Learning and Motivation 74 (2021) 101723

Contents lists available at ScienceDirect

Learning and Motivation

journal homepage: www.elsevier.com/locate/l&m

Predicting final grades in STEM courses: A path analysis of academic motivation and course-related behavior using self-determination theory

Diana Botnaru [a], Jessica Orvis [b], Jody Langdon [a], Christopher P. Niemiec [c,d,e], Shainaz M. Landge [b,*]

[a] Department of Health Sciences and Kinesiology, Georgia Southern University, United States
[b] Department of Chemistry and Biochemistry, Georgia Southern University, United States
[c] Department of Psychology, University of Rochester, United States
[d] Department of Public Health, University of Stavanger, Norway
[e] Centre for Learning Environment, University of Stavanger, Norway

ARTICLE INFO

Keywords:
Academic performance
Autonomous motivation
Controlled motivation
Self-determination theory
STEM

ABSTRACT

Within self-determination theory, a considerable amount of previous research has shown that autonomous motivation is associated with higher levels of academic achievement and wellness among students. However, it is notable that few studies have included large samples of undergraduates who are enrolled in science courses. Moreover, to our knowledge no previous research has investigated the associations among autonomous and controlled motivations, course attendance, time spent studying, perceived course difficulty, and final course grades simultaneously. The current study was designed to begin to fill this gap in the literature. In the fall (33 course sections) and spring (29 course sections) semesters, undergraduate students (N = 1284) who were enrolled in general chemistry, organic chemistry, and human anatomy and physiology courses responded to a 24-item survey at the beginning (Time 1) and at the end (Time 2) of the semester. The results revealed considerable stability in motivation over time as well as strong association between autonomous and controlled motivations at each time point. Autonomous motivation at Time 2 predicted higher levels of time spent studying and final course grades, and lower levels of perceived course difficulty. Controlled motivation at Time 2 predicted higher levels of course attendance, time spent studying, and perceived course difficulty, and lower levels of final course grades. These findings indicate that both autonomous and controlled motivations contribute to final course grades (albeit in opposite directions) and highlight the importance of creating need-supportive educational climates that facilitate the cultivation of autonomous motivation.

1. Introduction

The theoretical framework that guided the current study is self-determination theory (SDT; Deci & Ryan, 2008; Niemiec, Ryan, &

* Corresponding author at: 521 College of Education Drive, Department of Chemistry and Biochemistry, Georgia Southern University, Statesboro, GA, 30460, United States.
E-mail address: slandge@georgiasouthern.edu (S.M. Landge).

https://doi.org/10.1016/j.lmot.2021.101723
Received 10 March 2020; Received in revised form 26 February 2021; Accepted 28 February 2021
Available online 28 April 2021

Deci, 2010; Ryan & Deci, 2017; Vansteenkiste, Niemiec, & Soenens, 2010), which is a macro-theory of human motivation that has been applied broadly to life domains, including education (see Niemiec & Ryan, 2009; Ryan & Niemiec, 2009). At the core of SDT is the specification of basic psychological needs for autonomy (an experience of choicefulness), competence (an experience of effectance), and relatedness (an experience of mutual connection with important others) that, when supported (see Niemiec, Soenens, & Vansteenkiste, 2014), are conducive to behavioral persistence, high-quality performance, full functioning, and organismic wellness (cf. Niemiec & Ryan, 2013). More germane to the current study, support for these basic psychological needs facilitates the internalization of motivation (or reasons for action), which in turn promotes perceived competence and optimal outcomes.

According to SDT, motivation is a differentiated concept whose types exist along an underlying continuum of relative autonomy. With *amotivation*, a person perceives a lack of contingency between their behavior and attainment of desired outcomes and/or an inability to do what is necessary to attain desired outcomes, which tends to result in passivity. With *extrinsic motivation*, a person performs a behavior in order to attain a separable outcome, such as obtaining a reward or avoiding a punishment. SDT specifies four types of extrinsic motivation that vary in the degree to which they have been internalized into the self, and thus are experienced as more or less autonomous (Ryan & Deci, 2000). The least internalized (and least autonomous) type of extrinsic motivation is external regulation, in which a person engages in a behavior in order to satisfy external contingencies such as the receipt of rewards or avoidance of punishments (e.g., a student who studies in order to earn a good grade on an exam). The next type of extrinsic motivation is introjected regulation, in which a person engages in a behavior in order to satisfy internal contingencies such as the experience of pride or avoidance of guilt (e.g., a student who studies in order to feel like a "good student"). Both external and introjected forms of regulation are experienced as relatively controlled types of extrinsic motivation. As the process of internalization proceeds, the next type of extrinsic motivation is identified regulation, in which a person engages in a behavior because of its personal value and/or importance (e.g., a student who studies because the coursework is personally relevant). The most internalized (and most autonomous) type of extrinsic motivation is integrated regulation, in which a person engages in a behavior not only because of its personal value and/or importance but also because it is aligned with other abiding values and beliefs (e.g., a student who studies because the coursework is conducive to the attainment of self-endorsed aspirations). Both identified and integrated forms of regulation are experienced as relatively autonomous types of extrinsic motivation. With *intrinsic motivation*, a person performs a behavior because it is inherently satisfying and enjoyable to do—with no separable outcomes or contingencies that initiate and maintain the behavior. Indeed, intrinsic motivation often occurs spontaneously and is accompanied by experiences of interest, excitement, and enjoyment.

As suggested above, these types of motivation can be combined into two broad categories. Autonomous motivation means to endorse one's behavior fully, and includes intrinsic motivation, integrated regulation, and identified regulation. In an academic setting, autonomous motivation is linked to a student's desire to learn and develop conceptual understanding. In contrast, controlled motivation means to be coerced into behavior by non-self-endorsed forces, and includes introjected regulation and external regulation. In an academic setting, controlled motivation is linked to a student's desire for a certain grade or to meet personal and/or social expectations.

Within SDT, a considerable amount of previous research has shown that autonomous motivation is associated with higher levels of academic achievement and wellness among students (see Niemiec & Ryan, 2009), and a recent meta-analysis found a positive association between intrinsic motivation and performance at the population level (Cerasoli, Nicklin, & Ford, 2014). For instance, changes in autonomous motivation over a semester have been found to relate positively to changes in academic performance (Black & Deci, 2000). Also, across educational levels autonomous motivation has been found to relate positively to measures of self-regulated learning (Sobral, 2004), perceived academic performance (Jeno & Diseth, 2014), and optimal learning behavior and academic functioning (Vansteenkiste, Sierens, Soenens, Luyckx, & Lens, 2009).

Yet some previous research has revealed atypical patterns of association between autonomous and controlled motivations. For instance, Gillet, Morin, and Reeve (2017) found that positive outcomes among students are predicted by higher levels of both autonomous and controlled motivations, thus indicating a buffering role for autonomous motivation. Other research has shown that optimal motivation toward science is marked by higher levels of intrinsic and extrinsic motivations, and lower levels of failure avoidance, among undergraduates who are enrolled in physics, chemistry, and biology (Smith, Deemer, Thoman, & Zazworsky, 2014). Still other research did not find significant associations between academic motivation and achievement among medical students (Hulsman et al., 2007; Popovic, 2010) and organic chemistry students at the start of their semester (Black & Deci, 2000). Finally, some research has suggested that extrinsic motivation is the strongest predictor of final course grades (Sturges, Maurer, Allen, Gatch, & Shankar, 2016) and that controlled motivation contributes to academic success (Sobral, 2004).

A considerable amount of previous research has shown that academic motivation is associated with grade point average (GPA). For instance, a recent meta-analysis found a small but statistically significant positive association between intrinsic motivation and GPA, and no association between extrinsic motivation and GPA (Richardson, Abraham, & Bond, 2012). Other research has shown that amotivation is detrimental to GPA (Erten, 2014). It is important to reflect on reasons for this pattern of association. Generally speaking, time spent studying, amount of effort, and quality of the study environment are expected to predict academic performance (see Puzziferro, 2008), and time spent studying has been shown to be a better predictor of final course grades than course attendance among economics students (Andrietti & Velasco, 2015). Critically, though, autonomous motivation has been shown to be associated with better use of metacognitive strategies, critical thinking skills, effort regulation, effective study strategies, and study behavior (Hulsman et al., 2007; Kusurkar, Ten Cate, Vos, Westers, & Croiset, 2013; Michou, Vansteenkiste, Mouratidis, & Lens, 2014; Sobral, 2004), which are associated with higher levels of study effort (Kusurkar et al., 2013; Wilkinson, Wells, & Bushnell, 2007). These findings highlight the connection between autonomous motivation and specific outcomes that are predictive of academic performance.

It is not surprising that based on survey research, students perceive some courses as more difficult than others, and that perceptions of task difficulty in a course (a proxy for the overall difficulty level of a course; Mundfrom, 1991) are associated with performance in a course. Importantly, though, perceptions of course difficulty have implications for academic motivation. For instance, perceptions of course difficulty have been found to relate negatively to perceived competence among high school science students, which can lead to disengagement (Patall, Hooper, Vasquez, Pituch, & Steingut, 2018). In this way, course difficulty can have a direct impact on academic motivation and, in turn, performance. Yet teacher autonomy support (including provision of a meaningful rationale) can mitigate perceptions of course difficulty, such that psychology students performed better than non-majors when told that completion of a difficult task in a course was relevant to their major and future success (Britt, 2005).

It is also not surprising that course attendance is associated with performance in a course (Lukkarinen, Koivukangas, & Seppälä, 2016; Lyubartseva & Mallik, 2012). For instance, a meta-analysis of 52 published and 16 unpublished studies found that course attendance was a better predictor of academic performance than high school GPA, SAT score, study habits, or study skills (Credé, Roch, & Kieszczynka, 2010), although this association might not be uniform across demographic categories (see Cortright, Lujan, Cox, & DiCarlo, 2011; Dey, 2018). That being said, course attendance might not always predict academic performance. For instance, some research has shown that time spent studying is a stronger predictor of final course grades than course attendance among economics students (Andrietti & Velasco, 2015). Indeed, other research has found that Master's-level students who do not attend class but have

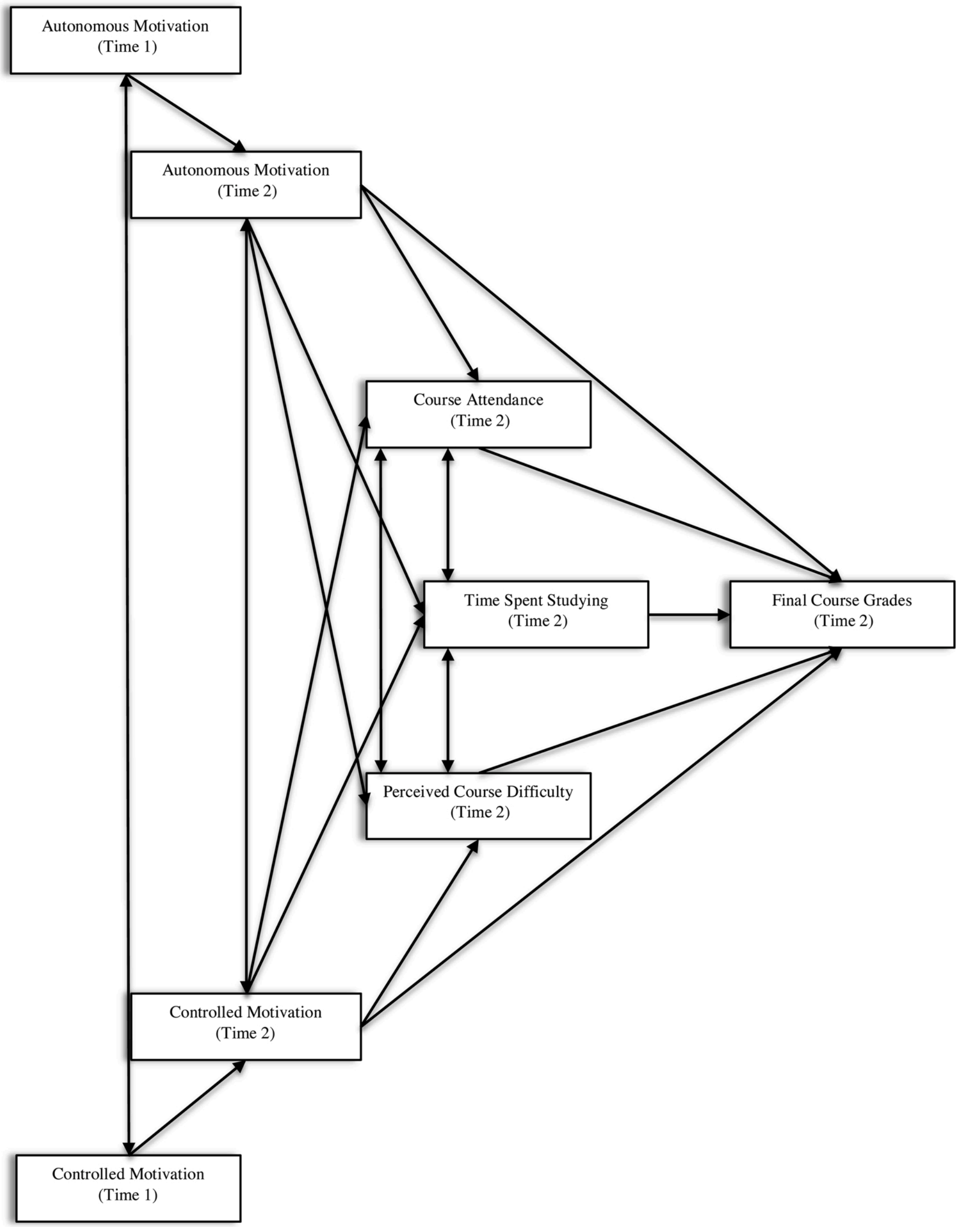

Fig. 1. The hypothesized model.

effective study skills still perform well in their courses (Lukkarinen et al., 2016). Germane to the focus of the current study, course attendance and student characteristics such as motivation appear to make unique contributions to academic performance (Credé et al., 2010).

This review of the literature—albeit incomplete—highlights the link between academic motivation and performance. However, it is notable that few studies have included large samples of undergraduates who are enrolled in science courses. Moreover, to our knowledge no previous research has investigated the associations among autonomous and controlled motivations, course attendance, time spent studying, perceived course difficulty, and final course grades simultaneously. The current study was designed to begin to fill this gap in the literature.

2. Research questions and hypotheses

The current study targeted students in three undergraduate courses, namely, Principles of Chemistry I and II (GChem), Organic Chemistry I and II (OChem), and Human Anatomy and Physiology I (HAP). Three research questions were proposed:

1 What is the association between autonomous motivation at the beginning (Time 1) and at the end (Time 2) of the semester, and what is the association between controlled motivation at the beginning (Time 1) and at the end (Time 2) of the semester?
2 What is the association between autonomous and controlled motivations at Time 1 and at Time 2?
3 What are the relations of autonomous and controlled motivations at Time 2 to course attendance, time spent studying, perceived course difficulty, and final course grades?

Examining Research Question 1, the hypothesized model specified a direct relation of autonomous motivation at Time 1 to autonomous motivation at Time 2, and a direct relation of controlled motivation at Time 1 to controlled motivation at Time 2. Examining Research Question 2, the hypothesized model specified correlations between autonomous and controlled motivations at Time 1 and at Time 2. Examining Research Question 3, the hypothesized model specified direct relations of autonomous and controlled motivations at Time 2 to course attendance, time spent studying, perceived course difficulty, and final course grades. This model also specified direct relations of course attendance, time spent studying, and perceived course difficulty to final course grades. Fig. 1 depicts the hypothesized model.

3. Method

3.1. Targeted courses in the current study

The targeted courses in the current study are two-sequence courses that require a grade of C or higher to progress in them and have larger enrollments in the first course of the sequence (in the fall semester). The GChem and OChem courses are required for majors in chemistry, biology, and nutrition, as well as all pre-health professions majors. The HAP course is required for all pre-health professions majors.

In terms of content, the GChem courses introduce students to many of the basic concepts in chemistry and emphasize chemical structure and reactivity. Beginning with the structure of the atom, the courses continue with the topics of chemical bonding, molecular structure, stoichiometry, acid/base reactions, thermodynamics, and electrochemistry. The OChem courses introduce students to the fundamental concepts in organic chemistry, namely, the structure and bonding of carbon-containing compounds, nomenclature of organic compounds, stereochemistry, spectroscopic techniques, and organic mechanisms utilizing various functional groups. The HAP course takes an organ system approach to the study of human anatomy and physiology and provides students with conceptual and practical information on the anatomy and physiology of the cell; the integumentary, skeletal, muscular, and nervous systems; and special senses.

3.2. Participants

Participants were 1284 (811 female, 473 male) undergraduate students who were in various science and allied health majors. A large percentage of participants self-identified as White, non-Hispanic (62.9 %), whereas the remainder self-identified as Black (27.6 %), Hispanic (4.0 %), Asian (2.3 %), and Other (3.2 %). Most of the participants were either freshmen or sophomores (68.0 %). Most of the participants self-reported a GPA of 2.50 or higher on a 4.0 scale (88.9 %). Finally, 629 participants were enrolled in the GChem courses, 307 participants were enrolled in the OChem courses, and 346 participants were enrolled in the HAP course (course enrollment data were unavailable for 2 participants).

3.3. Procedure

At the beginning (Time 1) and at the end (Time 2) of the fall or spring semester, participants completed a 24-item survey that assessed academic motivation (described below) along with age, race/ethnicity, class year, GPA (self-report), academic major, likelihood of continuing in the major, course attendance, time spent studying, and perceived course difficulty. Final course grades were obtained from the course instructors.

3.4. Measures

3.4.1. Academic motivation

The Self-Regulation Questionnaire (Ryan & Connell, 1989), which was modified slightly to reflect the language that is used in the collegiate setting (see Appendix A), presented participants with the following stem: "The reason I put effort into this class is". Participants then rated preselected responses that assessed external (3 items; Others would judge me if I did not put effort into this class), introjected (3 items; I would feel guilty if I did not put effort into this class), identified (3 items; I value the experience I have when I put effort into this class), and intrinsic (3 items; It is satisfying to be able to put effort into this class) types of motivation. Responses were made on a 7-point scale from 1 (*strongly disagree*) to 7 (*strongly agree*). A composite measure of autonomous motivation was created as the average of intrinsic motivation and identified regulation, and a composite measure of controlled motivation was created as the average of introjected regulation and external regulation. The reliability for autonomous motivation was $\alpha = .90$ at Time 1 and $\alpha = .90$ at Time 2. The reliability for controlled motivation was $\alpha = .73$ at Time 1 and $\alpha = .75$ at Time 2.

Historically, researchers have employed one of three approaches to the statistical aggregation of the internalization continuum using the Self-Regulation Questionnaire, namely, modeling the individual types of motivation, modeling composite scores of autonomous and controlled motivations, and modeling a relative autonomy index in which different weights are applied to the individual types of motivation (see Vansteenkiste et al., 2010). Previous research has revealed remarkable consistency across these three methodological approaches (see Deci & Ryan, 2000), and thus it is prudent for research questions and hypotheses to guide decision making around the use of these approaches. As described above, the current study focused on the relations of *both* autonomous *and* controlled motivations to course-related behavior, given the theoretical and practical relevance of such a focus. Accordingly, composite scores of autonomous and controlled motivations were modeled in order to address the research questions and hypotheses that were of interest in the current study.

3.5. Analytic overview

All variables were checked for statistical assumptions that are relevant to regression analysis. Descriptive statistics and scale reliabilities were computed using R with the "psych" package. The hypothesized path model[1] was tested using R with the "Lavaan" package. Good model fit is indicated by a chi-square likelihood ratio (χ^2/df) that is less than 3:1 (Gefen, Straub, & Boudreau, 2000), a comparative fit index (CFI) that is more than .95, and a root mean square error of approximation (RMSEA) that is less than .08 (Hu & Bentler, 1999). Unstandardized and standardized parameter estimates were examined to evaluate the hypothesized model (Hoyle & Panter, 1995), along with assessments of direct effects, indirect effects, and R^2 values. For the direct and indirect effects, estimates of .10–.29 indicate a "small" effect, .30–.49 indicate a "medium" effect, and .50 or higher indicate a "large" effect (Suhr, 2008).

4. Results

4.1. Descriptive statistics

Table 1 presents descriptive statistics for the study variables collapsed across GChem, OChem, and HAP courses. As shown, participants indicated that they attended the course with some regularity (47.4 %), studied between one and three hours per week outside of class (40.9 %), and perceived the course to be somewhat more difficult than initially expected (40.2 %). Though not shown in Table 1, most of the participants passed the course with a grade of A (n = 244), B (n = 439), or C (n = 393). With regard to motivation, participants reported moderately high levels of autonomous motivation at Time 1 ($M = 5.52$, $SD = 1.12$) and at Time 2 ($M = 5.18$, $SD = 1.23$), as well as moderately high levels of controlled motivation at Time 1 ($M = 5.38$, $SD = 0.98$) and at Time 2 ($M = 5.27$, $SD = 1.03$).

[1] Based on *a priori* considerations, observed variables (rather than latent variables) were used to model autonomous and controlled motivations in the hypothesized path model because these constructs were measured using self-reported items from a single source, and indeed the individual types of motivation that were used to assess autonomous and controlled motivations were measured using the same Self-Regulation Questionnaire (see Olafsen, Niemiec, Halvari, Deci, & Williams, 2017, for a similar approach to handling such data). Yet in response to a Reviewer's request, a Confirmatory Factor Analysis (CFA) was performed on the latent constructs *Autonomous Motivation at Time 1*, *Autonomous Motivation at Time 2*, *Controlled Motivation at Time 1*, and *Controlled Motivation at Time 2*—each indicated by their six corresponding items from the Self-Regulation Questionnaire. The CFA yielded acceptable fit of the model to the data, χ^2 (187) = 1002.75, $p <$ .001; $\chi^2/df = 5.36$; CFI = .950; RMSEA = .059. All item loadings were significant ($p <$ .001) and ranged in magnitude from .21 to .94 (mean λ = .67). Although the χ^2/df ratio was above the recommended cut-off, in large samples such as ours the χ^2 statistic tends to be overly sensitive to trivial deviations from the "perfect" model (for a review, see Putnick & Bornstein, 2016), and thus we followed Putnick and Bornstein's recommendation to assess measurement invariance with a focus on alternative fit indices. In order to assess metric invariance, this baseline model was compared to a restricted model in which the factor loadings for the corresponding constructs at Time 1 and Time 2 were constrained to be equal. The restricted model yielded acceptable fit to the data, χ^2 (199) = 1046.84, $p <$ .001; $\chi^2/df = 5.26$; CFI = .948; RMSEA = .059, and did not differ significantly from the baseline model [both ΔCFI = .002 and ΔRMSEA = .000 are aligned with Chen's (2007) cut-off values for establishing metric invariance]. As such, it is reasonable to conclude that autonomous and controlled motivations were represented and understood equivalently at both time points.

Table 1
Descriptive Statistics for the Study Variables.

Reported at Time 1				Reported at Time 2		
Major n (%) Total: 1255	GPA n (%) Total: 1263	Class Year n (%) Total: 1264	Likelihood n (%) Total: 1256	Attendance n (%) Total: 1141	Studying n (%) Total: 1257	Difficulty n (%) Total: 1154
Chemistry 174 (13.9 %)	3.50 – 4.00 395 (31.3 %)	Freshman 389 (30.8 %)	Not at all likely 9 (0.7 %)	Hardly ever 174 (15.2 %)	Less than 1 h 101 (8.0 %)	Much less difficult 40 (3.5 %)
Biology 427 (34.0 %)	3.00 – 3.49 465 (36.8 %)	Sophomore 471 (37.2 %)	Somewhat unlikely 32 (2.6 %)	Sometimes 427 (37.4 %)	1 – 3 h 514 (40.9 %)	Somewhat less difficult 126 (10.9 %)
Nursing 172 (13.7 %)	2.50 – 2.99 266 (21.1 %)	Junior 259 (20.5 %)	Neither unlikely nor likely 28 (2.2 %)	Most times 172 (15.1 %)	3 – 6 h 455 (36.2 %)	Same difficulty 201 (17.4 %)
Allied Health 335 (26.7 %)	2.00 – 2.49 101 (8.0 %)	Senior 119 (9.4 %)	Somewhat likely 172 (13.7 %)	Almost every time 335 (29.4 %)	6 – 9 h 133 (10.6 %)	Somewhat more difficult 464 (40.2 %)
Engineering 33 (2.6 %)	<2.00 36 (2.8 %)	Other 26 (2.1 %)	Very likely 1015 (80.8 %)	Every time 33 (2.9 %)	More than 9 h 54 (4.3 %)	Much more difficult 323 (28.0 %)
Physics 2 (0.2 %)	—	—	—	—	—	—
Other 112 (8.9 %)	—	—	—	—	—	—

Notes. Likelihood = Likelihood of continuing in the major. Attendance = Course attendance. Studying = Time spent studying. Difficulty = Perceived course difficulty. The variables “Major”, “GPA”, “Class Year”, and “Likelihood” were reported at Time 1. The variables “Attendance”, “Studying”, and “Difficulty” were reported at Time 2.

4.2. Model testing

The assumption of homogeneity of variance in motivation across courses at Time 1 and at Time 2 was violated. Therefore, a Kruskal-Wallis independent samples test was run with Bonferroni correction, which indicated significant differences across courses in autonomous motivation at Time 1 [χ^2 (2) = 15.56, $p <$ .001] and at Time 2 [χ^2 (2) = 24.32, $p <$ .001], and controlled motivation at Time 2 [χ^2 (2) = 19.93, $p <$ .001]. Controlled motivation at Time 1 did not violate the assumption of homogeneity of variance, and thus a one-way analysis of variance was run, which indicated significant differences in controlled motivation at Time 1 [F (2, 1279) = 3.21, $p =$ .04].

A series of post-hoc tests revealed the origin(s) of these differences. First, students in OChem [M = 5.34, SD = 1.17] reported lower levels of autonomous motivation at Time 1 than students in HAP [M = 5.69, SD = 0.99; $p <$ .001] and students in GChem [M = 5.51, SD = 1.17; $p =$ .04]. Second, students in HAP [M = 5.48, SD = 1.05] reported lower levels of autonomous motivation at Time 2 than students in GChem [M = 5.65, SD = 1.31; $p <$ .001] and higher levels of autonomous motivation at Time 2 than students in OChem [M = 5.10, SD = 1.25; $p =$ .001]. Third, students in GChem [M = 5.32, SD = 1.01] reported higher levels of controlled motivation at Time 1 than students in HAP [M = 5.49, SD = 0.91; $p =$ .03]. Fourth, students in HAP [M = 5.45, SD = 0.90] reported higher levels of controlled motivation at Time 2 than students in GChem [M = 5.14, SD = 1.06; $p <$ .001] and students in OChem [M = 5.33, SD = 1.08; $p =$ .02].

No clear pattern of significant differences was observed, and thus we proceeded with model testing. The initial fit of the hypothesized model to the data was poor, and so we followed modification indices that suggested the removal of direct relations of (1) autonomous motivation at Time 2 to course attendance and (2) time spent studying to final course grades. With these modifications, the fit of the model to the data was acceptable, χ^2 (10) = 27.58, $p =$ .002; χ^2/df = 2.76; CFI = .99; RMSEA = .038. Fig. 2 presents the hypothesized model with standardized parameter estimates.

Examining Research Question 1, autonomous motivation at Time 1 predicted autonomous motivation at Time 2, and controlled motivation at Time 1 predicted controlled motivation at Time 2. Examining Research Question 2, autonomous and controlled motivations were correlated at Time 1 and at Time 2. Examining Research Question 3, autonomous motivation at Time 2 predicted time spent studying, perceived course difficulty, and final course grades. Controlled motivation at Time 2 predicted course attendance, time spent studying, perceived course difficulty, and final course grades. Both course attendance and perceived course difficulty predicted final course grades. The indirect effect of controlled motivation at Time 2 on final course grades through course attendance and perceived course difficulty was significant. Overall, the model explained 21 % of the variance in autonomous motivation at Time 2, 18 % of the variance in controlled motivation at Time 2, 1% of the variance in time spent studying, .07 % of the variance in perceived course difficulty, and 7% of the variance in final course grades.

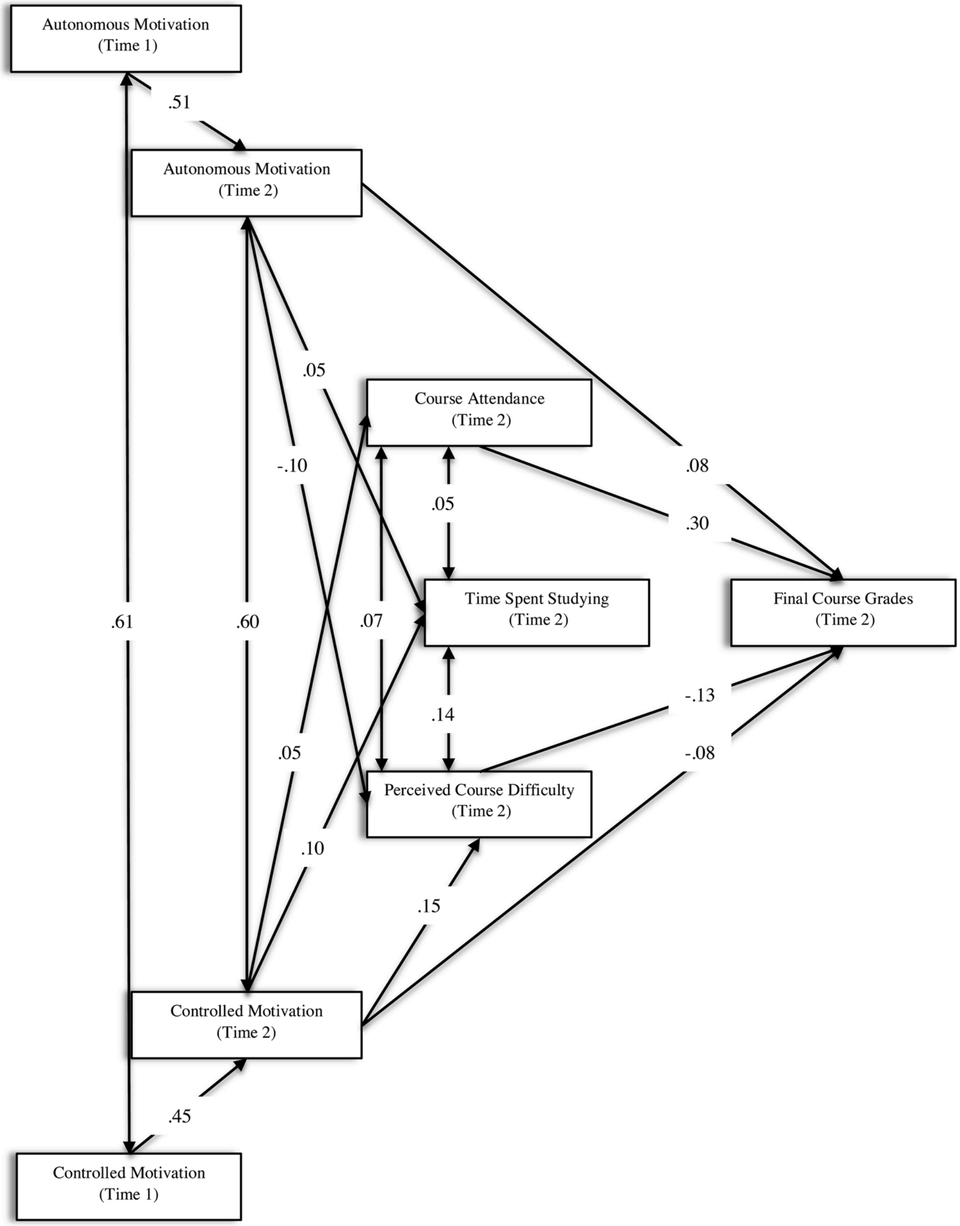

Fig. 2. The hypothesized model with standardized parameter estimates.
Notes. All depicted paths were significant at $p < .05$. Error terms are not depicted for the sake of clarity.

5. Discussion

Guided by self-determination theory, the current study examined the stability in autonomous and controlled motivations from the beginning (Time 1) to the end (Time 2) of the semester (Research Question 1) and the correlation between autonomous and controlled motivations at Time 1 and at Time 2 (Research Question 2). The results revealed considerable stability in motivation over time as well as strong association between these types of motivation at each time point. Of note, previous literature has revealed mixed findings on whether and how motivation changes over time. For instance, Brouse, Basch, LeBlanc, McKnight, and Lei (2010) reported that intrinsic and extrinsic motivation tend to decline over time. Similarly, Nilsson and Stomberg (2008) found that motivation tends to decline across several semesters among Swedish nursing students. However, Finch (2004) found that although intrinsic motivation tends to decline, extrinsic motivation tends to increase over time among massage therapy students. In a study of Turkish and American undergraduates, Isiksal (2010) reported that extrinsic motivation tends to decline from the first year to the final year of college among American students, whereas extrinsic motivation tends to decline from the first year to the second year of college but then increases thereafter among Turkish students. Finally, Young, Wendel, Esson, and Plank (2018) found that motivation tends to decline from before to after the semester among STEM students, but such changes might not be permanent.

Among applied and social science students, some research suggests that the type of motivation depends on class year, such that first-year students tend to report higher levels of intrinsic motivation than fourth-year students (Hakan & Münire, 2014). Yet again, this literature has revealed mixed findings, as Sturges et al. (2016) conducted a two-year study of academic motivation among HAP students and found stability in motivation during the course sequence. Similarly, Gillet et al. (2017) found no change in motivation profiles over two months among first-year undergraduate students. Our findings suggest that students in lower-level STEM courses report relatively high levels of autonomous and controlled motivations that remained stable over time, and we encourage additional research to continue to examine stability and change in academic motivation.

The results of the current study also revealed that autonomous and controlled motivations are strongly correlated among STEM students, such that the same student can report comparable levels of each type of motivation for the same course. In our sample, participants were recruited from core courses in which success was necessary to progress in one's major. Such pedagogic circumstances might have left students with a sense of pressure to perform well in the course, thereby engendering controlled motivation. Yet even in such circumstances students can be interested in the course material and find it personally relevant, thereby promoting autonomous motivation. Hence, it is important to examine the "downstream" consequences of different types of academic motivation.

Accordingly, the current study examined the relations of autonomous and controlled motivations at Time 2 to course attendance, time spent studying, perceived course difficulty, and final course grades (Research Question 3). The results revealed that autonomous motivation at Time 2 predicted higher levels of time spent studying and final course grades (but not course attendance), and lower levels of perceived course difficulty. Further, controlled motivation at Time 2 predicted higher levels of course attendance, time spent studying, and perceived course difficulty, and lower levels of final course grades. Finally, course attendance predicted higher levels of final course grades, and perceived course difficulty predicted lower levels of final course grades.

A large body of research speaks to the link between course attendance and course performance (as was found in the current study). Yet students who attend class for controlled reasons are not likely to "want to" do so, but rather they might attend class to earn attendance and/or participation points and complete quizzes that are linked to course grades (Devadoss & Foltz, 1996). As such, the benefit of course attendance might be attenuated among students who do so for controlled reasons. Contrary to some previous research (Andrietti & Velasco, 2015; Puzziferro, 2008), the results of the current study revealed no association between time spent studying and final course grades. Rather, both autonomous and controlled motivations predicted higher levels of time spent studying. More importantly, autonomous motivation predicted higher levels of final course grades whereas controlled motivation predicted lower levels of final course grades, which underscores the importance of the type of motivation for academic achievement.

GChem, OChem, and HAP courses tend to be perceived as difficult (Carter & Brickhouse, 1989; Sturges & Maurer, 2013). That being said, the results of the current study revealed that such perceptions can be shaped by motivation, such that autonomous motivation is associated with lower levels of perceived course difficulty and controlled motivation is associated with higher levels of perceived course difficulty. This is important because perceptions of course difficulty can undermine perceived competence among students (Patall et al., 2018), especially in the absence of teacher autonomy support (see Britt, 2005).

Accordingly, we encourage teachers to provide support for their students' autonomy, competence, and relatedness in the classroom (see Niemiec & Ryan, 2009)—even in the context of courses that are perceived as difficult, as such support is conducive to the process of internalization among students (Niemiec et al., 2006). To do so, teachers can strive to be student-centered in their pedagogy, present material in an approachable way, and design learning activities that are engaging for students. The current study revealed that both autonomous and controlled motivations predicted perceived course difficulty and final course grades (albeit in opposite directions). In this way, academic motivation had an impact on how students perceived the difficulty of their course and how they performed in it, which highlights the importance of creating need-supportive educational climates that facilitate the cultivation of autonomous motivation.

Several limitations deserve mention. First, although the sample that was analyzed in the current study was large and diverse, it might not be representative of students who pursue coursework outside of GChem, OChem, HAP, and related courses. Second, most of the variables (except final course grades) were self-reported and, thus, might be biased. Third, although the current study accounted for many of the salient predictors of academic performance, clearly it is important for future research to examine additional factors that might influence final course grades. Fourth, many of the effect sizes were small in magnitude, and therefore it is important to interpret these findings with caution. Fifth, although the assumption of homogeneity of variance in motivation across courses was violated at both time points, data were collapsed across courses for analysis because no clear pattern of significant differences was observed.

In conclusion, the current study suggests that autonomous and controlled motivations make unique contributions to academic performance—although in opposite directions. The courses that were of focus in the current study are central courses in science and allied health majors, and thus having an understanding of how motivation can influence course-related behavior and performance in these courses is paramount. Although some scholars have identified a difficulty with using academic motivation to predict student behavior (Svinicki, 2018), SDT asserts that autonomous motivation will be beneficial for students. Indeed, as suggested by our data, structuring a course with ample opportunities for student choice in learning can lead to more time spent studying, less perceived course difficulty, and better final course grades.

Appendix A

SURVEY

A Strongly Disagree B Moderately Disagree C Slightly Disagree D Neutral
E Slightly Agree F Moderately Agree G Strongly Agree

The reason that I put effort into this class is:
1. Others would judge me if I did not put effort into this class.
2. It is fun for me to put effort into this class.
3. I think that putting effort into this class is what I am supposed to do.
4. I value the experience I have when I put effort into this class.
5. It is satisfying to be able to put effort into this class.
6. I would feel guilty if I did not put effort into this class.
7. Others make me feel good about myself when I put effort into this class.
8. I really value how putting effort into this class deepens my college experience.
9. I believe that putting effort into this class is an important part of my college experience.
10. I would feel bad about myself if I did not put effort into this class.
11. I really enjoy putting effort into this class.
12. It would threaten my future plans if I did not put effort into this class.

13. Which class are you taking?
A. CHEM 1145 D. CHEM 3342
B. CHEM 1146 E. KINS 2531
C. CHEM 3341 F. KINS 2532

14. What is your gender?
A Male B Female

15. Which of the following most accurately reflects your ethnicity?
A White D Asian
B African-American E Other
C Hispanic

16. What is your class standing?
A Freshman D Senior
B Sophomore E Other
C Junior

17. Is this class required for your major? A Yes B No

18. What is your major/pre-major?
A Chemistry D Allied Health (Nutrition/ Athletic Training/ Exercise Science etc.)
B Biology E Engineering
C Nursing F Physics
G Other

19. How likely are you to continue with your current major?
A Not at all likely
B Somewhat unlikely
C Neither unlikely nor likely
D Somewhat likely
E Very likely

20. What is your current approximate GPA?
A <2.00
B 2.00-2.49
C 2.50-2.99
D 3.00-3.49
E 3.50-4.00

21. How often do you attend class?
A. Hardly ever
B. Some times
C. Most times
D. Almost every time
E. Every time

22. In the average week, how many hours do you spend studying for this class?
A. Less than 1 hour
B. 1-3 hours
C. 3-6 hours
D. 6-9 hours
E. More than 9 hours

23. What are your expectations for the difficulty level of this class in comparison to other classes in the program?
A I expect it to be much less difficult
B I expect it to be somewhat less difficult
C I expect it to be of the same difficulty
D I expect it to be somewhat more difficult
E I expect it to be much more difficult

24. What grade do you anticipate you will get in this class?
A A
B B
C C
D D
E F
F W

References

Andrietti, V., & Velasco, C. (2015). Lecture attendance, study time, and academic performance: A panel data study. *The Journal of Economic Education, 46*(3), 239–259.

Black, A. E., & Deci, E. L. (2000). The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: A self-determination theory perspective. *Science Education, 84*(6), 740–756.

Britt, T. W. (2005). The effects of identity-relevance and task difficulty on task motivation, stress, and performance. *Motivation and Emotion, 29*(3), 189–202.

Brouse, C. H., Basch, C. E., LeBlanc, M., McKnight, K. R., & Lei, T. (2010). College students' academic motivation: Differences by gender, class, and source of payment. *College Quarterly, 13*(1), 1–10.

Carter, C. S., & Brickhouse, N. W. (1989). What makes chemistry difficult? Alternate perceptions. *Journal of Chemical Education, 66*(3), 223.

Cerasoli, C. P., Nicklin, J. M., & Ford, M. T. (2014). Intrinsic motivation and extrinsic incentives jointly predict performance: A 40-year meta-analysis. *Psychological Bulletin, 140*(4), 980–1008.

Chen, F. F. (2007). Sensitivity of goodness of fit indexes to lack of measurement invariance. *Structural Equation Modeling: A Multidisciplinary Journal, 14*, 464–504.

Cortright, R. N., Lujan, H. L., Cox, J. H., & DiCarlo, S. E. (2011). Does sex (female versus male) influence the impact of class attendance on examination performance? *Advances in Physiology Education, 35*(4), 416–420.

Credé, M., Roch, S. G., & Kieszczynka, U. M. (2010). Class attendance in college: A meta-analytic review of the relationship of class attendance with grades and student characteristics. *Review of Educational Research, 80*(2), 272–295.

Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry, 11*(4), 227–268.

Deci, E. L., & Ryan, R. M. (2008). Self-determination theory: A macrotheory of human motivation, development, and health. *Canadian Psychology, 49*(3), 182–185.
Devadoss, S., & Foltz, J. (1996). Evaluation of factors influencing student class attendance and performance. *American Journal of Agricultural Economics, 78*(3), 499–507.
Dey, I. (2018). Class attendance and academic performance: A subgroup analysis. *International Review of Economics Education, 28*, 29–40.
Erten, İ. H. (2014). Interaction between academic motivation and student teachers' academic achievement. *Procedia - Social and Behavioral Sciences, 152*(7), 173–178.
Finch, P. (2004). The motivation of massage therapy students to enter professional education. *Medical Teacher, 26*(8), 729–731.
Gefen, D., Straub, D. W., & Boudreau, M. C. (2000). Structural equation modeling techniques and regression: Guidelines for research practice. *Communications of the Association for Information Systems, 4*(1), 7.
Gillet, N., Morin, A. J. S., & Reeve, J. (2017). Stability, change, and implications of students' motivation profiles: A latent transition analysis. *Contemporary Educational Psychology, 51*, 222–239.
Hakan, K., & Münire, E. (2014). Academic motivation: Gender, domain and grade differences. *Procedia - Social and Behavioral Sciences, 143*, 708–715.
Hoyle, R. H., & Panter, A. T. (1995). Writing about structural equation models. In R. H. Hoyle (Ed.), *Structural equation modeling: Concepts, issues, and applications* (pp. 158–176). Thousand Oaks, CA: Sage Publications, Inc.
Hu, L.-t., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6*(1), 1–55.
Hulsman, R. L., Van Der Ende, J. S. J., Oort, F. J., Michels, R. P. J., Casteelen, G., & Griffioen, F. M. M. (2007). Effectiveness of selection in medical school admissions: Evaluation of the outcomes among freshmen. *Medical Education, 41*(4), 369–377.
Isiksal, M. (2010). A comparative study on undergraduate students' academic motivation and academic self-concept. *The Spanish Journal of Psychology, 13*(2), 572–585.
Jeno, L. M., & Diseth, Å. (2014). A self-determination theory perspective on autonomy support, autonomous self-regulation, and perceived school performance. *Reflecting Education, 9*, 1–20.
Kusurkar, R. A., Ten Cate, Th. J., Vos, C. M. P., Westers, P., & Croiset, G. (2013). How motivation affects academic performance: A structural equation modelling analysis. *Advances in Health Sciences Education, 18*(1), 57–69.
Lukkarinen, A., Koivukangas, P., & Seppälä, T. (2016). Relationship between class attendance and student performance. *Procedia - Social and Behavioral Sciences, 228*, 341–347.
Lyubartseva, G., & Mallik, U. P. (2012). Attendance and student performance in undergraduate chemistry courses. *Education, 133*(1), 31–34.
Michou, A., Vansteenkiste, M., Mouratidis, A., & Lens, W. (2014). Enriching the hierarchical model of achievement motivation: Autonomous and controlling reasons underlying achievement goals. *The British Journal of Educational Psychology, 84*(4), 650–666.
Mundfrom, D. J. (1991). *Estimating course difficulty (Unpublished doctoral dissertation)*. Ames: Iowa State University.
Niemiec, C. P., & Ryan, R. M. (2009). Autonomy, competence, and relatedness in the classroom: Applying self-determination theory to educational practice. *Theory and Research in Education, 7*(2), 133–144.
Niemiec, C. P., & Ryan, R. M. (2013). What makes for a life well lived? Autonomy and its relation to full functioning and organismic wellness. In S. A. David, I. Boniwell, & A. C. Ayers (Eds.), *The Oxford handbook of happiness* (pp. 214–226). Oxford: Oxford University Press.
Niemiec, C. P., Lynch, M. F., Vansteenkiste, M., Bernstein, J., Deci, E. L., & Ryan, R. M. (2006). The antecedents and consequences of autonomous self-regulation for college: A self-determination theory perspective on socialization. *Journal of Adolescence, 29*(5), 761–775.
Niemiec, C. P., Ryan, R. M., & Deci, E. L. (2010). Self-determination theory and the relation of autonomy to self-regulatory processes and personality development. In R. H. Hoyle (Ed.), *Handbook of personality and self-regulation* (pp. 169–191). Malden, MA: Blackwell Publishing.
Niemiec, C. P., Soenens, B., & Vansteenkiste, M. (2014). Is relatedness enough? On the importance of need support in different types of social experiences. In N. Weinstein (Ed.), *Human motivation and interpersonal relationships: Theory, research and applications* (pp. 77–96). Dordrecht: Springer.
Nilsson, K. E. L., & Stomberg, M. I. W. (2008). Nursing students motivation toward their studies – A survey study. *BMC Nursing, 7*, 6.
Olafsen, A. H., Niemiec, C. P., Halvari, H., Deci, E. L., & Williams, G. C. (2017). On the dark side of work: A longitudinal analysis using self-determination theory. *European Journal of Work & Organizational Psychology, 26*(2), 275–285.
Patall, E. A., Hooper, S., Vasquez, A. C., Pituch, K. A., & Steingut, R. R. (2018). Science class is too hard: Perceived difficulty, disengagement, and the role of teacher autonomy support from a daily diary perspective. *Learning and Instruction, 58*, 220–231.
Popovic, C. (2010). Myth busting: An examination of teachers' beliefs about first-year medical students. How well do teachers know their students? *Innovations in Education and Teaching International, 47*(2), 141–154.
Putnick, D. L., & Bornstein, M. H. (2016). Measurement invariance conventions and reporting: The state of the art and future directions for psychological research. *Developmental Review, 41*, 71–90.
Puzziferro, M. (2008). Online technologies self-efficacy and self-regulated learning as predictors of final grade and satisfaction in college-level online courses. *The American Journal of Distance Education, 22*(2), 72–89.
Richardson, M., Abraham, C., & Bond, R. (2012). Psychological correlates of university students' academic performance: A systematic review and meta-analysis. *Psychological Bulletin, 138*(2), 353–387.
Ryan, R. M., & Connell, J. P. (1989). Perceived locus of causality and internalization: Examining reasons for acting in two domains. *Journal of Personality and Social Psychology, 57*(5), 749–761.
Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *The American Psychologist, 55*(1), 68–78.
Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. New York, NY: The Guilford Press.
Ryan, R. M., & Niemiec, C. P. (2009). Self-determination theory in schools of education: Can an empirically supported framework also be critical and liberating? *Theory and Research in Education, 7*(2), 263–272.
Smith, J. L., Deemer, E. D., Thoman, D. B., & Zazworsky, L. (2014). Motivation under the microscope: Understanding undergraduate science students' multiple motivations for research. *Motivation and Emotion, 38*(4), 496–512.
Sobral, D. T. (2004). What kind of motivation drives medical students' learning quests? *Medical Education, 38*(9), 950–957.
Sturges, D., & Maurer, T. W. (2013). Allied health students' perceptions of class difficulty: The case of undergraduate human anatomy and physiology classes. *The Internet Journal of Allied Health Sciences and Practice, 11*(4), 9.
Sturges, D., Maurer, T. W., Allen, D., Gatch, D. B., & Shankar, P. (2016). Academic performance in human anatomy and physiology classes: A 2-yr study of academic motivation and grade expectation. *Advances in Physiology Education, 40*(1), 26–31.
Suhr, D. (2008). Step your way through path analysis. *Western users of SAS software conference proceedings*.
Svinicki, M. (2018). *Why is teaching for motivation so confusing?*. Retrieved from https://tomprof.stanford.edu/posting/1690.
Vansteenkiste, M., Niemiec, C. P., & Soenens, B. (2010). The development of the five mini-theories of self-determination theory: An historical overview, emerging trends, and future directions. In T. C. Urdan, & S. A. Karabenick (Eds.), *Advances in motivation and achievement, v.16A—The decade ahead: Theoretical perspectives on motivation and achievement* (pp. 105–165). London: Emerald Group Publishing Limited.
Vansteenkiste, M., Sierens, E., Soenens, B., Luyckx, K., & Lens, W. (2009). Motivational profiles from a self-determination perspective: The quality of motivation matters. *Journal of Educational Psychology, 101*(3), 671–688.
Wilkinson, T. J., Wells, J. E., & Bushnell, J. A. (2007). Medical student characteristics associated with time in study: Is spending more time always a good thing? *Medical Teacher, 29*(2-3), 106–110.
Young, A. M., Wendel, P. J., Esson, J. M., & Plank, K. M. (2018). Motivational decline and recovery in higher education STEM courses. *International Journal of Science Education, 40*(9), 1016–1033.