Associations of Students' Creativity, Motivation, and Self-Regulation with Learning and Achievement in College Computer Science Courses

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***Abstract*—The need for more post-secondary students to major and graduate in STEM fields is widely recognized. Students' motivation and strategic self-regulation have been identified as playing crucial roles in their success in STEM classes. But, how students' strategy use, self-regulation, knowledge building, and engagement impact different learning outcomes is not well understood. Our goal in this study was to investigate how motivation, strategic self-regulation, and creative competency were associated with course achievement and long-term learning of computational thinking knowledge and skills in introductory computer science courses. Student grades and long-term retention were positively associated with self-regulated strategy use and knowledge building, and negatively associated with lack of regulation. Grades were associated with higher study effort and knowledge retention was associated with higher study time. For motivation, higher learning- and task-approach goals orientations, endogenous instrumentality, and positive affect and lower learning-, task-, and performance-avoid goal orientations, exogenous instrumentality and negative affect were associated with higher grades and knowledge retention and also with strategic self-regulation and engagement. Implicit intelligence beliefs were associated with strategic self-regulation, but not grades or knowledge retention. Creative competency was associated with long-term retention, but not grades, and with higher strategic self-regulation. Implications for STEM education are discussed.**

Keywords—motivation; self-regulation; engagement; STEM learning; goal orientation; emotion; perceived instrumentality

I. INTRODUCTION

The need for more post-secondary students to major and graduate in STEM fields is widely recognized as in the National Academies report "Rising above the gathering storm: Energizing and employing America for a brighter economic future" [1]. Substantial funding is provided for enhancing instruction in STEM fields [2]. A relatively low percentage of students major in STEM fields, and despite attracting students with generally better academic preparation and aptitude, students in STEM fields experience higher attrition than those in other post-secondary majors [2].

Students' strategic self-regulation has been identified as playing a critical role in their success in STEM learning [3,4], but how students' use of strategy, metacognitive self-regulation, and engagement impact different types of learning outcomes is not fully understood. Also, despite considerable past research, including recent work reported in prior Frontiers in Education conference proceedings [5, 6, 7], theory and research have not completely described the dynamics of student motivation for pursuing productive strategic self-regulation and engagement. Our goal in this study was to investigate how motivation and strategic self-regulation, together with creative competency, were associated with course achievement and long-term learning of computational thinking knowledge and skills in introductory computer science (CS1) courses.

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II. THEORETICAL FRAMEWORK

A. Motivation and Affect

Motivational variables in this study were drawn from goal orientation [8, 9, 10], future time perspective (FTP) [11], implicit belief theory [12, 13], and emotion/affect [14, 15, 16]. These aspects of motivation have been shown to be associated with higher academic achievement, greater engagement, and more strategic self-regulation [17].

Goal orientation concerns the types of goals students set. Goals exist at different levels of specificity. Consistent with Elliot *et al*. [9], there are goals for specific tasks and assignments anchored in the context of doing or evaluating the task and, at a more general level, students set goals for their courses [9, 10]. In this study, we used a framework proposed by Shell *et al*. [18] and Shell and Soh [4] that examines course goals in three dimensions (learning, performance, and task) with each dimension having an approach and avoid component. Learning-approach goals are goals directed at learning new knowledge or gaining competence consistent with most past formulations of learning or mastery goals [8, 10]. Learning-avoid goals are deliberate goals to avoid learning of course material. Think about the old saying *you can lead a horse to water, but you can't make it drink*. This reflects the Shell *et al*. [18] notion of learning avoidance. A student might complete all assignments and do enough to get a score on a test or a grade in a class, but not put forth the additional effort to really learn the material.

Performance-approach goals reflect a desire to obtain favorable judgments of one's abilities by others or perform better than others in the class and performance-avoid goals reflect the desire to avoid negative judgments of one's ability or do worse relative to others in the class [10]. Performance-approach and avoid goals have been found to motivate very different behaviors. Approach seems to be positive for increasing effort and positive self-regulation; avoid seems to be detrimental, decreasing effort and self-regulation [4, 10].

Task- or work-avoid goals reflect a desire to get through the class with as little time and effort as possible [20, 21, 22]. Task-approach goals reflect wanting to perform well on course assignments and tests [4]. They differ from performance goals because they are about doing well without reference to normative performance or gaining positive or avoiding negative evaluations evaluation of competence. They also differ from learning goals in that students can have a goal to "do my work to the best of my ability" without any expectation that they will learn anything.

Perceived Instrumentality (PI), is defined as a person's perception of how useful a present task is for a future goal [4, 24, 25]. Endogenous instrumentality reflects instrumentality for personally meaningful future goals and outcomes. Exogenous instrumentality reflects a utilitarian connection between task results and future outcomes. Past literature indicates that an individual's perception of instrumentality positively affects learning in the classroom [4, 7, 24, 25]. Students with high perceived instrumentality can see the connection between their current class activities and their more distant future academic, career, and life goals leading to increased motivation for their present learning in school [4, 7, 11].

Implicit beliefs about intelligence have been shown to impact students' goals, motivation, and achievement [12, 13]. Students who believe that intelligence is malleable and changeable through effort, learning, and practice set learning goals, achieve better, and engage in better strategic self-regulation. Students who believe that intelligence is fixed and unchangeable are more likely to set performance-avoid goals and be at risk for learned helplessness [12, 18]. Research has found that 50% of engineering students held an entity view of fixed intelligence [26].

Affect/emotion involves students' general feelings and reactions to the class [15, 16]. Positive emotions have been shown to increase students' engagement in academic work and support more adaptive self-regulation [4, 16, 21]. Negative emotions have been found to decrease motivation and lead to maladaptive self-regulation [4, 21].

B. Strategic Self-Regulation and Engagement

Four aspects of student strategic self-regulation in classes have a long history of research. The first is general metacognitive self-regulation. Students who are self-regulating engage in active planning, monitoring, and evaluation of their learning and apply general learning strategies to accomplish their goals. [27, 28]. They are what Pressley *et al*. [29] called good strategy users. The second aspect comes from the knowledge building approach to learning proposed by Bereiter, Scardamalia, and their colleagues [30, 31]. Central to the knowledge building approach is the idea that meaningful learning involves the production of knowledge rather than the reproduction of knowledge. This knowledge building is accomplished by an in-depth study of a topic that goes beyond simple factual or recall learning. Learning is tied to personally meaningful goals and includes examination and connection of new knowledge to existing knowledge and coursework in other classes.

The third aspect of strategic self-regulation concerns more dysfunctional self-regulatory strategies [8, 22, 32, 33]. Lack of regulation [4, 21, 32] describes students who are confused, have difficulty studying effectively and self-regulating, and also need support from others. Lack of regulation has been shown to be negatively associated with grades [4, 32] and is a key component of learned helplessness in classes [4, 21].

The final aspect is student engagement with the class as reflected in active participation and effort. Engagement concerns student study time and effort for the class [4, 21, 34]. Engagement also considers the extent of student active course involvement as indicated by question asking [4, 21, 35]. Students who are more engaged tend to have more positive experiences in the class and higher achievement [14, 16].

C. Creative Competency

Epstein's Generativity Theory defines creativity as a process integral to human intelligence, which can be exercised within any context and can be practiced, encouraged and developed [36, 37]. Epstein [36, 37] has identified four core cognitive competencies involved in creative thinking: (1) *broadening* by acquiring information and skills outside one's current domains of study and expertise; (2) *challenging* established thinking by engaging in difficult, ill-defined problems and tasks where new behaviors and approaches must be tried; (3) *surrounding* oneself with new people and environments that require one to look at things in new ways, and (4) *capturing* by recording novelty as it occurs. Epstein has substantiated the validity of his core competencies in numerous laboratory and applied studies [36, 37]. His core competencies have a solid anchoring in contemporary cognitive and neuroscience research on learning and cognition [18].

III. THE PRESENT STUDY

The goal of this study was to investigate how students' motivation, strategic self-regulation, and creative competency, were associated with course achievement and long-term learning of computational thinking in introductory computer science (CS-1) courses. This study was part of a larger NSF-funded effort to improve learning of computational thinking and better incorporate computational thinking principles into the disciplines through integration of computational and creative thinking [38, 39]. Courses included one for CS majors, one for a combined business/computer science honors program major, one for engineers with content tailored for engineering, one for a mix of CS, engineering, and general science majors, and one for humanities and journalism majors. The courses are all required within the students' major field of study (e.g., engineering, physics, computer science, etc.).

IV. Methods

A. Participants and Proceedures

Participants were 175 students who consented to participation (151 men; 24 women; 78 freshman, 49 sophomores, 32 juniors, 13 seniors, 3 other/unknown) from five courses in a suite of required introductory computer science course (CS-1) at a large Midwestern state university. Core content was the same for all courses, but courses were tailored for different majors with different programming languages and lab exercises. Participants completed all survey questionnaires on Survey Monkey in approximately 30 minutes during a single proctored course laboratory period in the final week of classes.

B. Strategic Self-Regulation Measures

Strategic self-regulation was assessed with three scales from the Student Perceptions of Classroom Knowledge Building instrument (SPOCK) [4, 21, 32]. All questions were answered on a five-point Likert scale from 1 (*almost never*) to 5 (*almost always*). Scores were computed as the mean score of the scale items. Coefficient alpha reliability estimates for the self-regulated strategy use, knowledge building, and lack of initiative scales were respectively .82, .86, and .69.

Self-regulated strategy use (5 items) assesses the extent of participant planning, goal setting, monitoring, and evaluation of studying and learning (e.g., "In this class, I tried to monitor my progress when I studied"). *Knowledge building* (5 items) assesses the extent of student exploration and interconnection of knowledge from the class [30, 31] (e.g., "As I studied the topics in this class, I tried to think about how they related to the topics I have studied in other classes"). *Lack of regulation* (4 items) assesses participants' lack of understanding of how to study and need for assistance and guidance in studying (e.g., "In this class, when I got stuck or confused about my work, I needed someone else to figure out what I needed to do").

C. Engagement Measures

Engagement was assessed with four measures. Two scales from the SPOCK assess the extent of question asking in class. *High-level question asking* (3 items) assesses the extent to which students ask questions that extend or expand on the basic information being provided in the class (e.g., "In this class, I asked questions to more fully understand the topics we were learning"). *Low-level question asking* (3 items) assesses the extent to which students ask questions to obtain or clarify basic course information ("In this class, I asked questions to be clear about what the instructor wanted me to learn"). Scores are computed as the mean of the items in each scale. Coefficient alpha reliability estimates for high-level and low-level question asking were respectively .87 and .86.

Two scales assessed self-reported studying [4, 21, 32]. Study time was assessed by asking participants to indicate the average number of hours per week they spent studying for the class on a 1–7 scale from 1 (<5 h per week) to 7 (over 30 h per week). Perceived study effort was assessed by asking participants to indicate their perception of the effort they put forth studying relative to most students on a 5-point Likert scale from 1 (*much less effort*) to 5 (*much more effort*).

D. Goal Orientation

Participants' goal orientation was measured with an instrument adapted from that used by Shell and Soh [4]. Scales were shortened to two items due to administrative time constraints. Participants rated goals on a 5-point Likert scale from 1 (*very unimportant*) to 5 (*very important*). Scores were computed as the mean score of the items in each scale. Reliability cannot be statistically estimated accurately for 2-item scales, however, coefficient alpha estimates for the parent scales [4] were .89, .88, .78, .87, .91, and .82 for the learning approach, learning avoid, performance approach, performance avoid, task approach, and task/work avoid scales respectively.

Learning-approach goals (2 items) assess goals for developing long-term, deep understanding of information and skills learned in the course (e.g., "Learning new knowledge or skills during the class just for the sake of learning them"). *Learning-avoid goals* (2 items) assess deliberate avoidance of long-term learning or retention of course information ("Getting a grade whether you remember anything beyond that or not"). *Performance-approach goals* (2 items) assess normative performance relative to other students and favorable assessments of ability by the instructor for ego protection (e.g., "Doing better than the other students"). *Performance-avoid goals* (2 items) assess avoiding negative performance evaluations and unfavorable assessments of ability by others (e.g., "Keeping others from thinking I am dumb"). *Task-approach goals* (2 items) assess efforts to achieve highly and do well on class assignments and activities without reference to normative comparisons (e.g., "Doing my best on course assignments and tests"). *Task-or work-avoid goals* (2 items) assess deliberate intention to put forth minimal effort in the course (e.g., "Getting through this course with the least amount of time and effort").

E. Perceived Instrumentality

Students' perceived instrumentality was measured with the Perceptions of Instrumentality Scale [4, 25]. The scale measures both endogenous instrumentality (4 items. e.g., "What I learn in this CS1 will be important for my future occupational success") and exogenous instrumentality (4 items. e.g., "The only aspect of this class that will matter after graduation is my grade"). Participants indicated their agreement with each question using a 5-point Likert scale from 1 (*strongly disagree*) to 5 (*strongly agree*). Scores are computed as the mean of the items in each scale. Coefficient alpha estimates for the endogenous and exogenous scales were respectively .94 and .92.

F. Implicit Intelligence Beliefs

Students' beliefs about intelligence were measured with the Implicit Theories of Intelligence Scale [12, 13]. The scale measures incremental beliefs (4-items) that intelligence is changeable (e.g., "No matter how much intelligence you have, you can always change it quite a bit") and entity beliefs (4-items) that intelligence is fixed (e.g., "You can learn new things, but you can't really change your basic intelligence"). Participants indicate their agreement with each question on a 6-point Likert scale from 1 (*strongly disagree*) to 6 (*strongly agree*). Scores are computed as the mean of the items in each scale. Coefficient alpha reliability estimates for the incremental and entity scales were respectively .95 and .94.

G. Course Affect

Participants' course affect was measured by a modified version [4, 21] of the Positive and Negative Affect Scale (PANAS) [40]. Participants rated the frequency with which they experienced 10 positive (e.g., excited, inspired, determined) and 10 negative (e.g., nervous, distressed, upset) emotions on a 5-point scale from 1 (*a few times or none*) to 5 (*most of the time, 80%-100% of the time*). Scores were computed as the mean of the items in each scale. Coefficient alpha reliability estimates for the positive and negative scales were respectively .92 and .90.

H. Creative Competency

Creative competency was measured with the Epstein Creative Competencies Inventory [37] administered at the Web site "mycreativityskills.com." The percentage score (0-100) for total creativity was used.

I. Computational Thinking Knowledge Test

Students' retention of computational thinking knowledge and skills from the course was measured with a computational thinking knowledge test developed by CSCE faculty [4]. The test contained 13 conceptual and problem-solving questions for the core computational thinking content common to all CS-1 classes. The coefficient alpha reliability estimate was .76.

V. RESULTS

A. Associations of Strategic Self-Regulation, Motivation, and Creative Competency to Grades and Retention

We used Pearson correlations (*r*) to examine how students' strategic self-regulation, motivation, and creative competency were associated with course grades and retention of core course content as indicated by the computational thinking knowledge test. These are shown in Table 1. Course grades and retention of course content were only moderately associated (r = .350), suggesting that students can achieve high grades without necessarily retaining much of the information from the course.

Student grades and knowledge retention were associated with similar but not identical patterns of strategic self-regulation, engagement, motivation, and creative competency. Both were positively associated with self-regulated strategy use and knowledge building, and negatively associated with lack of regulation. Engagement measures had considerably smaller correlations with grades and retention than strategic self-regulation measures with only study time associated with higher knowledge test scores and only study effort associated with higher grades. These findings suggest that the quality of strategies and self-regulation employed makes more difference in student achievement than general levels of active engagement.

Learning-approach goal orientation was positively associated with both grades and retention; conversely, learning-avoid goal orientation was negatively associated with both. Task-approach goal orientation to perform well and do one's best

TABLE I. ASSOCIATIONS OF STRATEGIC SELF-REGULATION, MOTIVATION AND CREATIVE COMPETENCY WITH GRADES AND KNOWLEDGE

Variable			***Course Grade***	***Knowledge Test***
	M	***SD***	***r***	***r***
Course Grade	2.72	1.35	--	.350**
Knowledge Test	7.60	3.40	.350*	--
SPOCK Self-Regulation	3.30	.74	.220**	.206**
SPOCK Knowledge Building	3.10	.84	.255**	.135*
SPOCK Lack of Regulation	2.82	.78	-.249**	-.305**
SPOCK Question Asking Low	2.88	.93	.140	.127
SPOCK Question Asking High	2.85	.98	.103	.061
Study time	3.19	1.55	.001	.144*
Study effort	3.05	.92	.147*	.071
GO Performance Approach	3.01	.94	.118	.120
GO Performance Avoid	2.70	1.03	-.178*	-.005
GO Learning Approach	3.99	.90	.197*	.211**
GO Learning Avoid	2.62	1.03	-.146*	-.171*
GO Task Approach	4.25	.93	.176*	.270**
GO Task Avoid	2.58	.99	.023	-.122
PI Endogenous	3.71	.99	.217*	.322**
PI Exogenous	2.26	1.03	-.258**	-.337**
Positive Affect	3.10	.84	.252**	.269**
Negative Affect	2.10	.79	-.407**	-.213**
Incremental Intelligence Belief	4.19	1.12	-.136	-.057
Entity Intelligence Belief	2.67	1.15	.051	.087
Creative Competency	56.80	15.02	.055	.139*

*p < =.05, **p < .01

also was associated with higher grades and knowledge retention. Consistent with prior research [4,10], performance-avoid goals were negatively associated with course grades confirming that focusing on goals to avoid low achievement and negative judgments of ability is detrimental to achievement.

Perceived instrumentality was associated with grades and knowledge retention. Endogenous instrumentality was associated with higher grades and knowledge retention; conversely, exogenous instrumentality was associated with lower grades and knowledge retention. It appears that students who focus on only the utilitarian value of grades do not achieve or learn as well as students who focus on more personally meaningful instrumentality.

Positive emotional/affective reactions to the class were associated with higher grades and knowledge retention, and negative emotions/affect in the class was associated with lower grades and retention. Unlike prior studies [12, 13], implicit beliefs about intelligence were not associated with either grades or retention. Dweck [12] and Shell *et al.* [18] have argued that implicit intelligence beliefs operate by influencing goals. To test this, correlations between implicit beliefs were examined. Consistent with theory [12, 18], incremental intelligence beliefs were associated with higher learning-approach (r = .24) and task-approach (r = .17) goal orientations and lower performance-avoid (r = -.17) and task-avoid (r = -.20) goal orientations. Entity intelligence beliefs were associated with higher performance-avoid (r = .25) and task-avoid (r = .22) goal orientations and lower learning-approach (r = -.16) goal orientation, suggesting that impacts of implicit intelligence beliefs on achievement and learning are likely indirect.

Studies have not examined how Epstein's creative competency [37] might be related to STEM course achievement and learning. Overall creative competency was significantly associated with knowledge retention but not grades, suggesting that creativity may be associated with deeper learning and building of expertise, but may not be related to course achievement,

B. *Strategic Motivation, Self-Regulation, and Engagement*

Because students' strategic self-regulation and engagement were associated with their course grades and retention, we were interested in what motivated students to engage in these behaviors. We again used Pearson correlations (r) to examine how students' strategic self-regulation and engagement were associated with their motivation, affect, and creative competency (Table 2).

Students' self-regulated strategy use and knowledge building strategies were associated with similar patterns of motivation, affect, and creative competency. Both were associated with higher performance-approach, learning-approach, and task-approach goal orientations and lower learning-avoid and task-avoid goal orientations. These associations are consistent

TABLE II. ASSOCIATIONS OF STRATEGIC SELF-REGULATION, MOTIVATION AND CREATIVE COMPETENCY WITH GRADES AND KNOWLEDGE

Variable	***Self-Reg. Strategy***	***Know. Building***	***Lack of Reg.***	***Study Time***	***Study Effort***
	r	***r***	***r***	***r***	***r***
GO Performance Approach	.19**	.20**	-.21**	.07	.13*
GO Performance Avoid	-.11	-.08	.12	.05	-.07
GO Learning Approach	.31**	.44**	-.20**	-.04	.05
GO Learning Avoid	-.27**	-.36**	.21**	.03	.06
GO Task Approach	.21**	.17*	-.19**	.16*	.19*
GO Task Avoid	-.27**	-.24**	.11	-.15*	-.16*
PI Endogenous	.46**	.60**	-.20**	.16*	.07
PI Exogenous	-.41**	-.43**	.28**	-.07	-.04
Positive Affect	.54**	.62**	-.34**	.22*	.14*
Negative Affect	-.13*	-.24**	.48**	.23*	.05
Incremental Intelligence	.07	.14*	-.10	.01	.01
Entity Intelligence	-.10	-.15*	.09	.04	-.03
Creative Competency	.32**	.29**	-.07	.08	.01

*p < =.05, **p < .01

with prior research on goals [4, 9, 10]. Self-regulated strategy use and knowledge building were associated with higher endogenous instrumentality and lower exogenous instrumentality similar to findings in prior studies [4, 7, 24, 25]. As in prior research [4, 21], positive course affect had a large correlation increasing self-regulated strategy use and knowledge building; and negative affect was associated with lower levels of these. Implicit intelligence beliefs were not associated with self-regulated strategy use, but incremental beliefs were positively associated and entity beliefs were negatively associated with knowledge building. Interestingly, creative competency was positively associated with both self-regulated strategy use and knowledge building, suggesting that creative competency can enhance positive strategic self-regulation.

Lack of regulation was associated with almost the reverse pattern of motivation and affect. Learning-avoid goals were associated with increased lack of regulation. Performance-approach, learning-approach, and task-approach goals were all associated with lower lack of regulation. Exogenous instrumentality and negative affect were associated with higher lack of regulation, and endogenous instrumentality and positive affect were associated with lower lack of regulation. These associations are consistent with prior research [4, 21, 33] suggesting that lack of regulation is a function of negative emotional/affective reactions to the class coupled with a utility-based instrumentality for the course and learning-avoid goals.

Study time and perceived study effort both were associated with higher task-approach and lower task-avoid goal orientation and with positive affect. Additionally, study time was associated with higher performance-approach goal orientation and endogenous instrumentality. Higher study time also was associated with negative affect, suggesting that engagement may possibly be motivated by both positive and negative reactions to the class. Perhaps those experiencing negative emotions make themselves study and persist more to compensate. This aspect of motivation for studying needs more study.

VI. DISCUSSIONS AND CONCLUSIONS

Recent theorizing in the fields of motivation and self-regulation [4, 16-18, 21, 27] has emphasized the complex links among motivation, affect, and students' strategic and self-regulated behavior in classrooms. The need to consider how multiple aspects of motivation influence a broad constellation of strategies, engagement, and self-regulation to advance course achievement and learning is increasingly recognized. Because motivational and self-regulatory constructs have emerged within different theoretical and research traditions [17, 27], research and discussion have tended to focus on only one (or a few) constructs and strategic behaviors at a time. Our findings show the need to consider how multiple aspects of strategic self-regulation and engagement produce higher grades and retention and how achievement and effective strategic self-regulation are motivated by different facets of students' goals, beliefs, and emotional reactions.

We found that course grades and retention of course content were associated with classic cognitive and metacognitive self-regulation [27, 28, 29] and active engagement [4, 16, 21, 34]. But, achievement and knowledge retention also were associated with a knowledge building approach [30, 31]. These findings suggest that high achievement and long-term retention require both effective studying and self-regulation and in-depth examination of course content through personally meaningful knowledge building. Findings also suggest that STEM educators need to pay attention to students who are not being effective in their studying and self-regulatory efforts, as we found that lack of regulation was associated with lower grades and knowledge retention. Prior research [4, 21] has implicated lack of regulation as a key component in learned helplessness [8] that can potentially lead to disengagement and failure.

Effective interventions to enhance student strategic self-regulation have been reported [28]. These typically involve special courses in study skills [28] or other outside-of-class interventions. Referral to these resources may help alleviate lack of regulation difficulties. Instructors themselves can help students manage time and prioritize by being clear about assignment time demands. They can encourage students to ask questions when they do not understand course material or assignments. Interventions in classrooms to foster knowledge building have been described [18, 30, 31]. Collaborative activities, especially those involving Computer Supported Collaborative Learning (CSCL), have been shown to increase knowledge building [30, 31, 32].

We found that similar patterns of motivation and emotion/affect were associated both with grades and knowledge retention and with higher strategic self-regulation and engagement. These findings support theoretical views that motivation and emotion work through their impact on strategic self-regulation and engagement [14, 15, 17, 18]. Learning-approach goal orientation has been singled out as critical to effective learning and building of expertise [18]. Our findings supported the association of learning-approach goal orientation with increased achievement, knowledge retention, and strategic self-regulation. Our findings also suggest the potential for learning-avoidance goal orientation to undermine these, as they were negatively associated with grades, knowledge retention, and strategic self-regulation and were positively associated with lack of regulation. Shell *et al.* [18] discuss a number of strategies for helping students adopt learning-approach goals. Instructional strategies such as worked examples and models that focus on learning as opposed to solving problems or producing products have been found to be especially effective by directing students to attend to learning rather than outputs [41].

Task-approach goal orientation also is necessary to motivate the self-regulation and engagement needed to study and practice enough to build knowledge and skill [18]. Our findings supported this linkage, as task-approach goal orientation was associated with achievement, knowledge retention, self-regulated strategy use, knowledge building, and engagement while task-avoid goal orientation was associated with decreased self-regulated strategy use, knowledge building, and engagement. But, task-approach goals need to be balanced by learning-approach goals. As noted by Bereiter and Scardamalia [19], students often approach school as a series of tasks to complete rather than as an opportunity to learn. Instructors need to be sure that students are focused on learning the content and not just focused on getting the assignments completed.

Perceived instrumentality has been identified as crucial to student motivation in STEM [4, 7, 18, 25]. Our findings supported this connection as endogenous instrumentality was positively associated with achievement, knowledge retention, self-regulated strategy use, and knowledge building and negatively associated with lack of regulation. Utility-based exogenous instrumentality, on the other hand, was negatively associated with these. These associations suggest that seeing "getting a grade" as the only important outcome of the class does not necessarily lead to effective strategic self-regulation and learning. Students need to see the endogenous instrumental connections between the course and personally meaningful future goals [11, 18]. Research suggests that students do not necessarily see these connections [4, 39], so STEM educators may need to be very explicit about how course material links to the students' major and career aspirations. Endogenous instrumentality can be impacted by classroom intervention, such as providing videos of past students talking about how they used the course content in their other courses [7].

Having incremental intelligence beliefs has been shown to be important for setting learning-approach goals and for fostering knowledge building strategies. Our results supported this prior work as we found a positive association between incremental intelligence beliefs and knowledge building and a negative association between entity beliefs and knowledge building. Numerous studies at all educational levels have shown that incremental intelligence beliefs can be fostered by instructor feedback focusing on how ability and skill can be improved through study and practice and by specific interventions such as having students read a passage about brain plasticity [13].

Our findings that positive emotions were associated with higher levels of achievement, knowledge retention, strategic self-regulation, and engagement and negative emotions were associated with lower levels of these were consistent with much prior research [4, 14, 15, 16, 21]. Research [4, 39] suggests that students in STEM courses that are required but not specifically in their major often have very negative emotional reactions to the course as a whole and to specific assignments designed to enhance deep learning. Establishing a learning-approach climate in the class and fostering higher perceived instrumentality are thought to increase positive affect [15], but there is limited research on how to overcome strong negative emotions in the class [15].

This study is one of the first to look at the role of creative thinking in STEM course achievement and student strategic self-regulation. The Center for Computational Creativity research team has proposed that that using Epstein's [36, 37] model, creative competency can improve learning of computational thinking [39]. The findings provide support for this contention. *Creative competency was not associated with grades, but was associated with higher retention of course material*. Also, *creative competency was associated with higher self-regulated strategy use and knowledge building*. These results suggest that creative competency may enhance the strategic learning strategies associated with building new knowledge and understanding that lead to greater long-term retention and development of expertise. This suggests that enhancements to creative competency may be a valuable instructional tool [39].

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