Changes in motivation levels and academic achievement of first year STEM students

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INTRODUCTION

Even though there is a high market demand for Science, Technology, Engineering, and Math (STEM) graduates, the combination of a declining interest of high school students for STEM studies with low success rates of first year university students remains problematic. It is not sufficient to attract more students towards STEM programs, but also retention of first year STEM students must be improved. To better understand the STEM first-year experience and to identify targets for effective interventions, further research on academic achievement and retention in STEM programs is essential.
STEM programs typically require a strong academic preparation in mathematics since math modules of varying complexity are obligatory in all first-year STEM programs, and numerous achievement studies in STEM have focused on the effect of cognitive variables, such as high school scores and entrance math test scores [1,2] Besides these cognitive variables, also motivational factors are crucial in the learning process, and both academic self-concept and autonomous motivation have been associated with the use of more optimal learning strategies and better academic achievement [3–5].

Motivational factors are dynamic and a longitudinal approach is recommended especially when motivation is studied during transitions to new learning environments, such as the first year of university, which is a time of substantial change that requires adjustment to the discipline area and to university life. Academic self-concept develops in a reciprocal interaction with academic achievement: prior academic self-concept predicts subsequent achievement, which in turn influences subsequent academic self-concept after controlling for prior achievement [6]. Until now, little is known on how both autonomous motivation and academic self-concept change during the unstable transition phase of the first year in university, and if so, which factors influence these changes. A better understanding of the evolution of motivation and self-concept of first year STEM students can contribute to the development of an improved first year curriculum and of effective coaching programs.

1 OBJECTIVES

In this study, we investigate the association of motivation and self-concept with academic achievement in first year academic bachelor students in various academic STEM programs, and changes in motivation and self-concept during the first semester. Given the importance of mathematics for achievement in STEM studies, not only general academic self-concept but also domain-specific mathematics self-concept is included in the study. Based on the available literature, we hypothesize that students who initially have a higher level of autonomous motivation, a higher general academic self-concept and a higher mathematics self-concept, will have a

higher academic achievement after controlling for cognitive variables, such as prior achievement and prior education (hypothesis 1). Given the reciprocal relationship between academic achievement and academic self-concept, we expect that students with a higher academic achievement will subsequently have a higher autonomous motivation and a higher general academic self-concept (hypothesis 2).

2 METHODS

2.1 Data collection and survey methodology

We carried out a questionnaire survey at the University of Leuven during academic year 2012-2013 with new bachelor students enrolled in five different academic STEM program clusters: bioscience engineering, chemistry/biochemistry & biotechnology/biology/geology/geography (hereafter referred to as ChemBioGeo), engineering science, engineering technology, and mathematics/physics/computer science (hereafter referred to as MathPhysComp). The questionnaires tapped students' motivation of study choice for their particular study program, their general academic self-concept and their mathematics self-concept. To have a representative group of respondents, paper-and-pencil questionnaires were presented during a class period at two different time points: at the start of the academic year (time point T1) and at the beginning of the second semester, after disclosure of exam results of the first semester (time point T2). Participation was voluntary and confidentiality was guaranteed, and students provided informed consent for their participation (Table 1).

Table 1. Number of respondents that participated both at T1 and T2 by STEM cluster and gender

STEM cluster	Male	Female	Total (%)
Bioscience Engineering	71	73	144 (12,8%)
ChemBioGeo	104	81	185 (16,5%)
Engineering science	349	59	408 (36,3%)
Engineering Technology	279	36	315 (28,0 %)
MathPhysComp	63	9	72 (6,4%)
Total	866	258	1124 (100%)

To measure academic motivation, we used a shortened version of the Academic Self-regulation Scale [4,7] tapping students' motivational drive for studying their chosen bachelor program, on a 5–point Likert scale. Composite scales were created for autonomous and controlled motivation, by averaging the subscales for intrinsic and identified regulation (autonomous regulation), and for introjected and external regulation (controlled motivation)[4] The composite scales had good internal consistencies: autonomous motivation T1 ($\alpha = 0.76$) and T2 ($\alpha = 0.81$); controlled motivation T1 ($\alpha = 0.76$) and T2 ($\alpha = 0.78$). The absence of motivation (called a-motivation) was measured with two items, the scale had a satisfactory internal consistency (T1: $\alpha = 0.64$; T2: $\alpha = 0.68$).

Students' self-concept was tapped by focusing on their academic outcome expectancy in terms of study success. Three items were used about how confident and prepared students felt to succeed in their study. The items were "*I expect that I will be able to succeed in my study*", "*I feel well prepared for this study*", and "*I fear this study will be too difficult for me*" (reverse scored). The reliability in terms of internal consistency of the scale was good (T1: $\alpha = .71$; T2 : $\alpha = .78$).

Mathematics self-concept was measured at T1 only, with three items judging their ability in mathematics. The items were "*I usually get good grades on mathematics*", "*I am good in courses that require mathematical reasoning*", and "*I am good in mathematics*" The reliability in terms of internal consistency of the scale was very good ($\alpha = .85$).

Students' prior achievement was based on the overall percentage obtained at the end of high school, which was labeled as "prior high school result". Also background information on student's gender and students secondary education program was collected, namely the amount of mathematics during the last year of secondary education (hours per week), and the previous study program in secondary school (obtained from the university database). Since in Flanders many different secondary study programs exist, every program was classified to one of four "prior study program groups", of which students from group 1 traditionally have the lowest academic success rate, and students of group 4 traditionally have the highest academic success rate.

Students' academic achievement data were obtained from the university database after the first examination period in January (mean of scores on all exams, expressed as percentage). Percentage of credits obtained was used to classify students into low achievers (40% or less credits obtained), medium achievers (41%-80% of credits obtained) and high achievers (more than 80% of credits obtained).

2.2 Data analyses

Data analyses were performed using SPSS version 20.0 (SPSS, Inc., Chicago) and SAS 7 (SAS Institute, Cary NC) using standard statistical procedures as described in the results section (factor analysis, independent samples t-test, paired samples t-test, regression analysis).

3 RESULTS AND DISCUSSION

3.1 Effect of initial motivation and self-concept on academic achievement

To investigate hypothesis 1, a regression analysis was performed with academic achievement as dependent variable, and the various motivational variables at T1 (autonomous motivation, controlled motivation, a-motivation, academic self-concept, math self-concept) as predictor variables. To control for prior cognitive variables and for background variables, the final model was built in different steps.

In the first model (Table 2), cognitive and background variables were added as predictors to the model. A dummy variable was constructed for gender (1= female), for prior study program group (reference prior study program group = 2) and for STEM cluster (reference STEM cluster = bioscience engineering). Prior high school result was the most powerful predictor for academic achievement. Also number of weekly hours of mathematics in prior secondary education, prior study program group and STEM cluster had significant effects on academic achievement. The model with cognitive variables and background variables explained 35 % of the observed variance in academic achievement.

The second model contained the motivational variables measured at T1. Only mathematical self-concept was a significant predictor of academic achievement. This model with motivational variables only had a small explanatory power of 8,3 %.

Table 2. Effect of initial motivational variables at T1 on academic achievement

DV Academic achievement	**Model 1**	**Model 2**	**Model 3**
predictor	**Standardized β**	**Standardized β**	**Standardized β**
prior high school result	**,552*** **		**,504*** **
weekly hours of math	**,182*** **		**,163*** **
prior study program group:			
1	**-,206*** **		**-,202*** **
2	**-,097*** **		**-,092*** **
3 (reference)			
4	,041 *ns*		,037 *ns*
gender (0-1 female)	-,055*		-,050*ns*
STEM cluster:			
Engineering Science	-,109*		**-,131****
Engineering Technology	**,188*** **		**,162*** **
Bioscience engineering (ref)			
ChemBioGeo	,071 *ns*		,066 *ns*
MathPhysComp	,039*ns*		,028*ns*
Academic Self-Concept T1		,069*	,024*ns*
Math Self-concept T1		**,258*** **	,072*
A-motivation T1		,064*ns*	,058*
Controlled motivation T1		,043*ns*	,038*ns*
Autonomous motivation T1		-,042*ns*	,034*ns*
N	*980*	*1098*	*980*
R^2_{adj}	**0.350**	**0.083**	**0.357**

**** p < .001, ** p < .01, * p < .05*

In the third and final model, we included both cognitive variables, background variables and motivational variables. The final model explained 35,7 % of the observed variance in achievement, which is only slightly more compared to the first model. There were no meaningful contributions of any of the various motivational variables: even though math concept had a significant contribution in Model 2, the weight of it in Model 3 is so small that it becomes negligible in comparison with the contributions of prior high school result and study program.

The absence of an effect of motivational variables on academic achievement does not support the first hypothesis and contrasts with the results of a recent meta-analysis [5] that identified self-efficacy and self-concept as the most consistent predictors of achievement. A possible explanation for the absence of a detectable effect of motivational variables on achievement might be the fact that the first measurement of motivation took place in the first week of the academic year. It can be expected that the majority of new students are highly motivated at the start of their study. Also, it is obvious that at this starting point, many of them are unable to exactly gauge how well they will perform in a new demanding learning environment: while some students underestimate their potential, others have unrealistic expectations

and are overly confident. During the first semester, the reality of university life and the heavy requirements of the study program might have a dampening effect on students' initial motivation levels, and also exam results are expected to have a profound effect on both academic self-concept and motivation.

3.2 Effect of academic achievement on subsequent motivation and self-concept

To gain more insight in the evolution of motivation during the semester, we investigated whether academic achievement at the end of the first semester is a significant predictor of subsequent levels of autonomous motivation and academic self-concept measured at the start of the second semester. We speculate that a high academic achievement will have a positive effect on academic self-concept and autonomous motivation, whereas weak academic achievement will have the opposite effect.

To investigate the second hypothesis, regression analyses were performed with academic self-concept at T2 as dependent variable. In the first model, prior cognitive variables and background variables were entered as predictors, together with the various motivational variables at T1 (autonomous motivation, controlled motivation, a-motivation, academic self-concept, math self-concept) (Table 3).

Table 3. Effect of academic achievement on academic self-concept at T2

DV Academic Self-concept T2	**Model 1**	**Model 3**
predictor	**Standardized β**	**Standardized β**
prior high school result	**,159*** **	-,052^{ns}
weekly hours of math	**,186*** **	**,105*** **
prior study program group:		
1	**-,112*** **	-,032^{ns}
2	-,052^{ns}	-,023^{ns}
3 (reference)		
4	-,014^{ns}	,034^{ns}
gender (0-1 female)	**-,112*** **	**-,091*** **
STEM cluster:		
Engineering Science	**-,170** **	**-,114** **
Engineering Technology	-,019 ^{ns}	-,079*
Bioscience engineering (ref)	,039^{ns}	
ChemBioGeo	,067^{ns}	,039^{ns}
MathPhysComp	-,058^{ns}	-,071*
Academic Self-Concept T1	**,431*** **	**,423*** **
Math Self-concept T1	,073*	,050^{ns}
A-motivation T1	,021^{ns}	-,017^{ns}
Controlled motivation T1	,036^{ns}	,015^{ns}
Autonomous motivation T1	,053^{ns}	,031^{ns}
Academic achievement		**,433*** **
N	*999*	*980*
$\mathbf{R^2_{adj}}$	**0.369**	**0.500**

*** p < .001, ** p < .01, * p < .05*

Academic Self-concept at T1 was the most powerful predictor for Academic Self-concept at T2. Also weekly hours of math in prior secondary education and prior high school result, had significant effects on Academic Self-concept at T2. The first model explained 36,9 % of the observed variance in Academic Self-concept at T2.
In the second model academic achievement was added as predictor. This model explained 50 % of the observed variance in academic self-concept at T2. Academic self-concept at T1 and academic achievement are equally powerful predictors of academic self-concept at T2. The weekly hours of math in prior secondary education had a small positive contribution on the level of academic self-concept at T2, whereas being female or being enrolled in the Engineering Science program had a small negative impact.

We also regressed autonomous motivation at T2 on the various motivational variables at T1 (autonomous motivation, controlled motivation, a-motivation, academic self-concept, math self-concept). Model 1 in Table 4 shows that autonomous motivation at T1 was the most powerful predictor for autonomous motivation at T2. Cognitive background characteristics had little effect, whereas being enrolled in Engineering Science had a small negative effect on autonomous motivation at T2. In Model 2, academic achievement was added as predictor, but this had only a minor additional effect on the explanatory power.

Table 4. Effect of academic achievement on autonomous motivation at T2

DV Autonomous motivation T2	**Model 1**	**Model 3**
predictor	**Standardized β**	**Standardized β**
prior high school result	,069*	-,022^{ns}
weekly hours of math	,017^{ns}	-,017^{ns}
prior study program group:		
1	-,008^{ns}	,029^{ns}
2	,005^{ns}	,022^{ns}
3 (reference)		
4	-,006^{ns}	-,003^{ns}
gender (0-1 female)	,006^{ns}	,017^{ns}
STEM cluster:		
Engineering Science	**-,126****	-,098*
Engineering Technology	-,076^{ns}	-,103*
Bioscience engineering (ref)		
ChemBioGeo	-,042^{ns}	-,057^{ns}
MathPhysComp	-,016^{ns}	-,022^{ns}
Academic Self-Concept T1	-,010^{ns}	-,012^{ns}
Math Self-concept T1	-,048^{ns}	-,068*
A-motivation T1	-,054^{ns}	-,064*
Controlled motivation T1	,016^{ns}	,005^{ns}
Autonomous motivation T1	**,543*****	**,537*****
Academic achievement		**,189*****
N	*999*	*980*
R^2_{adj}	**0,321**	**0,343**

**** p < .001, ** p < .01, * p < .05*

These results support the second hypothesis partially: academic achievement significantly contributes to adjustment of academic self-concept at T2, but the effect on autonomous motivation is very limited.

To investigate the impact of academic achievement on the change in self-concept and motivation from T1 to T2, we compared the mean self-concept and motivation levels between both time points and between 3 achievement groups: low achievers (40% credits or less) *versus* medium achievers (41-80% credits) *versus* high achievers (80 % credits or more) (Table 5).

A paired samples t-test was used to investigate mean differences between T1 and T2 per motivational variable and per achievement group. Significant differences of a particular row are indicated in the last column of Table 5.
ANOVA with a post-hoc analysis of significant differences (Tukey HSD) was used to compare mean differences between achievement groups, per time period and per motivational variable. Significant differences are indicated by different subscripts in each column block of table 5, containing mean values of 1 motivational variable of the 3 achievement groups at 1 time point.

Table 5. Means (M) and changes in motivational variables from T1 to T2 by achievement group (low (N = 389), medium (N = 325), high (N = 385))

Motivational variable	**Achievement Group**	**M T1 (SD)**	**M T2 (SD)**	**t (1)**	**Sig (1)**
Autonomous motivation	Low	3,96 $_{a}$ (0,49)	3,83 $_{a}$ (0,56)	4,927	<.001
	Medium	3,96 $_{a}$ (0,53)	3,85 $_{ab}$ (0,58)	3,895	<.001
	High	3,94 $_{a}$ (0,52)	3,95 $_{b}$ (0,51)	-0,333	*ns*
Controlled motivation	Low	1,74 $_{a}$ (0,59)	1,81 $_{a}$ (0,61)	-2,308	<.05
	Medium	1,77 $_{a}$ (0,57)	1,86 $_{a}$ (0,61)	-3,081	<.01
	High	1,80 $_{a}$ (0,64)	1,85 $_{a}$ (0,65)	-1,599	*ns*
A-motivation	Low	1,30 $_{a}$ (0,52)	1,56 $_{a}$ (0,70)	-7,347	<.001
	Medium	1,31 $_{a}$ (0,51)	1,43 $_{b}$ (0,68)	-3,478	<.001
	High	1,37 $_{a}$ (0,59)	1,35 $_{b}$ (0,50)	0,689	ns
Academic Self-concept	Low	3,52 $_{a}$ (0,59)	3,21 $_{a}$ (0,65)	9,594	<.001
	Medium	3,65 $_{b}$ (0,51)	3,74 $_{b}$ (0,57)	-3,077	<.01
	High	3,73 $_{c}$ (0,58)	4,02 $_{c}$ (0,57)	-10,654	<.001

[1] *paired samples t-test*

At T1, there are no significant differences in autonomous motivation, controlled motivation or a-motivation between the three achievement groups. However, when evaluating the changes from T1 to T2, low and medium achievers change towards a less optimal motivation profile, with a decrease in autonomous motivation and an increase in controlled motivation and a-motivation, whereas high achievers show no change in mean motivational levels.

At T1, significant differences exist in mean levels of academic self-concept between the achievement groups, with low achievers having a significantly lower academic self-concept. At T2, the differences between the achievement groups increase, since

low achievers have a significant drop in academic self-concept, whereas medium and high achievers show a moderate resp. high increase in academic self-concept.

4 SUMMARY

At the transition point from secondary school to university, initial autonomous motivation and academic self-concept levels are not related to subsequent academic achievement in STEM programs, when cognitive and background characteristics are taken into account. After one semester at university, early academic achievement is significantly and positively related to subsequent academic self-concept and, to a much lesser extent, to autonomous motivation. Apparently, knowledge of exam results allows students to adjust their academic self-concept accordingly. The effect of achievement on changes in motivation is more subtle and different for high achievers *versus* low achievers. Motivation levels of high achieving students do not change significantly from T1 to T2, but their initial self-concept, which is already high compared to low achievers, increases significantly. Low achievers change towards a less favourable motivational profile (lower autonomous motivation, higher controlled motivation, and higher a-motivation) and their already low self-concept decreases significantly. The implications of these findings will be discussed, and further research will investigate whether the adjusted self-concept and motivational levels at T2 are related to later academic achievement.

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