Kirschner, 2016; Newmann & Wehlage, 1993). Educators may also value caring for children when guiding their learning more than treating learning ability as a condition that can be manipulated (Stein, 2010). Third, cognitive enhancement beyond normal has become normalized in the US workplace (Sales et al., 2019) and is desired among professionals such as surgeons, lawyers, transportation and construction workers (Leon et al., 2019), and even scientists (Maher, 2008). Competitive bioscience students trying to gain admission to highly selective post-graduate and medical programs may also think similarly. By comparison, there are more on-ramps to the teaching profession. Education students may have felt less pressure or need for cognitive enhancement.

Enhance up to the Norm

As expected from previous studies (Cabrera et al., 2015a), for current respondents, enhancement up to the norm for LAS and especially SLD students was more favorably viewed than enhancement beyond the norm for HAS students. Many of the approaches considered here were initially developed for the purpose of medical diagnosis or treatment. Their current or potential use for cognitive enhancement, educational diagnosis or assessment can be considered similarly to off-label applications of approved medicines and medical devices. There, treatment is defined as interventions to improve or return functioning up to normal level, whereas enhancement is defined as improvements above normal levels of functioning. However, in practice this dichotomy really is a continuum, dependent upon the individual and the context (Daniels, 2000; Shook et al., 2014; Singh & Kelleher, 2010). Medically, some drugs are prescribed to ameliorate a risk state (e.g. high blood pressure) and prevent an illness rather than to simply treat an illness (Hyman, 2011). Similarly, cognitive enhancement might be less categorical and more continuous (Hyman, 2011).

Invasiveness of Neuroscience Measures: Integrity Matters

Among the different scenarios, those that measured brain activity, EEG or fMRI, to assess or predict intellectual abilities were deemed more acceptable than manipulations of mental activity by drug use or stimulation techniques, which may violate body integrity. We cannot distinguish between non-invasiveness and diagnostic utility as reasons for the more favorable ratings as both were characteristics of only the EEG and fMRI vignettes. Diagnosis ranges from predicting a learning disability and a need for an individualized learning plan to actually assessing comprehension of subject matter (Hoeft et al., 2011; Mason & Just, 2016). Short of truth serum or biopsies, drugs or invasive devices do not currently lend themselves to educational diagnostic purposes. If diagnostic applications arise in the future for drugs or invasive devices, the acceptability of invasive diagnosis for educational purposes would have to be assessed separately. Safety issues may also have contributed to the non-invasive/diagnostic preference. The scenarios utilizing drugs or devices were less desirable. The experimental nature of the neuroprosthetics and tDCS may also figure into their disfavor, but assessing student performance with EEG or fMRI or determining if classrooms run better with oxytocin in the air are also experimental at this juncture. Thus, focusing on the further development of non-invasive neuroscience assessments should be a priority. Such measures are more acceptable to bioscientists who will be asked to develop them than to the teachers who will be asked to utilize them in their classroom practice. The risks of measuring educational attainment using physiological measures disconnected from the actual performance include projecting decreased expectations, stigmatization or incorrect categorization for individual children. In addition, they are large-budget items. These prospects threaten to diminish enthusiasm for using such techniques in place of traditional educational testing.

The current use of prescription neuroenhancers in educational settings is commonly accepted for the treatment of ADHD. However, a number of ethical considerations still exist surrounding this practice. Students feel social pressures to self-enhance and maintain personal integrity yet they also perceive the use of neuroenhancers as a substitute for their own authentic performance, suffer from identity issues, or social stigma associated with their use (C. Forlini & Racine, 2009; Singh & Kelleher, 2010). From the teachers' and schools' points of view, encouraging neuroenhancement may have benefits beyond enhancing individual performance when enhancers are used to control disruptive behaviors or when widespread enhancer use promotes meeting mandated proficiency levels on standard exams (Singh & Kelleher, 2010).

Respondents expressed appropriate skepticism about the invasive scenarios that were more experimental in nature. They are not alone. In a university-wide Irish survey, only 15% favored using tDCS for enhancement in education (Karok & Witney, 2017). Among Italian psychology and medical undergraduates, only 21%

favored using tDSC for self-enhancement (Karok & Witney, 2017). Even researchers working on tDCS viewed its effectiveness as moderate with clinical use favored over research, and lastly enhancement applications (Riggall et al., 2015). The most invasive scenario involved implantation of a device to stimulate brain activity with hypothetical enhancement capabilities. This possibility is now not that far into the future. Stimulation via electrodes used for localization of epileptic foci in brain areas relevant to memory formation can enhance performance on specific experimental memory tasks (Khan et al., 2019; Kucewicz et al., 2018). While current interest in this technique focuses upon restoration of memory in neurodegenerative disease, conceivably, a child with epilepsy might be in a position to receive such enhancement now. However, ethical issues concerning loss of agency in adults with deep brain stimulation remain unresolved (Goering et al., 2017), and will be even thornier for students in education.

From Acceptability Ratings to Ethical Judgments and Policy

This study only measured acceptability ratings; it did not probe the ethical reasoning behind these choices by asking respondents to provide rationales. Thus the ethical positions of respondents can only be imputed from their ratings. This section explores how the acceptability judgments captured in the current study can inform discussions of regulation of these neuroscience applications in educational and broader policies.

Most likely, the complex reasoning behind individual ratings was highly diverse, as evidenced by an in-depth analysis of Dutch student, parent, and teacher focus groups discussing acceptability of using neuroimaging in assessing and adapting teaching methods to individual learners' needs (Edelenbosch et al., 2015). Opinions ranged from the benefits to be gained by tailoring teaching to individual needs to the stresses this would place on teachers or the loss of social interaction among students who would be segregated away from the class by this personalized instruction. Critically, each stakeholder group emphasized different aspects of this tension. High school students emphasized the social aspects of learning and the desire to choose their own instructional paths. Parents worried about privacy and possible stigmatization related to the consequences of using the brain scans. Teachers felt the personalized learning would undercut their roles as deliverer of stories and relegate them to supervisors of computer use (Edelenbosch et al., 2015). As indicated in these examples, future studies might adopt qualitative methods or structured interviews to probe more deeply into how different educational stakeholders reason about the ethics of different neuroscience applications to improve academic outcomes. Such in depth discussions could be part of community processes leading to decision making by appropriate regulatory bodies, whether educational, medical or governmental (Escobar, 2014).

While youth may be the beneficiaries of these new technologies, teachers, parents and administrators are the decision makers who opt to purchase or engage with such practices (Horwitz, 2007). In most countries, national policies can drive educational practices and purchasing decisions; in the US, such decisions largely occur at the level of the local school or district. Accountability for student performance has been a dominant educational policy theme both in the US and internationally (Teltemann & Schunck, 2020; Mathis 2016) that could drive policy decisions favoring the interventions in the current vignettes. Only at the university level do students have the agency to seek or reject enhancements. As of 2017, only one out of 191 US universities specifically prohibited non-prescription use of stimulants as a violation of academic integrity, while virtually all institutions had broader policies complying with state and federal laws regarding alcohol and other drugs as part of the student code of conduct (Aikins et al., 2017).

Educational policy makers are under pressure to make decisions based upon high quality educational research involving randomly controlled trials measuring performance outcomes longitudinally that are scalable (Horwitz, 2007). As evidence-based pedagogical practices spread, neuro-technologies may become more commonplace in education. For example, EEG can detect attention or lack thereof in real time. In a RCT study, an EEG-based attention training game reduced childrens' ADHD symptoms (Lim et al., 2019). EEG caps that assess mental workload and engagement, providing personal feedback, are being prepared for market (So et al., 2017). More complex systems have already been incorporated into computer-based intelligent tutoring systems which detect and respond to attention lapses (Kuo et al., 2017). Such developments are driven by combining neuroscience understanding of learning with commercial interests and may not be incorporating input from all educational stakeholders. Recently, organized social media campaigns have reacted against existing policies, leading to state by state modifications of the Common Core standards (Daly 2019). So public opinion can become a powerful determinant of adoption and should appropriately be taken into consideration as part of educational innovation.

Regulatory issues surrounding the use of cognitive enhancers in education fall upon doctors who prescribe these drugs as well as educational institutions (Ricci, 2020). Commercial regulation would fall under governmental auspices. The American Medical Association policy discourages physicians from prescribing cognitive enhancers in healthy individuals (American Medical Association 2016). Both US and Italian governments have formally considered the ethical implications of enhancement up to and beyond normal, releasing reports, but neither have formally enacted legal limits (Ricci, 2020). Regulatory authority over the educational use of neurotechnologies is unclear as all of the applications in the vignettes except the neuroprosthesis are available for purchase on open or private markets (e.g. (So et al., 2017); (Kuo et al., 2017); (Fitz & Reiner, 2015; Smith & Farah, 2011)). Major proponents of cognitive enhancer use are the businesses that seek to market over-the-counter supplements and devices to audiences of "brain hackers" (Glionna, 2017). As nutritional supplements, these are unregulated in the US. Attempts to advance ethical policies around the use of brain imaging technologies in Scotland involved extensive public discourse that eventually failed to reach the threshold needed for legislation (Escobar, 2014). More recent calls for policy making around use of devices such as fMRI or tDCS propose an iterative process engaging multiple stakeholders willing to form communities of practice to weigh the benefits and potential harms of using such technologies in educational settings on children (Ahmed & Hens, 2020; Schuijer et al., 2017; Seghier et al., 2019).

With such discourse rightly centered at the community level, the acceptance data gathered here can contribute to those discussions. Under current US law, cognitive enhancement could conceivably be coercively administered to minors by parents or private schools without further regulation, although challenges to safety and efficacy might limit such practices (Jwa, 2019). Current regulatory policies in the UK surrounding the use of cognitive enhancing pharmaceuticals, grounded in the idea of a drug-free culture, do not appear to be inhibiting the use or growing acceptance of such practices by specific segments of the population (Coveney et al., 2019). Changes in regulatory policies to deal with off label use of cognitive enhancers should be both sensitive to public opinion, captured here and more broadly, and the successes and failures in the regulation of psychoactive drugs (Collins, 2017; Dinh et al., 2020; Greer & Ritter, 2020).

The current study is a first attempt to assess permissibility of these emerging educational neurointerventions among a community involved in education. However, acceptability ratings are a coarse indicator. Future studies should adopt qualitative methods or structured interviews to probe more deeply into how people reason about the ethics of different neuroscience applications to improve academic outcomes and who should regulate these. Such studies can investigate the importance of the breadth of ethical values and issues relating to these applications to determine which values underpin the moral acceptability observed here.

Limitations and Concerns

Two limitations derive from the composition of the sample. Demographically, fewer males were present among the education respondents. As males are generally more accepting of technology (Broos, 2005), it is an open question whether this resulted in the lower acceptability ratings of the education students versus the biosciences student.[7] Thus, exploring whether there are gender effects in evaluating the acceptability of neuroscience applications to education remains a direction for future research. Additionally, the reported acceptability of these hypothetical educational applications of neuroscience reflects the cultural orientation of students attending a large Midwestern university in the United States. Attitudes and acceptability of

[7] At the suggestion of one of the anonymous reviewers, we undertook an exploratory analysis of gender in our sample. There were simply too few men among the education students (8 of the 84 participants) to support a statistical analysis of gender in that group. However, the numbers were better for the biosciences students (29 of the 82 participants). We conducted an ANOVA of acceptability ratings with between-subjects factor Gender (female, male) and the within-subjects factors Scenario, Perspective, and recipient Population. There were two notable findings. First, there was a main effect of Gender ($F(1,80) = 11.08$, $p < 0.001$, $\eta_p^2 = 0.12$), with male participants judging neuroscience applications to be more acceptable than female participants, consistent with the literature (Broos 2005). Second, there was a Gender x Perspective interaction ($F(1,80) = 4.97$, $p = .029$, $\eta_p^2 = 0.06$). Participants rated neuroscience application more favorably when taking the perspective of a student (versus a teacher), and this was particularly the case for male participants.

all proposed interventions would vary considerably in the context of another country or culture (Rommelfanger et al. 2018). Engagement of larger and more diverse respondents is necessary to explore these potential confounds.

Of concern, respondents reported a high incidence of having been prescribed drugs or brain stimulation to improve their learning, ranging from 3 to 52%. By contrast, the reported prevalence of pharmacological enhancement in educational settings ranges from 5 to 35% depending upon context (Benson et al., 2015; Wilens et al., 2008) with prescription use recently increasing (Sales et al., 2019). This concern could arise because the current set of respondents were all from a university setting. The heavy prior use in our sample could be affecting the overall degree of acceptability encountered. However, respondents differentiated acceptability across a range of other variables, indicating their ability to reason independently of their own experiences.

A final set of limitations concerns the materials. Although we devoted significant effort to developing the six scenarios and piloting them along with the associated items, they are limited in several ways. One limitation is that there are other dimensions of variation across the six scenarios besides the one we focused on here (i.e., non-invasive vs. pharmacological vs. physical hardware). For example, both non-invasive scenarios also share the property that they have no direct effect on student learning. It is possible that this shared property drives participants' acceptability ratings. Such confounds were unavoidable given our goal of using naturally occurring examples of neuroscience applications to education to ensure the external validity of the results. Nevertheless, future studies should improve the scenarios to reduce such confounds. Another limitation is a possible ambiguity in the items where participants rate, from the perspective of the teacher, the acceptability of neuroscience applications. This prompt is ambiguous because it does not specify *who* is making the decision to use the intervention: the teacher, the student, a parent, or school administrator (McCall et al., 2020). Future studies should improve these items to explicitly name the decision maker; this will reduce this source of variability. (We thank the anonymous reviewers for these suggestions.)

Conclusion

Providing teachers with background neuroscience knowledge may be necessary so that they can critically appraise these futuristic technologies, which are practically implemented, and interpret their results for students (Coch, 2018; Howard-Jones, 2009; Dubinsky et al., 2013, 2019; Schwartz et al., 2019). The work of improving teacher understanding of how learning occurs in the brain is already being done (Dubinsky et al., 2019). This raises the parallel question of educating the designers of tomorrow's neuroscience measures and treatments about the ethical dimensions of their application to education. While they did not embrace these ideas overwhelmingly, bioscience respondents were more favorable towards infusing neuroscience-related technologies into classrooms than education respondents. In the near future, these young adults will join students, parents, teachers, administrators, and policy makers in conversations about neuroscience interventions, and they must be sensitive to the potentially conflicting views of different stakeholders (Ahmed & Hens, 2020; Hardiman et al., 2012; Maxwell & Racine, 2016). We agree with Ahmed and Fens (Ahmed & Hens, 2020) that follow-up qualitative studies should extend the current findings to delve deeper into the prevailing reasons for and against acceptance of these applications. Such studies should include potential cognitive costs, probe the concepts of access, equity, authenticity, agency and safety and utilize continuous rating scales.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval The questionnaire and methodology for this study was approved by the University of Minnesota Institutional Review Board (protocol 1503P66601). All participants gave their informed consent prior to taking the survey.

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References

Ahmed, E., & Hens, K. (2020). Cognitive enhancement: Toward a rational public consensus. *AJOB Neuroscience, 11*(4), 263–265. https://doi.org/10.1080/21507740.2020.1830871

Aikins, R., Zhang, X., & McCabe, S. E. (2017). Academic doping: Institutional policies regarding nonmedical use of prescription stimulants in U.S. higher education. *Journal of Academic Ethics, 15*(3), 229–243. https://doi.org/10.1007/s10805-017-9291-0

Allen, M. D., & Fong, A. K. (2008). Clinical application of standardized cognitive assessment using fMRI II. Verbal fluency. *Behavioural Neurology, 20*(3), 141–152.

American Medical Association (2016). AMA confronts the rise of nootropics.

Ansari, D., Konig, J., Leask, M., & Tokuhama-Espinosa, T. (2017). Developmental cognitive neuroscience: Implications for teachers' pedagogical knowledge. In S. Guerriero (Ed.), *Pedagogical knowledge and the changing nature of the teaching profession* (pp. 195–222). OECD Publishing.

Axelrod, V., Rees, G., Lavidor, M., & Bar, M. (2015). Increasing propensity to mind-wander with transcranial direct current stimulation. *Proceedings of the National Academy of Sciences USA, 112*(11), 3314–3319.

Ball, N., & Wolbring, G. (2014). Cognitive enhancement: Perceptions among parents of children with disabilities. *Neuroethics, 7*, 345–364.

Benson, K., Florey, K., & Humphreys, K. L. (2015). Misuse of stimulant medication among college students: A comprehensive review and meta-analysis. *Clinical Child and Family Psychology Review, 18*, 50–76.

Brem, A. K., Fried, P. J., Horvath, J. C., Robertson, E. M., & Pascual-Leone, A. (2014). Is neuroenhancement by noninvasive brain stimulation a net zero-sum proposition? *Neuroimage, 85*(3), 1058–68.

Broos, A. (2005). Gender and information and communication technologies (ICT) anxiety: Male self-assurance and female hesitation. *CyberPsychology and Behavior, 8*, 21–31.

Burstin, K., Doughtie, E. B., & Raphaeli, A. (1980). Contrastive vignette technique: An indirect methodology designed to address reactive social attitude measurement. *Journal of Applied Social Psycnology, 10*(2), 147–165.

Butterworth, B., Varma, S., & Laurillard, D. (2011). Dyscalculia: From brain to education. *Science, 332*(6033), 1049–1053.

Cabrera, L. Y., Fitz, N. S., & Reiner, P. B. (2015a). Empirical support for the moral salience of the therapy-enhancement distinction in the debate over cognitive, affective and social enhancement. *Neuroethics, 8*(3), 243–256.

Cabrera, L. Y., Fitz, N. S., & Reiner, P. B. (2015b). Reasons for comfort and discomfort with pharmacological enhancement of cognitive, affective, and social domains. *Neuroethics, 8*, 93–106.

Cetron, J. S., Connolly, A. C., Diamond, S. G., May, V. V., Haxby, J. V., & Kraemer, D. J. M. (2019). Decoding individual differences in STEM learning from functional MRI data. *Nature Communications, 10*(1), 2027. https://doi.org/10.1038/s41467-019-10053-y

Clausen, J., Fetz, E., Donoghue, J., Ushiba, J., Sporhase, U., Chandler, J., et al. (2017). Help, hope, and hype: Ethical dimensions of neuroprosthetics. *Science, 356*(6345), 1338–1339.

Coch, D. (2018). Reflections on neuroscience in teacher education. *Peabody Journal of Education, 93*(3), 309–319.

Cohen Kadosh, R., Levy, N., O'Shea, J., Shea, N., & Savulescu, J. (2012). The neuroethics of non-invasive brain stimulation. *Current Biology, 22*(4), R108–R111.

Cohen Kadosh, R., Soskic, S., Iuculano, T., Kanai, R., & Walsh, V. (2010). Modulating neuronal activity produces specific and long-lasting changes in numerical competence. *Current Biology, 20*(22), 2016–2020.

Colaneri, N., Sheldon, M., & Adesman, A. (2018). Pharmacological cognitive enhancement in pediatrics. *Current Opinion in Pediatrics, 30*(3), 430–437.

Collins, J. (2017). Regulation as global drug governance: How new is the NPS phenomenon? In *Novel psychoactive substances* (pp. 23–41): Springer.

Coveney, C., Williams, S. J., & Gabe, J. (2019). Enhancement imaginaries: Exploring public understandings of pharmaceutical cognitive enhancing drugs. *Drugs Education, Prevention and Policy, 26*(4), 319–328. https://doi.org/10.1080/09687637.2019.1593318

Daly, A., Supovitz, J. A., & Del Fresno, M. (2019). The social side of educational policy: How social media is changing the politics of education. *Teachers College Record, 121*(14), 1–26.

Daniels, N. (2000). Normal functioning and the treatment-enhancement distinction. *Cambridge Quarterly of Healthcare Ethics, 9*(3), 309–322.

Davis, N. J. (2017). A taxonomy of harms in cognitive enhancement. [Review]. *Frontiers in Human Neuroscience*. https://doi.org/10.3389/fnhum.2017.00063

De Bruyckere, P., & Kirschner, P. A. (2016). Authentic teachers: Student criteria perceiving authenticity of teachers. *Cogent Education*. https://doi.org/10.1080/2331186X.2332016.1247609

de Jongh, R., Bolt, I., Schermer, M., & Olivier, B. (2008). Botox for the brain: Enhancement of cognition, mood and pro-social behavior and blunting of unwanted memories. *Neuroscience and Biobehavioral Reviews, 32*(4), 760–776.

Deadwyler, S. A., Hampson, R. E., Song, D., Opris, I., Gerhardt, G. A., Marmarelis, V. Z., et al. (2017). A cognitive prosthesis for memory facilitation by closed-loop functional ensemble stimulation of hippocampal neurons in primate brain. *Experimental Neurology, 287*(Pt 4), 452–460.

Desmond, H. (2020). Service and status competition may help explain perceived ethical acceptability. *AJOB Neuroscience, 11*(4), 258–260. https://doi.org/10.1080/21507740.2020.1830874

Dikker, S., Wan, L., Davidesco, I., Kaggen, L., Oostrik, M., McClintock, J., et al. (2017). Brain-to-brain synchrony tracks real-world dynamic group interactions in the classroom. *Current Biology, 27*(9), 1375–1380.

Dinh, C. T., Humphries, S., & Chatterjee, A. (2020). Public opinion on cognitive enhancement varies across different situations. *AJOB Neuroscience, 11*(4), 224–237. https://doi.org/10.1080/21507740.2020.1811797

Dolen, G. (2015). Oxytocin: Parallel processing in the social brain? *Journal of Neuroendocrinology, 27*(6), 516–535.
Dubljevic, V. (2012). Toward a legitimate public policy on cognition-enhancement drugs. *AJOB Neuroscience, 3*(3), 29–33. https://doi.org/10.1080/21507740.2012.700681
Dubinsky, J. M., Roehrig, G. H., & Varma, S. (2013). Infusing neuroscience into teacher professional development. *Educational Researcher*, *42*(6), 317–329.
Dubinsky, J. M., Guzey, S., Schwartz, M. S., Roehrig, G., MacNabb, C., Schmied, A., et al. (2019). Contributions of neuroscience knowledge to teachers and their practice. *The Neuroscientist*, https://doi.org/10.1177/1073858419835447
Edelenbosch, R., Kupper, F., & Broerse, J. (2015). Neuroimaging and personalized learning: Value reflection with societal stakeholders. In B. J. Koopps (Ed.), *Responsible innovation 2: Concepts, approaches, and applications* (pp. 139–160). Springer International Publishing.
Escobar, O. (2014). Upstream public engagement, downstream policy-making? The Brain Imaging Dialogue as a community of inquiry. *Science and Public Policy, 41*(4), 480–492. https://doi.org/10.1093/scipol/sct073
Fitz, N. S., & Reiner, P. B. (2015). The challenge of crafting policy for do-it-yourself brain stimulation. *Journal of Medical Ethics, 41*(5), 410–412.
Forlini, C., & Racine, E. (2009). Autonomy and coercion in academic "cognitive enhancement" using methylphenidate: Perspectives of key stakeholders. *Neuroethics, 2*, 163–177.
Forlini, C., & Racine, E. (2012). Stakeholder perspectives and reactions to "academic" cognitive enhancement: Unsuspected meaning of ambivalence and analogies. *Public Understanding of Science, 21*(5), 606–625. https://doi.org/10.1177/0963662510385062
Fountain, J., Bartlett, H., Griffiths, P., Gossop, M., Boys, A., & Strang, J. (1999). Why say no? Reasons given by young people for not using drugs. *Addiction Research, 7*(4), 339–353. https://doi.org/10.3109/16066359909004391
Franke, A. G., Gransmark, P., Agricola, A., Schuhle, K., Rommel, T., Sebastian, A., et al. (2017). Methylphenidate, modafinil, and caffeine for cognitive enhancement in chess: A double-blind, randomised controlled trial. *European Neuropsychopharmacology, 27*, 248–260.
Gamez, D. (2018). Could neurolecturing address the limitations of live and recorded lectures? *Humana. Mente Journal of Philosophical Studies, 11*(33), 43–58.
Geake, J. (2013). Neuromythologies in education. *Educational Research, 50*(2), 123–133.
Giordano, J. (2017). Toward an operational neuroethical risk analysis and mitigation paradigm for emerging neuroscience and technology (neuroS/T). *Experimental Neurology, 287*, 492–495.
Glionna, I. (2017). Brain hackers seeking peak performance use risky chemical cocktails. *Scientific American*. https://www.scientificamerican.com/article/brain-hackers-seeking-peak-performance-use-risky-chemical-cocktails/
Goering, S., Klein, E., Cougherty, D. D., & Widge, A. S. (2017). Staying in the loop: Relational agency and identity in next-generation DBS for psychiatry. *AJOB Neuroscience, 8*(2), 59–70.
Greer, A., & Ritter, A. (2020). The legal regulation of drugs and role of government: Perspectives from people who use drugs. *Drug and Alcohol Dependence, 206*, 107737. https://doi.org/10.1016/j.drugalcdep.2019.107737
Hampson, R. E., Song, D., Robinson, B. S., Fetterhoff, D., Dakos, A. S., Roeder, B. M., et al. (2018). Developing a hippocampal neural prosthetic to facilitate human memory encoding and recall. *Journal of Neural Engineering, 15*(3), 36014–32552.
Hardiman, M., Rinne, L., Gregory, E., & Yarmolinskaya, J. (2012). Neuroethics, neuroeducation, and classroom teaching: Where the brain sciences meet pedagogy. *Neuroethics, 5*, 135–143.
Hoeft, F., McCandliss, B. D., Black, J. M., Gantman, A., Zakerani, N., Hulme, C., et al. (2011). Neural systems predicting long-term outcome in dyslexia. *Proceedings of the National Academy of Sciences, 108*(1), 361. https://doi.org/10.1073/pnas.1008950108
Horwitz, P. (2007). Successful scale-up in three stages: Insights and challenges for educational research and practice. In B. Schneider & S. K. McDonald (Eds.), *Scale-up in education: Ideas in principle* (Vol. 1, pp. 259–268). Rowman & Littlefield Publishers Inc.
Howard-Jones, P. A. (2009). Scepticism is not enough. *Cortex, 45*(4), 550–551.
Howard-Jones, P. A., & Fenton, K. D. (2012). The need for interdisciplinary dialogue in developing ethical approaches to neuroeducational research. *Neuroethics, 5*, 119–134.
Hyman, S. E. (2011). Cognitive enhancement: Promises and perils. *Neuron, 69*, 595–598.
Illes, J., & Raffin, T. A. (2005). No child left without a brain scan? Toward a pediatric neuroethics. *Cerebrum, 7*(3), 33–46.

Im, S. H., Cho, J. Y., Dubinsky, J. M., & Varma, S. (2018). Taking an educational psychology course improves neuroscience literacy but does not reduce belief in neuromyths. *PLoS One*, *13*(2), e0192163.
Iuculano, T., & Cohen Kadosh, R. (2013). The mental cost of cognitive enhancement. *Journal of Neuroscience, 33*(10), 4482–4486.
Jacobs, J., Miller, J., Lee, S. A., Coffey, T., Watrous, A. J., Sperling, M. R., et al. (2016). Direct electrical stimulation of the human entorhinal region and hippocampus impairs memory. *Neuron, 92*(5), 983–990.
Jwa, A. S. (2019). Regulating the use of cognitive enhancement: An analytic framework. *Neuroethics, 12*(3), 293–309. https://doi.org/10.1007/s12152-019-09408-5
Karok, S., & Witney, A. G. (2017). Topical issues of transcranial direct current stimulation usage revealed through a cross-sectional university-wide survey. *Journal of Cognition and Neuroethics, 4*(3), 1–32.
Khan, I. S., D'Agostino, E. N., Calnan, D. R., Lee, J. E., & Aronson, J. P. (2019). Deep brain stimulation for memory modulation: A new frontier. *World Neurosurg, 126*, 638–646.
Kucewicz, M. T., Berry, B. M., Miller, L. R., Khadjevand, F., Ezzyat, Y., Stein, J. M., et al. (2018). Evidence for verbal memory enhancement with electrical brain stimulation in the lateral temporal cortex. *Brain, 141*(4), 971–978.
Kuo, Y. C., Chu, H. C., & Tsai, M. C. (2017). Effects of an integrated physiological signal-based attentionpromoting and English listening system on students' learning performance and behavioral patterns. *Computers in Human Behavior, 75*(218), 227.
Lalancette, H., & Campbell, S. R. (2012). Educational neuroscience: Neuroethical considerations. *International Journal of Environmental & Science Education, 7*(1), 37–52.
Landhuis, E. (2017). Do D.I.Y. Brain-booster devices work? *Scientific American Mind, Jan. 2017*, https://www.scientificamerican.com/article/do-diy-brain-booster-devices-work/.
Langer, N., Peysakhovich, B., Zuk, J., Drottar, M., Sliva, D. D., Smith, S., et al. (2017). White matter alterations in infants at risk for developmental dyslexia. *Cerebral Cortex, 27*(2), 1027–1036.
Leon, M. R., Harms, P. D., & Gilmer, D. O. (2019). PCE use in the workplace: The open secret of performance enhancement. *Journal of Management Inquiry, 28*(1), 67–70.
Lim, C. G., Poh, X. W. W., Fung, S. S. D., Guan, C., Bautista, D., Cheung, Y. B., et al. (2019). A randomized controlled trial of a brain-computer interface based attention training program for ADHD. *PLoS One, 14*(5), 16225.
Maher, B. (2008). Poll results: Look who's doping. *Nature, 452*(7188), 674–675.
Mason, R. A., & Just, M. A. (2015). Physics instruction induces changes in neural knowledge representation during successive stages of learning. *Neuroimage, 111*, 36–48.
Mason, R. A., & Just, M. A. (2016). Neural representations of physics concepts. *Psychological Science, 27*(6), 904–913. https://doi.org/10.1177/0956797616641941
MathisTrujillo, W. J. T. M. (2016). *Lessons from NCLB for the every student succeeds act*. School of Education, University of Colorado.
Maxwell, B., & Racine, E. (2016). Two cases in neuroeducational knowledge transfer behavioral ethics and responsive parenting. In C. W. Joldersma (Ed.), *Neuroscience and education. A philosophical appraisal.* Routledge.
McCabe, D. P., & Caster, A. D. (2008). Seeing is believing: The effect of brain images on judgements of scientific reasoning. *Cognition, 107*, 343–352.
McCall, I. C., McIntosh, T., & Dubljević, V. (2020). How public opinion can inform cognitive enhancement regulation. *AJOB Neuroscience, 11*(4), 245–247. https://doi.org/10.1080/21507740.2020.1830881
McDonald, S. K. (2997). Technology and scale-up: Implications for research and practice. In B. M. Schneider, S.K. (Ed.), *Scake-up in education ideas in principle* (Vol. 1, pp. 269-278). Lanham, MD: Rowman & Littlefield Publishers, Inc.
Molfese, D. L. (2000). Predicting dyslexia at 8 years of age using neonatal brain responses. *Brain and Language, 72*(3), 238–245.
MTA Cooperative Group. (1999). A 14-month randomized clinical trial of treatment strategies for attention-deficit/hyperactivity disorder. The MTA cooperative group. Multimodal treatment study of children with ADHD. *Archives of General Psychiatry, 56*(12), 1073–1086.
Newmann, F. M., & Wehlage, G. G. (1993). Five standards of authentic instruction. *Educational Leadership, 50*(7), 8–12.

Parker, K. J., Oztan, O., Libove, R. A., Sumiyoshi, R. D., Jackson, L. P., Karhson, D. S., et al. (2017). Intranasal oxytocin treatment for social deficits and biomarkers of response in children with autism. *Proceedings of the National Academy of Science USA, 114*(30), 8119–8124.

Peters, L., & De Smedt, B. (2018). Arithmetic in the developing brain: A review of brain imaging studies. *Developmental Cognitive Neuroscience, 30*, 265–279.

Petersen, M. A., Enghoff, O., & Demant, J. (2019). The uncertainties of enhancement: A mixed-methods study on the use of substances for cognitive enhancement and it's unintended consequences. *Performance Enhancement & Health, 6*(3), 111–120. https://doi.org/10.1016/j.peh.2018.09.001

Petersen, M. A., Petersen, I. L., Poulsen, C., & Nørgaard, L. S. (2021). #studydrugs–persuasive posting on instagram. *International Journal of Drug Policy*. https://doi.org/10.1016/j.drugpo.2020.103100

Ragan, C. I., Bard, I., & Singh, I. (2013). What should we do about student use of cognitive enhancers? An analysis of current evidence. *Neuropharmacology, 64*, 588–95.

Rajala, A. Z., Henriques, J. B., & Populin, L. C. (2012). Dissociative effects of methylphenidate in nonhuman primates: Trade-offs between cognitive and behavioral performance. *Journal of Cognitive Neuroscience, 24*(6), 1371–1381.

Ricci, G. (2020). Pharmacological human enhancement: An overview of the looming bioethical and regulatory challenges. [Review]. *Frontiers in Psychiatry*. https://doi.org/10.3389/fpsyt.2020.00053

Richards, T. L., Berninger, V. W., Yagle, K., Abbott, R. D., & Peterson, D. (2018). Brain's functional network clustering coefficient changes in response to instruction (RTI) in students with and without reading disabilities: Multi-leveled reading brain's RTI. *Cogent Psychology, 5*, 1424680. https://doi.org/10.1080/23311908.23312018.21424680

Richards, T. L., Berninger, V. W., Yagle, K. J., Abbott, R. D., & Peterson, D. J. (2017). Changes in DTI diffusivity and fMRI connectivity cluster coefficients for students with and without specific learning disabilities in written language: Brain's response to writing instruction. *Journal of Natural Science, 3*(4), 350.

Riggall, K., Forlini, C., Carter, A., Hall, W., Weier, M., Partridge, B., et al. (2015). Researchers' perspectives on scientific and ethical issues with transcranial direct current stimulation: An international survey. *Scientific Reports, 5*, 10618.

Rommelfanger, K. S., Jeong, S. J., Ema, A., Fukushi, T., Kasai, K., Ramos, K. M., et al. (2018). Neuroethics questions to guide ethical research in the international brain initiatives. *Neuron, 100*(1), 19–36.

Royal Society. (2011). *Brain waves module 2: Neuroscience: Implications for education and lifelong learning*.

Ruggiero, F., Lavazza, A., Vergari, M., Priori, A., & Ferrucci, R. (2018). Transcranial direct current stimulation of the left temporal lobe modulates insight. *Creativity Research Journal, 30*(2), 143–151.

Sales, P., Murphy, F., Murphy, S., & Lau, N. (2019). Burning the candle at both ends: Motivations for non-medical prescription stimulant use in the American workplace. *Drugs: Education, Preventions and Policy, 26*(4), 301–308.

Sarkar, A., Dowker, A., & Cohen Kadosh, R. (2014). Cognitive enhancement or cognitive cost: Trait-specific outcomes of brain stimulation in the case of mathematics anxiety. *Journal of Neuroscience, 34*(50), 16605–16610.

Sattler, S. (2020). Using social learning theories to better understand the variation of the moral acceptability of performance enhancement drug use. *AJOB Neuroscience, 11*(4), 248–250. https://doi.org/10.1080/21507740.2020.1830880

Schmied, A. (2017). *Students' attitudes towards the use of advances derived from or related to neuroscience research in educational contexts*. University of Minnesota.

Schuijer, J. W., de Jong, I. M., Kupper, F., & van Atteveldt, N. M. (2017). Transcranial electrical stimulation to enhance cognitive performance of healthy minors: A complex governance challenge. [Review]. *Frontiers in Human Neuroscience*. https://doi.org/10.3389/fnhum.2017.00142

Schwartz, M. S., Hinesley, V., Chang, Z., & Dubinsky, J. M. (2019). Neuroscience knowledge enriches pedagogical choices. *Teaching and Teacher Education*, *83*, 87–98.

Seghier, M. L., Fahim, M. A., & Habak, C. (2019). Educational fMRI: From the lab to the classroom. [Review]. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2019.02769

Shook, J. R., Galvagni, L., & Giordano, J. (2014). Cognitive enhancement kept within contexts: Neuroethics and informed public policy. *Frontiers in System Neuroscience, 8*, 1–8. https://doi.org/10.3389/fnsys.2014.00228

Singh, I., & Kelleher, K. J. (2010). Neuroenhancement in young people: Proposal for research, policy, and clinical management. *AJOB Neuroscience, 1*(1), 3–16.

Smith, M. E., & Farah, M. J. (2011). Are prescription stimulants “smart pills”? The epidemiology and cognitive neuroscience of prescription stimulant use by normal healthy individuals. *Psychological Bulletin, 137*(5), 717–741.

So, W. K. Y., Wong, S. W. H., Mak, J. N., & Chan, R. H. M. (2017). An evaluation of mental workload with frontal EEG. *PLoS One, 12*(4), e0174949.

Sprague, R. L., & Sleator, E. K. (1977). Methylphenidate in hyperkinetic children: Differences in dose effects on learning and social behavior. *Science, 198*(4323), 1274–1276.

Stein, Z. (2010). On the difference between designing children and raising them: Ethics and the use of educationally oriented biotechnology. *Mind, Brain, and Education, 4*(2), 53–67.

Suthana, N., Aghajan, Z. M., Mankin, E. A., & Lin, A. (2018). Reporting guidelines and issues to consider for using intracranial brain stimulation in studies of human declarative memory. *Frontiers in Neuroscience, 12*, 905. https://doi.org/10.3389/fnins.2018.00905.eCollection;%2018,905

Suthana, N., & Fried, I. (2014). Deep brain stimulation for enhancement of learning and memory. *Neuroimage, 85*(3), 996–1002.

Teltemann, J., & Schunck, R. (2020). Standardized testing, use of assessment data, and low reading performance of immigrant and non-immigrant students in OECD countries. [Original Research]. *Frontiers in Sociology*. https://doi.org/10.3389/fsoc.2020.544628

Varma, S., McCandliss, B. D., & Schwartz, D. L. (2008). Scientific and pragmatic challenges for bridging education and neursocience. *Educational Researcher*, *37*(3), 140–152.

Voarino, N., Dubljević, V., & Racine, E. (2017). tDCS for memory enhancement: Analysis of the speculative aspects of ethical issues. [Hypothesis and Theory]. *Frontiers in Human Neuroscience*. https://doi.org/10.3389/fnhum.2016.00678

Volkmer, S., & Schulte-Korne, G. (2018). Cortical responses to tone and phoneme mismatch as a predictor of dyslexia? A systematic review. *Schizophrenia Research, 191*, 148–160.

Wagner, K., Maslen, H., Oakley, J., & Savulescu, J. (2018). Would you be willing to zap your child’s brain? Public perspectives on parental responsibilities and the ethics of enhancing children with transcranial direct current stimulation. *AJOB Empirical Bioethics, 9*(1), 29–38.

Weisberg, D. S., Keil, F. C., Goodstein, J., Rawson, E., & Gray, J. R. (2008). The seductive allure of neuroscience explanations. *Journal of Cognitive Neuroscience, 20*(3), 470–477.

Westwood, S. J., & Romani, C. (2017). Transcranial direct current stimulation (tDCS) modulation of picture naming and word reading: A meta-analysis of single session tDCS applied to healthy participants. *Neuropsychologia, 104*, 234–249.

Widge, A. S., Zorowitz, S., Basu, I., Paulk, A. C., Cash, S. S., Eskandar, E. N., et al. (2019). Deep brain stimulation of the internal capsule enhances human cognitive control and prefrontal cortex function. *Nature Communications, 10*(1), 1536–09557.

Wilens, T. E., Adler, L. A., Adams, J., Sgambati, S., Rotrosen, J., Sawtelle, R., et al. (2008). Misuse and diversion of stimulants prescribed for ADHD: A systematic review of the literature. *Journal of the American Academy of Child and Adolescent Psychiatry, 47*(1), 21–31.

Zocchi, M., & Pollack, C. (2013). Educational neuroethics: A contribution from empirical research. *Mind, Brain, and Education, 7*(1), 56–62.

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