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'Discover, Understand, Implement, and Transfer': Effectiveness of an intervention programme to motivate students for science

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Considerable research has focused on how best to satisfy modern societies' needs for skilled labour in the field of science. The present study evaluated an intervention programme designed to increase secondary school students' motivation to pursue a science career. Students from 3 schools of the highest educational track participated for up to 2 years in the intervention programme, which was implemented as an elective in the school curriculum. Our longitudinal study design for evaluating the effectiveness of the intervention programme included all students at the grade levels involved in the programme with students who did not participate serving as a control group. Mixed-model analyses of variance showed none of the intended effects of the intervention programme on science motivation; latent growth models corroborated these results. When the programme began, students who enrolled in the science elective ($n = 92$) were already substantially more motivated than their classmates ($n = 228$). Offering such an intervention programme as an elective did not further increase the participating students' science motivation. It seems worthwhile to carry out intervention programmes with talented students who show (comparatively) little interest in science at the outset rather than with highly motivated students who self-select into the programme.

Keywords: *Interest; Motivation; Career choice; Intervention; Science; STEM*

The prosperity of societies as well as the global community has become increasingly dependent on science (as well as on technology, engineering, and mathematics;

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STEM; see e.g. Committee on Prospering in the Global Economy of the 21st Century, & Committee on Science, Engineering, and Public Policy, 2007). Moreover, tremendous challenges like sustainability issues need to be addressed. When talented students opt for non-science careers, this may not only deprive them of a wealth of career options in a growing labour market, but it is also unfortunate for the societies in which they live. Consequently, how to induce and preserve students' motivation in science is a research topic of major importance. A project-based long-term intervention programme was developed to increase secondary school students' motivation to study and pursue a career in science. This programme was implemented as part of the school curriculum of the highest educational track. We present an evaluation of this programme with a longitudinal design and deduce recommendations for teaching approaches aiming to motivate students for science.

Individual Determinants of Science Career Motivation

What specific student characteristics should be targeted by intervention programmes seeking to increase the number of students intending to pursue a science career? The expectancy–value theory of motivation holds that the cognitive representations of persons' own relevant academic abilities (which translate into their expectations for success) and the subjective values they assign to a task impact their choice behaviour (i.e. the activities they engage in, the courses they enrol in, and the careers they pursue; Eccles (Parsons) et al., 1983; Wigfield & Eccles, 2000). This is in line with other models of career choice (e.g. Lent, Brown, & Hackett, 1994; Super, 1990). In the case of subjective task values, expectancy–value theory distinguishes among four components: (1) attainment value, (2) intrinsic value, (3) utility value, and (4) cost. Attainment value refers to the personal importance of doing well at the respective task; it is higher, the more central the task is to how the person defines herself. Failing to accomplish a task in science class will not negatively affect students who attach little importance to science (and thus attach little attainment value to science tasks) and whose self-esteem is not based on their science achievement (Aronson, 1968). Intrinsic value, which may also be termed interest, is the enjoyment a person derives from performing an activity. More specifically, it corresponds to the affective interest component (see e.g. Hidi, Renninger, & Krapp, 2004). Students who enrol in a science elective, for example, may do so solely because of the pleasure they take in engaging in science.

Utility value, in contrast, represents a more extrinsic kind of motivation. Tasks hold utility value if they relate to an individual's goals (e.g. career objectives). Thus, a student whose goal is to become a physician may enrol in a science elective, thinking that this might facilitate access to medical school, despite not particularly enjoying the activities that elective involves. The fourth component of subjective task values is costs. This refers to the effort and emotional costs associated with engaging in the activity as well as the costs of forgoing other activities. Students opting for a science elective forgo opportunities to participate in other electives; they might also fear failing in the new learning environment. A forgone career choice is a prime example of lost opportunities resulting from making one choice over another. In the present study, however, we will not consider costs, but will instead focus on the value components assumed to foster students' motivation to pursue a science career.

Self-concept captures the expectancy component of the expectancy–value model (Eccles (Parsons) et al., 1983; Wigfield & Eccles, 2000). The higher their science self-concepts are, the more likely students are to entertain positive achievement-related beliefs with regard to science tasks. Students' cognitive representations of their academic abilities are a stronger predictor of their preferred career choice than their actual abilities (Bandura, Barbaranelli, Caprara, & Pastorelli, 2001); that is, believing oneself to be competent in science is psychologically more important for choosing a science course or a science career than actual competence (e.g. Marsh & Yeung, 1997; Nagengast & Marsh, 2012). A major source of information for students' domain-specific self-concepts is their achievement in that domain (see Marsh & Martin, 2011, for a review of the reciprocal effects model, which posits that self-concept and achievement are mutually reinforcing). Students participating in a science elective or science club receive more science instruction than their classmates; they can be expected to gain more science skills and knowledge than their classmates in other electives. If students in the science elective perceive improvements in their science competencies, their science self-concept is likely to improve as well (Zell & Alicke, 2009). As self-concept is derived in part from social comparisons (Huguet et al., 2009; Van Yperen & Leander, 2014), participating in a science elective is also likely to benefit students' science self-concepts to the extent that they compare themselves favourably with students receiving only regular science instruction. A possible adverse effect of offering additional science activities to boost students' interest in science careers is that bringing scientifically talented students together might discourage some of them. Measuring themselves against this select group, they may conclude that they are not as competent after all (see Seaton, Marsh, & Craven, 2009, for a cross-cultural study demonstrating that the effect of average achievement within a school on a student's self-concept is negative; i.e. the higher the average achievement, the lower the individual's self-concept). Science electives, however, do not seem too risky in this regard, as talented students mingle with less talented students during regular science classes.

Relationships between subjective values and ability-related beliefs. Empirical research has corroborated the assumption that self-concepts and subjective values affect subsequent course choices (Nagy, Trautwein, Baumert, Köller, & Garrett, 2006; Simpkins, Davis-Kean, & Eccles, 2006). At the same time, the domain-specific cognitive representations of one's abilities and subjective values are not independent. Students who perceive their science competence as low are likely to show little interest in science (e.g. Denissen, Zarrett, & Eccles, 2007; Rottinghaus, Larson, & Borgen, 2003). They are also more likely than students with high science self-concepts to assign little value to science (Heckhausen, Wrosch, & Schulz, 2010; Schütte, 2015; Steele, 1997). A reciprocal relationship between self-concept and interest is conceivable: Highly interested students who assign a high value to the domain enthusiastically engage in learning behaviour, which leads to higher achievement and consequently, higher self-concepts. This, in turn, enhances the subjective value of the domain. In line with self-determination theory (Deci & Ryan, 2000) and social cognitive career theory (Lent et al., 1994), empirical evidence suggests that the effect of one's perceived competence on interest is the primary driver of the relationship (Marsh, Trautwein, Lüdtke, Köller, & Baumert, 2005). This evidence thus underscores the detrimental motivational effect of excessive demands posed by a learning environment: Students' self-concepts wither and so will their interest in the domain.

Developmental change in motivation. Mean levels of science motivation decline during adolescence (e.g. Gottfried, Fleming, & Gottfried, 2001; Häussler, 1987). However, this developmental trend is neither specific to science (e.g. Gottfried et al., 2001; Jacobs, Lanza, Osgood, Eccles, & Wigfield, 2002; Lepper, Corpus, & Iyengar, 2005; Watt, 2004) nor inevitable (Vedder-Weiss & Fortus, 2011). As adolescents mature, their sphere of action expands and they may struggle with identity formation; they may encounter new objects and activities that kindle their interest, and peer relations gain in importance. These changes may impose time constraints that require students to focus on some topics or domains at the expense of others (Baumert & Köller, 1998). It is therefore common for science motivation to decline, although there are exceptions to this rule. Consequently, it is imperative to identify those factors that foster sustained interest in science.

Instructional Approaches Promoting Students' Science Career Motivation

Instructional approaches that seek to actively engage students in the learning process include project-based learning, problem-based learning, and inquiry-based learning. Students collaboratively investigate authentic problems or questions and engage in activities corresponding to those carried out by professionals (e.g. Blumenfeld et al., 1991; Minner, Levy, & Century, 2010). It is believed that such approaches foster students' understanding of scientific concepts, processes, and practices as well as their motivation and interest in science. From a psychological perspective, these instructional approaches make it possible to satisfy innate psychological needs (Deci & Ryan, 2000). Students are more autonomous during project-based learning than in regular science lessons because they take on the role of active learners who are responsible for the learning process and the project's outcome. The emphasis on collaborative learning helps to satisfy their need for relatedness. Working in teams also lightens the burden of the unfamiliar responsibilities associated with the new role. Finally, when students meet the requirements of project-based learning and experience feelings of efficacy, their need for competence is satisfied, and this benefits their self-concepts. Feedback may be more direct and perceived as more meaningful when students are required to communicate their ideas and their results to others. As the learning context provides opportunities to satisfy students' needs, it increases their motivation and interest in the subject (Andersen & Nielsen, 2011; Deci & Ryan, 2000; Krapp, 2005). Hidi, Weiss, Berndorff, and Nolan (1998), for example, found that efficacy experienced during a cooperative learning task enhanced interest in science. Specifically, each student was responsible for acquiring unique information and conveying it to classmates (jigsaw technique; e.g. Aronson & Patnoe, 2011). It is critical, however, to strike the right balance between student autonomy and teacher guidance (see Kirschner, Sweller, & Clark, 2006, for a discussion of detrimental effects resulting from insufficient guidance). Even college students' motivation may be undermined when they experience a lack of guidance in a problem-based learning environment (Wijnia, Loyens, & Derous, 2011). Research has also shown that students' perceptions of an effectively managed classroom had positive effects on the experience of autonomy and competence which, in turn, positively affected their interest in the domain (Kunter, Baumert, & Köller, 2007), indicating that the optimal level of autonomy generally involves some degree of structure provided by the teacher.

In addition, such activity-based approaches to science teaching allow students to become familiar with authentic activities associated with particular science careers. Despite the importance of science in modern societies, people tend to have little contact with science-related occupations in everyday life, and adolescents' access to science outside of school is limited. As a result, students may not be aware of the demands and activities possible careers would involve, or they may have false expectations (see also DeWitt, Archer, & Osborne, 2013). Activity-based approaches also foster career exploration, supporting students as they embark on the developmental task of choosing a career (e.g. Havighurst, 1948). Students depend on adequate information about possible careers to arrive at a career choice that matches their preferences and abilities and thus offers the prospect of a fulfilling professional life (e.g. Foskett & Hemsley-Brown, 2001; Super, 1990).

The Present Research

'Discover, Understand, Implement, and Transfer' was part of a regional initiative aiming to alleviate the shortage of skilled labour in STEM occupations. The purpose of the intervention programme was to maintain and increase students' interest in science and technology. The Kinderforscher an der TUHH developed a teaching approach for secondary schools of the highest educational track in the school system (in German: Gymnasium) and schools volunteered (i.e. self-selected) to integrate the programme, as an elective, into their school curriculum. It was primarily the teachers' responsibility to implement the teaching approach. However, funding under the regional initiative covered not only the evaluation of the intervention programme, but also support for teachers and students by the Kinderforscher an der TUHH. Students participating in the intervention programme opted for this elective from a set of electives offered by their respective schools for their grade levels. All students were admitted to the elective of their choice. Composition of the science elective was thus the result of self-selection and differed from the composition of regular science classes.

The intervention was characterised by project-based learning and involved regional companies offering science-based positions. As a first step, students familiarised themselves with their respective companies by gathering information about them—the products they produced, production processes, and the science involved. After such independent exploration, the students and their teachers took a field trip to the respective production site. Before touring the site, the students presented what they had learnt about the company. During these field trips, they were also given opportunities for hands-on activities and information about science careers with the companies.

Back at school, teams of students designed experiments based on the scientific knowledge they had acquired. They were at liberty to choose any topic they found interesting, provided that it was related to the subject matter they had encountered in connection with their cooperating company, that the experiment was based primarily on everyday materials, and that it was suitable for students in Grades 5 or 6. Towards the end of the school year, all teams taught science lessons at their respective schools, conducting the experiments with students in the lower middle-school grades. The prospect of teaching younger students—learning by teaching—is a pivotal characteristic of the intervention programme.

A longitudinal study design was employed to evaluate the effects of the intervention programme on students' science motivation. The summative evaluation is based on a number of motivational constructs targeted by the intervention as assessed by student self-reports at the beginning and towards the end of the intervention. Although teachers were instructed to follow the same teaching approach and received support from the Kinderforscher an der TUHH who had conceptualised it, the intervention is by no means a standardised procedure. For instance, the topics covered vary from class to class, depending on the regional company involved. Another source of variation inherent in the teaching approach is the degrees of freedom students should have while designing their experiments. Conceptually, students were assigned the role of active learners who shared responsibility for the learning process and for seeking help from the teacher or the Kinderforscher an der TUHH when necessary. The summative evaluation provides no data on how successful students and teachers were at fulfilling their respective roles.

Based on previous research and the conceptualisation of the teaching approach, we expected students participating in the intervention programme (i.e. students who had opted for the science elective) to report higher subjective values of science and higher science self-concepts towards the end of the intervention than at its beginning; a slight decrease in the values students attached to science was expected for the control group. Students' enjoyment of science and the importance they attach to the domain, as well as their motivation to learn science, were predicted to increase in the intervention group and to decrease in the control group. Although the intervention programme targeted only science motivation explicitly, we reasoned that given the additional learning opportunities, involving authentic problems or questions that actively engaged students in activities corresponding to scientists' professional activities, the intervention might enhance students' nature of science views more than merely attending regular science classes (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Finally, addressing the primary objective of the intervention programme, whereas control group students' motivation to pursue science careers was likely to decline, students participating in the programme were expected to be equally or even more strongly inclined to pursue a science career after participating in the programme than when they entered it.

Method

Participants

Two cohorts in each of the three participating schools took part in the programme. The intervention started with students from one grade level in each school and continued throughout the subsequent school year. Thus, students in this first cohort spent two consecutive years in the programme. The second cohort entered the programme a year later and participated for only one year. In two schools, the intervention was offered as an elective in Grades 8 and 9, in the third school in Grades 11 and 12. All students at the respective grade levels were surveyed; classmates of the students in the intervention group served as a control group (i.e. those students who attended the same classes as students in the intervention group with the exception of the elective). For the present analyses, only those students were considered who provided both pre- and post-test data.

Of the $n = 189$ students in Grade 8 (59.8% female) and the $n = 131$ students in Grade 11 (47.3% female), about a quarter opted for the science elective (30.7% in Grade 8, 26.0% in Grade 11). At the baseline assessment, the eighth graders were on average 13.61 years old (SD = 0.41) and the eleventh graders' mean age was 16.81 (SD = 0.52).

Procedure

The evaluation of the intervention was conducted by researchers who were not involved in its conceptual development or implementation. Care was taken to ensure students' anonymity in the scientific study. At no time did teachers have access to individual student's responses. Trained test administrators visited the schools at the beginning and end of the respective school years. Informed consent was obtained from parents before the questionnaires were administered; students' participation in the surveys was voluntary.

Measures

Student questionnaires contained 4-point rating scales measuring students' motivation to enter a science career, interest in science, the value students attach to science, and their science self-concept, as well as their conceptions of the nature of science (cf. e.g. Lederman et al., 2002). Except for the nature of science scale, all measures had been developed for the 2006 survey of the Programme for International Student Assessment (PISA; Organisation for Economic Co-operation and

Development [OECD], 2007). Motivation to enter a science career was measured with 4 items such as 'I would like to work on science projects as an adult'. Reliability of the scale was excellent (Cronbach's $\alpha = .93/.94$).[1] Enjoyment of science (i.e. the affective interest component; Hidi et al., 2004) was measured with 5 items such as 'I enjoy acquiring new knowledge in science' ($\alpha = .92/.92$). The 8 items designed to assess general interest in learning science asked students to indicate the extent to which they were interested in learning about the specified science topics (e.g. 'human biology' or 'what is required for scientific explanations'; $\alpha = .71/.75$). Two dimensions of value of science tapped the attainment value as conceptualised by the expectancy–value model and were measured by a mixed scale containing 5 items for each dimension (e.g. 'I find that science helps me to understand the things around me' measuring the personal value of science and 'Advances in science and technology usually improve people's living conditions' measuring the general value of science). The reliability of both scales was acceptable ($\alpha = .82/.83$ and $\alpha = .72/.76$). Students' science self-concept was measured with 6 items assessing agreement with statements like 'School science topics are easy for me' ($\alpha = .90/.92$). Students were explicitly instructed to base their responses on regular science classes. Adding a cognitive student characteristic to complement the evaluation of the intervention's success in increasing students' motivation for science, we assessed students' conceptions of the nature of science using 15 items such as 'Scientific theories change over time' ($\alpha = .77/.82$; e.g. Höffler, Lüthjohann, & Parchmann, 2014). The rating scale to indicate general interest in learning science ranged from 1 = *high interest* to 4 = *no interest*; all other scales ranged from 1 = *strongly agree* to 4 = *strongly disagree*. All items were recoded so that higher values of the composite indices reflect higher motivation, interest, value attached to science, and science self-concept, as well as a more appropriate conception of the nature of science, respectively.

Analyses

Mixed-model analyses of variance (ANOVAs) based on observed data were conducted with the IBM SPSS Statistics 19 software. Alternative analyses to estimate the amount of change and the between-subjects factors' effects with the M*plus* 7 software accounted for possibly different mean values in intervention and control groups at the start of the programme (latent growth models, LGM; e.g. Duncan, Duncan, & Strycker, 2006). Before conducting the LGMs, missing values for single constructs were multiply imputed ($m = 20$) for the $n = 320$ students who provided both pre- and post-test data. These analyses yielded effectively the same results as the ANOVAs. Therefore, we confine the report on the LGM results to those that differed between both types of analysis.

Results

A set of $2 \times 2 \times 2 \times 2$ mixed-model ANOVAs with treatment group (intervention, control), grade (Grade 8 or Grade 11 at the time of the baseline assessment), and cohort as between-subjects factors and the measurement occasions at which the students were surveyed (baseline, post-test) as a within-subjects factor revealed no main effects of cohort nor interaction effects of cohort with either grade, treatment group, or measurement occasion. The only exception was a significant two-way interaction of cohort and measurement occasion with regard to students' motivation to enter a science career, $F(1, 295) = 3.99$, $p = .047$, $\eta_p^2 = .013$. However, the difference in students' motivation to enter a science career between baseline and post-test assessment was not statistically significant in either cohort, $F(1, 159) = 1.64$, $p = .20$, and $F(1, 142) = 2.45$, $p = .12$. Therefore, data were collapsed across cohorts for subsequent analyses.

To evaluate the effects of the intervention programme on a range of motivational variables, we conducted 2 × 2 × 2 mixed-model ANOVAs with treatment group (intervention, control) and grade (Grade 8 or Grade 11 at the time of the baseline assessment) as between-subjects factors and the measurement occasions at which the students were surveyed (baseline, post-test) as a within-subjects factor on all dependent variables. Two-factor LGMs (e.g. Duncan et al., 2006) assessed the effects of treatment group and grade and their interaction on students' baseline scores as well as on the difference scores observed for the respective motivational constructs.

A substantial main effect of treatment group was observed for students' motivation to enter a science career, $F(1, 299) = 55.97$, $p < .001$, $\eta_p^2 = .158$. Students in the intervention group were more motivated to enter a science career than their classmates in the control group (cf. Table 1). The other main effects and all interaction effects were not statistically significant, Fs$(1, 299) < 1.34$, ps $> .24$.

With regard to students' enjoyment of science, the main effect of treatment group was also highly significant, $F(1, 312) = 50.29$, $p < .001$, $\eta_p^2 = .139$. Students in the intervention group reported greater enjoyment of science than the students in the control group. Moreover, the main effect of grade was statistically significant, $F(1, 312) = 4.01$, $p < .05$, $\eta_p^2 = .013$. Students in Grade 11 showed higher scores for enjoyment of science than students in Grade 8. The within-subjects factor and all interaction effects were not statistically significant, Fs$(1, 312) < 1.78$, ps $> .18$. The LGM, however, revealed a statistically significant effect of grade on the difference score in addition to the effects of treatment group and grade on the baseline score, $\beta = -0.14$, $p < .05$. Enjoyment of science decreased slightly in eleventh graders, but not in eighth graders.

The main effect of treatment group was also statistically significant for students' general interest in learning science, $F(1, 309) = 36.30$, $p < .001$, $\eta_p^2 = .105$. Students in the intervention group were generally more interested in learning science than students in the control group. In addition, the main effect of the within-subjects factor was statistically significant, $F(1, 309) = 9.70$, $p < .01$, $\eta_p^2 = .030$. However, the decline in students' interest in learning science was qualified by an interaction of the within-subjects factor and grade, $F(1, 309) = 8.74$, $p < .01$, $\eta_p^2 = .028$. Separate analyses revealed that interest in learning science remained stable in Grade 8 students, $F < 1$; however, Grade 11 students' interest in learning science was substantially lower at the post-test assessment as compared with baseline level, $F(1, 128) = 17.34$,

$p < .001$, $\eta_p^2 = .119$. In the LGM, the overall intercept of the difference score for general interest in learning science was not significantly different from zero, $z = 0.07$, $p = .12$; yet, the difference score was also predicted by grade, $\beta = -0.27$, $p < .001$. The main effect of grade and the other interaction effects were not statistically significant, *F*s(1, 309) < 1.64, *p*s > .20.

With regard to the value students attached to science for themselves personally as well as to science more generally, the main effect of treatment group was statistically significant for both value constructs, $F(1, 310) = 44.07$, $p < .001$, $\eta_p^2 = .124$, and $F(1, 313) = 15.95$, $p < .001$, $\eta_p^2 = .048$, for personal and general value of science, respectively. Students in the intervention group attached more value to science than did their classmates in the control group. For personal value of science, the main effect of the within-subjects factor was also statistically significant, $F(1, 310) = 8.74$, $p < .01$, $\eta_p^2 = .027$. It was, however, qualified by an interaction effect of the within-subjects factor and treatment group, $F(1, 310) = 4.17$, $p < .05$, $\eta_p^2 = .013$. Separate analyses for the intervention group and control group demonstrated that intervention group students attached lower personal value to science at post-test than baseline, $F(1, 89) = 9.38$, $p < .01$, $\eta_p^2 = .095$. Students in the control group attached similar personal value to science at both measurement occasions, $F < 1$. Further exploring mean differences between the groups, an independent samples *t*-test demonstrated that students in the intervention group still attached higher value to science at the post-test assessment than did students in the control group, $t(315) = -4.75$, $d = -0.58$. The main effect of grade and the other interaction effects were not statistically significant, *F*s(1, 310) < 1.30, *p*s > .25. However, LGM did not corroborate the ANOVA result that the personal value students participating in the intervention attached to science decreased from baseline to post-test assessment. The difference score was not significantly different from zero, $z = -0.13$, $p = .16$, nor was the effect of treatment group on the difference score statistically significant, $\beta = -0.11$, $p = .11$. With regard to the general value students attached to science, the significant main effect of the within-subjects factor indicated that it too was lower at the post-test assessment than at baseline, $F(1, 313) = 7.85$, $p < .01$, $\eta_p^2 = .024$. The main effect of grade and the interaction effects were not statistically significant, *F*s(1, 313) < 1.01, *p*s > .31. However, the decrease in the general value of science was also not found to be statistically significant in the LGM (i.e. the difference score was not significantly different from zero), $z = -0.11$, $p = .12$.

A main effect of treatment group was also observed for students' science self-concept, $F(1, 263) = 30.75$, $p < .01$, $\eta_p^2 = .105$. Students in the intervention group perceived themselves to be scientifically more competent compared with the self-perceptions of their classmates (cf. Table 1). The other main effects and all interaction effects were clearly not significant, *F*s(1, 263) < 1.30, *p*s > .25. Lastly, we addressed mean group differences in students' conceptions of the nature of science. As was the case for all other constructs considered, the main effect of treatment group was statistically significant, $F(1, 302) = 8.49$, $p < .01$, $\eta_p^2 = .027$. Students in the intervention group held more appropriate conceptions of the nature of science than did students in the control group. The main effect of grade was also statistically significant,

Table 1. Means and standard deviations by treatment group, grade, and measurement occasion

		Motivation to enter a science career				Interest in and enjoyment of science				General interest in learning science			
		Baseline		Post-test		Baseline		Post-test		Baseline		Post-test	
		M	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD
Group													
Control													
	Grade												
	8	2.07	0.81	2.12	0.83	2.54	0.79	2.58	0.78	2.59	0.61	2.67	0.61
	11	2.09	0.90	2.13	0.98	2.83	0.80	2.72	0.74	2.65	0.41	2.45	0.56
Intervention													
	Grade												
	8	2.77	0.75	2.73	0.85	3.24	0.54	3.17	0.66	2.99	0.49	2.91	0.51
	11	3.02	0.79	2.92	0.92	3.35	0.52	3.33	0.57	3.07	0.44	2.88	0.45

		Personal value of science				General value of science				Science self-concept				Nature of science			
		Baseline		Post-test		Baseline		Post-test		Baseline		Post-test		Baseline		Post-test	
		M	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD
Group																	
Control																	
	Grade																
	8	2.49	0.72	2.40	0.63	3.05	0.55	2.99	0.54	2.88	0.65	2.80	0.64	3.10	0.38	3.26	0.39
	11	2.48	0.60	2.50	0.71	3.01	0.48	2.94	0.54	2.68	0.65	2.72	0.61	3.29	0.28	3.24	0.39
Intervention																	
	Grade																
	8	3.01	0.56	2.79	0.76	3.28	0.39	3.18	0.54	3.19	0.49	3.16	0.56	3.16	0.36	3.34	0.39
	11	3.11	0.51	2.95	0.61	3.28	0.34	3.13	0.41	3.23	0.59	3.19	0.55	3.40	0.19	3.46	0.22

$F(1, 302) = 11.40$, $p < .001$, $\eta_p^2 = .036$. Students in Grade 11 viewed the nature of science more accurately than those in Grade 8. In accordance with this finding, the significant main effect of the within-subjects factor indicated that the nature of science scores increased over time, $F(1, 302) = 12.95$, $p < .001$, $\eta_p^2 = .041$. But this main effect was qualified by an interaction effect of the within-subjects factor and grade, $F(1, 302) = 11.97$, $p < .001$, $\eta_p^2 = .038$. Separate analyses for students in Grade 8 and Grade 11 revealed a highly significant effect in the former sub-sample, $F(1, 175) = 28.00$, $p < .001$, $\eta_p^2 = .138$, while no change was observed in the latter sub-sample, $F < 1$. Eighth graders' conceptions of the nature of science became substantially more appropriate over the period covered by the present study, whereas eleventh graders' understanding of the nature of science did not improve further. The other interaction effects were not statistically significant, Fs$(1, 302) < 1.75$, ps $> .18$. In contrast, the LGM revealed no difference between students in the intervention group and students in the control group with respect to the appropriateness of their conceptions of the nature of science; the effect of treatment group on the baseline score did not reach conventional levels of statistical significance, $\beta = 0.07$, $p = .20$.

Discussion

None of the motivational measures in our study indicated that the intervention programme, which was conceptualised to maintain and increase secondary school students' science motivation, had the intended effects. As the intervention programme was offered as an elective, students self-selected into the programme. Quite naturally, students who opted for the science elective were more interested in learning science and pursuing a career in science than were their classmates who had chosen other electives, they reported enjoying engaging in science more, they attached greater value to science, and they felt more competent. While the significant main effect of treatment group on the understanding of the nature of science in the ANOVA suggested that students in the intervention group were indeed more competent than their classmates, the LGM did not corroborate such a difference between these two groups. Participating in the intervention programme did not further increase students' science motivation—regardless of whether students spent one or two years in it.

Students in the intervention group valued science more than control group students at both measurement occasions. However, ANOVA results indicated that the personal value of science declined in the intervention group, despite regular exposure to the carefully designed intervention. Although LGM did not show a statistically significant decrease in personal value of science, the ANOVA result is consistent with the fact that talented students have multiple options (Wang, Eccles, & Kenny, 2013): Students who are highly competent in one academic domain are likely to be highly competent in other academic domains as well. Thus, their competencies place talented students in a position where they are able to consider careers in both science and non-science fields. Familiarising these students with possible science careers might be expected to raise the odds that they will choose a science career, provided that they perceive that career as matching their interests and abilities (e.g. Super, 1990; Wigfield & Eccles, 2000). Engaging students in activities corresponding to those carried out by professionals and giving them opportunities for hands-on activities and information about careers in science offered by the cooperating companies did not, however, increase their motivation to pursue a science-related career in the present study. A possible explanation for a decrease in the personal value that the intervention group students attached to science (although such a decrease was not corroborated by LGM) is that while in the programme, some students may have intensified their engagement in a non-science domain, or they may have encountered a new non-science topic that caught their interest, resulting in greater involvement with that topic. To rationalise shifting their interest away from science, students may have begun to attach less value to science for themselves personally (cf. Schütte, 2015). An alternative or complementary explanation is that students may have started the programme with expectations that have not been met. The selection of the cooperating company seems critical in this regard; it may not have been a good match for some students' interests. Having to engage with a particular science topic that a student does not relate to over the course of a whole school year may be harmful, in that it reduces the personal value students attach to science; science as a domain may be tainted by unsatisfying experiences with a particular topic or subfield. With a view to a successful and fulfilling professional life, the discouraging effect the intervention seems to have had on some students might in fact be a welcome effect: Unless students are truly interested in the activities that a science career involves, they would be ill advised to pursue it.

Among other factors, time constraints require adolescent students to focus their engagement on certain topics or domains at the expense of others. Against this background, and given previous research demonstrating the decline of students' interest in science (as well as in other domains; see e.g. Gottfried et al., 2001), it is remarkable that no decrease in students' science motivation was observed in either the intervention or the control group over the course of a one- or two-year period. This might be due in part to the fact that all of the schools—whose faculties or principals had initiated the implementation of this intervention programme—provided an environment that generally fostered students' motivation for science. Whether or not students eventually embark on science careers will depend on the strength of their motivation for science relative to other domains. Students in Grade 8 in the highest educational track have a couple of years before they will actually have to make their career choice. These students' interest in science may yet decline. It is therefore important to continue to provide activities designed to support and refine students' interest in science.

The observation that students in Grade 11 scored higher for enjoyment of science than did students in Grade 8 is in contrast to the robust finding that interest in academic domains declines during adolescence. In line with expectations and this research, eleventh graders' general interest in learning science declined between baseline assessment and post-test. Students in Grade 11 are all enrolled in the same school, so grade and school are confounded in our study. Although there seems to be great enthusiasm about science in all participating schools, students in Grade 11 shared an environment that may be even more advantageous with regard to science motivation than those provided by the other two schools. While students in Grade 11 reported higher mean scores than students in Grade 8 only for the enjoyment of science variable, the absence of further mean differences is remarkable, as previous research would suggest that younger students might be expected to report higher motivation than older students.

Moreover, it is possible that our rather global measures of students' science motivation failed to capture interest in a more specific scientific topic kindled by the intervention programme. For students to enter a science career that matches their interest, they need not be highly interested in science in general. But the pivotal measure in the current study showed no indication that students were won over for science careers by the intervention.

The intervention programme employed the approach 'learning by teaching'. Principally, this approach is suitable to foster a deep and persistent understanding (Fiorella & Mayer, 2013): Students who are required to teach a scientific issue that they have recently learnt about will be more inclined to engage with it cognitively, to elaborate on it, and to contemplate different ways to address it. Confronted with the task of teaching students in Grades 5 and 6 instead of peers, students in the intervention programme needed to design rather simple experiments comprehensible for much younger students. The scientific issues demonstrated through their experiments may not have been sufficiently engaging or cognitively challenging for students in the intervention. Moreover, in each school year, each team of students designed only one experiment or series of experiments. As a result, they spent a great deal of time in the role of a teacher rather than that of a scientist. Putting less emphasis on the teaching aspect and more on engaging in typical scientists' activities might increase the programme's effectiveness in motivating students to pursue science careers (Hunter, Laursen, & Seymour, 2007; Seymour, Hunter, Laursen, & DeAntoni, 2004).

Considerable research on science-related career aspirations has focused on underrepresented groups (Ceci, Williams, & Barnett, 2009; Hernandez, Schultz, Estrada, Woodcock, & Chance, 2013); particular barriers seem to apply to these students. However, much remains to be learnt about how to increase and maintain motivation for science careers among all students. Schools might more systematically address another aspect of students' career choices: the low visibility of many science occupations in everyday life. This may lead students to have ill-formed or false expectations of those occupations. The intervention allowed students to become thoroughly acquainted with the science occupations offered by the cooperating companies. This approach may have been too narrow, however. Science instruction might take on the task of conveying information about various science occupations. It seems vital, however, that students obtain a realistic concept of science occupations instead of being lured into careers that do not match their preferences.

Limitations

When an extensive intervention programme is implemented primarily by a third party, such as teachers, it is difficult to assess implementation fidelity—how strictly the teaching approach has actually been followed. A multitude of complications may have interfered with implementing the programme exactly as intended. However, teaching approaches like the one evaluated in the present study need to demonstrate their positive effects under real-life conditions; they cannot assume that conditions will be perfect. The teachers of the students surveyed for this evaluation were in fact actively supported by the researchers who had conceptualised the teaching approach; no such support will be available to other teachers seeking to implement this intervention to increase their students' science motivation. The teaching approach placed some responsibility for the learning process on the students. While they were expected to make decisions themselves, they could also seek help at all times. In the absence of relevant data, however, it is impossible to know whether or not students successfully self-regulated and experienced an optimal level of autonomy.

Another potential source of bias, in addition to the exceptional support provided for teachers who started the intervention programme, might come from the student sampling procedure: Only those students who provided data for both the baseline and the post-test assessment were considered for this evaluation. Participation was voluntary, and students who were willing to fill out the questionnaires may have had generally more positive attitudes towards science than their classmates who chose not to participate. Such selection bias is particularly likely with regard to the control group. Nevertheless, students in the possibly positively selected control group reported substantially lower science motivation on all of the variables considered in the evaluation, even at the outset. Even if the present sample was positively biased, this would not render the demonstration of the intervention's effectiveness more difficult.

However, a different kind of control group would allow for another insightful comparison to gauge the effectiveness of the intervention: a control group with students whose science motivation at the baseline assessment was comparable to that of the students in the intervention group and who would have liked to participate in the intervention programme but were not admitted to it. Such a control group would provide insight into how the science motivation of highly motivated students would have developed without the influence of the intervention. In the absence of such a control group, we can only speculate as to whether or not the intervention maintained a comparatively high level of motivation that would otherwise have decreased. Implementing such an additional control group was not possible in the current setting, however.

A further limitation of the present study was that it included only students in the highest educational track. While the measure employed to assess students' career aspirations related explicitly to academic science careers, conceptual replication studies should include students in lower educational tracks to provide a more complete picture of the programme's effectiveness. Implementing the proposed intervention programme in lower track schools might constitute a relatively more important complement of regular practice in science lessons. As previously mentioned, the investigated schools are recognised to provide a generally favourable environment with regard to science and science learning.

Conclusion

The intervention programme 'Discover, Understand, Implement, and Transfer' was conceptualised to increase the number of students who consider pursuing a science career. Kindling students' interest in science is a first important step, but sustaining this interest is equally important. To our knowledge, our study is the first to rigorously evaluate the effectiveness of a prolonged intervention programme (lasting up to 2 years).

Even at the start of the intervention programme, participating students were more motivated to enter a science career than their classmates. Participating in the programme did not further increase these students' science motivation. It would be interesting to investigate whether the intervention programme would achieve the expected effect of increasing students' science motivation if the participating students did not self-select, and if they were less motivated at the outset. Given the plethora of science topics and the low visibility of many science occupations in everyday life, talented but rather uninterested students may not have a good understanding of what science and science careers actually have to offer. A generally high interest in (school) science is unnecessary for students to be passionate about a particular science topic and to flourish as a scientist.

With a view to increasing the number of students who consider pursuing a science career, the major challenge appears to be to provide all students with opportunities to engage in scientific activities that match their respective interests. In the absence of meaningful ways of engaging in science, even highly interested students may turn their back on this field. Cooperating with a regional company would seem to be an excellent way to provide first-hand experiences of the careers in science offered by the company and to establish contacts between potential future employers and employees. However, the company prescribes the range of science topics students will focus on over the course of an entire school year. It seems unlikely that the science involved in a company's products and production processes—however fascinating it might be for some students—will match the interests of all participating students. Allowing students to expand the scope of scientific topics they address within the intervention programme and providing them with a broader range of information might make the intervention programme more effective. At the same time, increasing the level of interest of those who are already highly interested may be an unreasonable goal. With these students, interventions should focus on maintaining and refining their interest in science.

Furthermore, the teachers involved in the programme were highly motivated and highly supportive with regard to students learning science. Implementing an intervention programme might increase motivation to explore science when the school environment is generally less conducive to achieving that goal. However, unless teachers are enthusiastic about science, they are unlikely to adopt a teaching approach such as the one presented here, as it places higher demands on them relative to regular science teaching.

The programme 'Discover, Understand, Implement, and Transfer' might be improved further by placing greater emphasis on engaging students in typical scientists' activities rather than (preparing for) teaching younger students. Such a conceptual modification would also make it possible to cover a broader range of science topics. If teachers were required to launch such a class on their own, this would place even higher demands on them than the current approach. However, educational research as well as teacher collaboration might promote the development of appropriate teaching materials, thus ultimately helping to prepare society to meet the challenges of the future.

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Note

1. Reliabilities as obtained for the baseline assessment and for the post-test assessment, respectively.

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