# Designing Courses for Autonomy Support: A Practical Framework Inspired by Self-Determination Theory for Motivation

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***Abstract*—This research-to-practice paper presents a framework that breaks down the complex constructs of learner autonomy and instructor autonomy support into actionable course design and pedagogical decisions. Grounded in self-determination theory for motivation and self-regulated learning theory, the framework encourages instructors to consider various areas of learner autonomy along a spectrum from teacher-controlled to student-controlled. By conceptualizing autonomy as a range of course design options, the framework enables instructors to creatively envision different ways to promote learners' internalized engagement and motivation through autonomy support. In this study, the framework is applied to the design and assessment of two project-based engineering science courses that offer learners structure alongside different forms and levels of autonomy. Findings show that the instructor's intentional design decisions regarding student choice and control prompted a strong sense of autonomy and high perceived instructor autonomy support among students. As predicted by SDT, autonomy and autonomy support showed significant positive correlations with identified regulation and intrinsic motivation, two forms of internalized drive. Results suggest that the autonomy framework may offer utility value to any instructor seeking to promote student choice and internalized control within the practical constraints commonly associated with college courses.**

***Keywords— motivation, self-determination theory, instructional change, project-based learning, autonomy support, basic psychological need satisfaction***

## I. Introduction

Research illustrates that autonomy-supportive instruction provides important benefits to learning engagement and outcomes. Autonomy support is often difficult to realize in college classes, however, due to a diverse range of personal, disciplinary, institutional, and cultural factors that constrain the ways individuals think about autonomy and effectively reduce student choice, control, and freedom in learning. For example, departments may explicitly prescribe course-level content and assessments and implicitly encourage instructors to adopt controlling teaching styles over autonomy-supportive pedagogies. Low levels of student autonomy in college settings may also arise from a lack of practical curriculum design tools that could guide instructors toward intentional decisions about autonomy and autonomy support in their courses. Practical autonomy-supportive interventions are not well developed outside of K-12 settings, and empirical research that illustrates connections between autonomy-supportive practices and undergraduate student engagement is limited, particularly in engineering education.

This study begins to address the research-to-practice gap in autonomy-supportive learning at the college level, by presenting a flexible framework for autonomy-supportive curriculum design. The framework's practical utility is demonstrated via a case study involving the design of autonomy-supportive project-based courses for an undergraduate engineering program, and measurement of students' motivations and perceived autonomy support in the courses.

### *A. Self-Determination Theory for Motivation*

This exploration is guided by Self-Determination Theory (SDT), a contemporary macro-theory for human motivation and well-being. SDT is based on the premise that people attain intrinsic motivation and well-being when three basic psychological needs are satisfied [1,2]. These needs are *competence*, a sense of mastery, progress, self-efficacy, or expectations for success; *relatedness*, a sense of positive and supportive connections to others; and *autonomy*, a sense of volition, freedom, internalized control, and ownership. As an innate psychological need, SDT posits that autonomy is essential to the forms of positive motivational engagement that lead to growth, optimal functioning, and personal well-being [1,2].

Another key concept in SDT is organismic integration theory, which distinguishes among different types of motivations along a continuum from more controlled/external motivations to more autonomous/internal motivations. Controlled motivations include *amotivation,* described as a disconnection between actions and outcomes and perceived lack of control or intention, and *external regulation*, described as a striving to earn contingent rewards, avoid punishments, or respond to external pressures [1,2,3]. Autonomous motivations include *identified regulation*, a partially internalized drive based on a sense of meaningfulness, usefulness, or importance, and *intrinsic motivation*, a volitional drive tied to deeply internalized interest, enjoyment, or passion [1,2,3].

Organismic integration theory also describes the process of *internalization*, whereby people shift more controlled or external motivations toward more autonomous motivations [1]. While students' situational motivations in college classrooms are complex and multifaceted [4], the general benefits of internalized motivations to learning are clear. Decades of SDT-based empirical research illustrates that self-determined or autonomous forms of motivation, such as identified regulation and intrinsic motivation, show positive relationships to learning engagement, performance, persistence, and well-being [5,6,7]. Highly controlled forms of motivation, such as external regulation, do not share these positive connections [5,6,7].

### B. *Autonomy and Autonomy Support in Learning*

Autonomy and autonomy support have been conceptualized and operationalized in several ways in the educational literature. The autonomy concept is sometimes oversimplified as learner independence, or the existence of learning options or choices in a narrow sense [8]. SDT research shows that provision of choice in learning is important, but learning choices may hold different meanings or manifest in different ways for different people. The simple act of choosing does not necessarily lead to psychological need satisfaction [9]. Feelings of autonomy and self-determined motivations arise when learners have opportunities for *meaningful* and *interesting* choices, when they are enabled to select tasks aligned with their goals and interests, and when they personally endorse or 'own' their actions whether or not external inputs or influences are present [10,11]. Choices viewed as meaningless, uninteresting, or irrelevant may undermine learners' sense of self-determination [8,12]. Too much choice or too many options can feel overwhelming if learners have not yet developed appropriate self-regulated learning skills, or if the choices are coupled to perceived external pressures to choose correctly or pick the 'right' option [8].

A key to satisfying the psychological need for autonomy lies in nurturing individuals' sense of autonomy support. In classroom settings, instructors can support autonomy by enabling choice and control over diverse aspects of the learning process and environment. Stefanou et al. break down teacher autonomy support in the classroom into three distinct categories, each with associated strategies [13]. *Organizational* autonomy support empowers students to engage in creating and implementing classroom rules, and in choosing group members, assignment due dates, and room arrangements. *Procedural* autonomy support manifests as student choice in project materials, deliverables, and modes of demonstrating competence. *Cognitive* autonomy support relates to student opportunities to set goals, select learning strategies, modify assignments, engage freely in discourse, share expertise, self-evaluate, and self-reflect. Patall et al.'s teacher autonomy support measure [14] mirrors certain components of the Stefanou et al. framework, with student survey prompts focused on choosing which parts of an assignment to work on, having options for the kinds of assignments or activities to pursue, choosing how to do work or how to use class time, expressing preferences or opinions about assignments, connecting work to personal interests, and working in individualized ways [13,14].

Notably, much of the theoretical and empirical research on learner autonomy and teacher autonomy support is conducted in K-12 school settings. Studies focused on K-12 classrooms appear to integrate certain assumptions about the teacher and student roles, as well as limitations for consideration of the forms and levels of learner autonomy and teacher autonomy support. For example, Reeve and Jang's definitions of autonomy supportive teacher behaviors such as "offering hints," "allowing students to work in own way," or "being responsive to student-generated questions" imply a certain level of teacher control and conventional classroom setup [15]. While these assumptions regarding autonomy may be appropriate for K-12 learning, they do not always translate well to the highly open-ended or self-directed learning experiences found in many college-level courses.

Self-regulated learning (SRL) models based in social cognitive theory provide an expansive view of learner autonomy that is well-suited to college learning. For example, SRL models describe how learners may express agency in goal setting, information searching and selecting, seeking social assistance, self-evaluation, and environmental structuring [16,17,18]. In his four-phase SRL model, Pintrich elaborates on how self-regulated learners may take volitional control of the learning environment or context [18]. He draws a distinction between traditional classrooms, in which the instructor controls the classroom climate and structure, and self-regulated situations in which learners have the freedom to structure their environment by choosing where and how to work, or by modifying their contextual conditions [18]. As we see with conceptions of autonomy based on K-12 settings, these SRL models are limited in certain ways due to traditional assumptions about the nature of student work in classes, e.g., studying for examinations. Shifting the pedagogical perspective toward active learning, such as problem- or project-based learning, reveals numerous additional opportunities for learner autonomy in the classroom environment. For example, learners pursuing projects may modify their physical spaces, build equipment based on project needs, procure materials and supplies from different sources, conduct work in shop or laboratory spaces, or leave the building or campus entirely to work in remote locations.

Self-directed learning (SDL) and adult learning models align well with SDT and SRL theory in distinguishing between learner autonomy as a *choice*, and autonomy support as a psychological *feeling* of agency or self-endorsed choice and control. SDL and adult learning perspectives further extend the autonomy discussion with an increased emphasis on aspects of choice and control that may be less commonly found in formal settings like college classrooms. For example, Knowles emphasizes learners' self-diagnosis of needs and translation of needs into learning objectives at the start of a learning process, identification of human and material resources throughout the learning process, and development of self-evaluation tools and processes, even when standardized assessments or grades are not present [19]. SDL and adult learning also suggest that highly skilled self-directed learners are able to thoughtfully choose types and levels of autonomy, and make well-informed decisions about when to self-manage their learning versus when to opt for external control from a teacher or expert [20].

### C. *Benefits and Challenges of Autonomy Support*

Studies of autonomy-supportive interventions show that instructors can learn how to become more autonomy supportive, and that autonomy-supportive classroom practices provide benefits to learners and the learning process and environment [21]. Empirical research supports the SDT postulate that perceived autonomy and teacher autonomy support are linked to educational benefits such as vitality, interest, enjoyment, curiosity, deep processing, self-regulation, persistence, and academic achievement [22,23,24,25]. Patall et al. illustrated that when high school students have choice, they express higher intrinsic motivation, feel more competent, and perform better compared to conditions without choice [9]. Within STEM, Brakhage et al. showed that supporting student autonomy through choice of self-relevant topics increases engagement and interest in physics activities [26]. Dell et al. suggested that as part of a larger system enabling learner self-determination, autonomy-supportive structures and practices may help improve retention of women in engineering technology programs [27]. Stolk et al. reported significant positive correlations between autonomy and self-determined motivations in a project-based engineering course [28]. Wang et al. showed positive correlations between perceived autonomy and autonomous motivation, exam scores, grades, and knowledge transferability in college mathematics courses; but they also identified a need for more research on the effectiveness of autonomy-supportive interventions in undergraduate courses [29].

Despite their demonstrated importance to learning, autonomy and autonomy support can be difficult to realize in real-world educational contexts. Research illustrates that instructors often adopt autonomy-thwarting structures and controlling behaviors even if they recognize the potential benefits of autonomy support, a phenomenon Reeve refers to as a "recurring paradox" in education [23]. Reeve identifies and classifies several reasons why K-12 teachers may adopt controlling styles, including "pressure from above" tied to teachers' powerful social roles, dual burdens of responsibility and accountability, cultural valuing of control, and equating of control with structure in the learning environment [23]. Reeve also points to student passivity or lack of motivation as "pressure from below" that can shift teachers into more controlling modes, and "pressure from within" in the form of teachers' motivational beliefs or orientations toward controlling styles [23]. Many of these same pressures exist at the college level, where faculty may encounter rigidly constrained curricula or programs, traditional views of or expectations for instructor and student roles, historically embedded teacher-centered pedagogies, and student engagement driven by extrinsic rewards.

Even if instructors are able to overcome systemic pressures for controlling teaching and embrace autonomy-supportive approaches, they may face challenges in operationalizing the concepts of autonomy and autonomy support in courses due to a lack of practical guidance. While research illustrates that autonomy-supportive instruction provides important benefits to learning, practical autonomy-supportive interventions are more frequently developed for teachers in K-12 settings rather than college instructors [21]. Of the 51 studies included in Reeve and Cheon's meta-analysis of autonomy supportive interventions, only four studies involved university student participants [21]. While college instructors can apply the strategies developed for high school settings with some success [30], many of the available guidelines for autonomy-supportive interventions implicitly limit the forms of learner choice and extents of learner control. College courses can provide rich opportunities for autonomy-supportive learning at levels that enable the transition to self-regulated and lifelong learning, but college instructors may need more than simple suggestions like "offer choices" [31] or "allow the choice of content among different options, offer level options in the tasks" [30]. In the absence of appropriate curriculum design tools for autonomy support, college instructors may find it difficult to imagine a balance between their need for structure and guidance and learners' need for freedom and control; or instructors may imagine an autonomy-supportive classroom as chaotic, unpredictable, unrealistic, inappropriate, or apathetic toward learning outcomes [23]. The framework presented in Section II attempts to addresses the need for a practical interpretation of autonomy befitting adult learners and applicable to college-level curriculum design.

## II. Autonomy Framework

Fig. 1 presents an autonomy framework that breaks down the complex construct of learner autonomy support into practical pedagogical choices instructors may make. Grounded in self-determination theory [1] and self-regulated learning theory [18], the framework enables instructors to envision how autonomy and autonomy support may manifest in different ways in their courses, by offering a diverse menu of opportunities for learner choice and control (Table I). Adapting the high-low autonomy support distinction from existing research [13,32], the framework enables instructors to consider varying levels of autonomy along a spectrum from teacher controlled to student self-determined. At the "student-controlled" extreme lie entirely self-determined and self-directed learning experiences, such as student-initiated independent study activities or thesis projects. At the other extreme lie classes in which instructors specify or control all aspects of the learning experience.

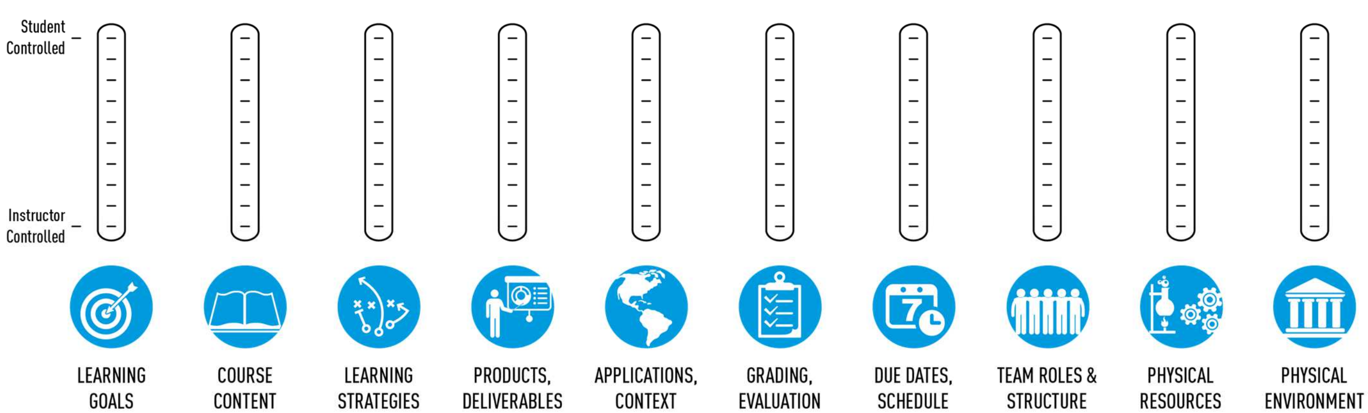


Fig. 1. The autonomy framework, showing different areas and levels of learner autonomy.

Instructors may apply the autonomy framework in several ways, including as a *communication tool* within faculty groups and teaching teams, or between instructors and students; as an *analytical tool* for understanding existing course experiences; or as a *design tool* for the generation and development of autonomy-supportive course interventions or curriculum revisions [21]. The present study focuses on the curriculum design application of the autonomy framework.

Importantly, the framework centers on instructors' provision of choice and freedom and enabling of learner control and ownership in courses, rather than students' sense of autonomy support in the learning experience. As such, it is appropriate to view the autonomy areas and levels in Fig. 1 as independent variables determined by the course designer. Learners' sense of autonomy support – their response to the course design – is a dependent variable that is shaped by the opportunities for choice and control as well as other personal, interpersonal, and contextual factors not described in the framework. That is, the framework is a potentially useful tool for autonomy-oriented course design, and not a prescription for or guide to learners' perceived autonomy support in a given course context. The success of any autonomy-supportive course design is best gauged through student feedback and empirical research measurements of learners' autonomy need satisfaction and situational motivations.

TABLE I. DESCRIPTIONS OF AUTONOMY AREAS [13, 18]

| **Autonomy Area** | **Description**<br>***Students have opportunities to…*** |
|---|---|
| Learning goals | Provide input to course goals, shape course or assignment learning objectives, or formulate personal goals for the experience |
| Course content | Select specific topics or subjects to learn or to integrate with their assignments |
| Learning strategies | Decide the way they approach a task or project, explore multiple solutions to problems, revise processes or methods |
| Products, deliverables | Choose the forms of their learning outputs, decide how they will share their work |
| Applications, context | Identify personally relevant or meaningful connections to their work, develop rationale for purpose or meaning |
| Grading, evaluation | Choose evaluation processes and performance measures, self-evaluate competence; assign grades |
| Due dates, schedule | Develop process timelines, set assignment due dates, shape the course calendar |
| Team roles & structure | Choose teammates; specify individual and group roles; plan peer communications, processes, interactions, and feedback |
| Physical resources | Select and/or procure equipment, tools, materials, and supplies for assignments; design physical setups; manage budgets |
| Physical environment | Modify classroom, lab, or studio arrangements; choose where to work; move freely in and out of learning spaces |

In applying the autonomy framework to course design and pedagogical practice, instructors may consider learner-centered and context-centered questions such as:

- What types and levels of student choice and control does your course currently support? Why did you choose to support these areas of autonomy?
- Where do you see opportunities to increase student autonomy?
- What choices are most meaningful to your students?
- What areas of student autonomy are most appropriate for your course goals?
- What do you see as the upper limits of choice and control for your students, given their development as self-directed learning skills and attitudes? What levels and areas of autonomy might be overwhelming?
- How might different individual students respond differently to increased autonomy?
- What areas and levels of autonomy are you most comfortable or least comfortable supporting?
- What are the biggest challenges with increased autonomy in your course?
- How might your institutional or departmental culture affect students' responses to increased autonomy?
- How is autonomy constrained by external factors, such as disciplinary or course requirements, shared (departmental) syllabi and curricula, governmental standards, or accreditation guidelines?

Personal variables such as learners' academic backgrounds and prior experiences, as well institutional, disciplinary, course contexts and constraints are critically important to consider when designing for student autonomy. Instructors' beliefs about learning, educational values, and pedagogical skills will also shape their ability to effectively design for and support learner autonomy.

## III. APPLICATION OF THE AUTONOMY FRAMEWORK

For this study, the autonomy framework was applied to the design of two project-based engineering science courses that offer learners structure alongside different forms and levels of autonomy. Implementation of the framework and effectiveness of the course design for autonomy were tested through measurements of engineering students' motivations and perceptions of autonomy support.

### *A. Participants and Study Environment*

Participants in the study were college students an undergraduate engineering school in the northeastern U.S., who enrolled in one of the two project-based courses to satisfy a graduation requirement of their engineering major degree program. The participant group included 57 total students, with self-defined gender identities of: 24 men (42.1%), 25 women (43.9%), and 8 non-binary, unspecified or self-defined (14.0%). Respondents included 23 (40.4%) second-year students (sophomores), 16 (28.1%) third-year students (juniors), and 17 (29.8%) fourth-year students (seniors), and 1 (1.8%) of unspecified year of study. Students reported major degree programs of Electrical and Computer Engineering (22.8%), Mechanical Engineering (40.4%), Engineering (31.6%), or unspecified (5.3%).

The two courses selected for this study shared a common theme of materials systems and sustainability. The first course introduced materials science through exploration of consumer products students encounter in their everyday lives, with projects that integrated concepts and questions about the impacts of materials on our world, e.g., waste streams and environmental justice challenges associated with single-use plastics, the environmental toxicity of metals in discarded consumer products, and personal connections to product design and consumer cultures. The second course introduced materials science through studies of electrical and electronic products and their waste streams (e-waste), metal processing methods and their associated energy and emissions impacts, and circular economies or closed loop recycling of metals and alloys. Through a series of analytical projects, students explored materials-related questions that were personally interesting and culturally relevant. The self-directed project work, combined with structured assignments, encouraged students to think critically about the connections among material chemistry, structure, processing, properties, and sustainability impacts. A variety of project deliverables helped students gain skills in synthesizing, contextualizing, and communicating ideas and insights. In short, this courses enabled students to explain how materials behave, why they behave that way, and why it matters for maximizing technical performance or minimizing negative sustainability impacts.

The overall levels of autonomy in the courses are visually represented in Fig. 2. Descriptions of the forms of instructor control and learner autonomy in the courses are provided below.

- *Learning goals*. The instructor set broad, competency-based goals for the course, as well as more detailed learning objectives for each major project. Within these constraints, students formulated personal learning goals for the course, and student teams developed detailed goals as part of their planning for each project.
- *Course content.* For 12 of the 15 weeks of the academic term, the instructor assigned readings and activities in specific technical (e.g., polymer chemistry, mechanical properties, thermal properties, phase diagrams) and contextual (e.g., waste flows, recycling, environmental justice, life cycle assessment) topic areas. Student teams identified additional content relevant to their project plan, and integrated this content with the assigned topics.
- *Learning strategies.* For each project, student teams developed strategies to make progress toward their goals and answer questions relevant to their project. For example, project teams planned how they would select and use laboratory equipment to identify unknown materials or test material properties, how they would apply technical theory and contextual research to their project, and how they would analyze and interpret data gathered through hands-on experimentation or research.
- *Products, deliverables.* Student teams chose the format and design of their project deliverables, within style and content guidelines provided by the instructor. Teams could choose to create posters, physical displays or artifacts, websites, videos, written reports, slide decks, or other products to showcase their work.
- *Applications, context*. The instructor framed overall course themes, e.g., Single-Use Plastics, E-Waste, Circular Economies, or Consumer Products and Cultures. Within these themes, student teams freely selected any product, topic, or contextual theme of shared interest.
- *Grading, evaluation.* The instructor provided competency-based feedback and grades for all major assignments, and formative feedback on weekly submissions. Students could opt to revise and resubmit any assignment for re-assessment and grade adjustment by the instructor.
- *Due dates, schedule.* The instructor specified all major due dates and project deadlines, but accommodated individual and project team requests for late submissions and minor extensions on project due dates.
- *Team roles and structure.* The instructor specified a flexible range for team size, and facilitated team formation based on shared interests in technical or contextual topics. Students managed all team processes, including work distribution, scheduling of meetings,

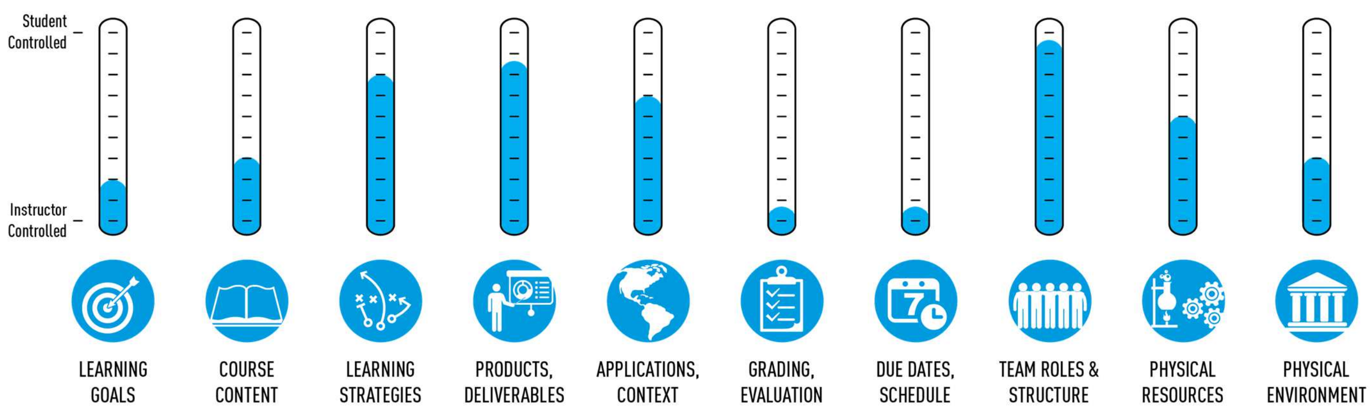


Fig. 2. Areas and levels of student autonomy for courses in this study.

communication mechanisms, interactive style, and collaborative creation of deliverables.

- *Physical resources.* The courses took place in a well-equipped physical space with laboratory equipment and project studio workspace. Each project was constrained by a small budget and available equipment and supplies in the assigned lab-studio space; but teams used the project budget, lab equipment, and materials and supplies in self-defined ways. The instructor recommended usage of certain lab equipment for each project, and provided training for all students on that equipment. Students could opt to learn additional testing or analytical techniques for their project, and get training on an as-needed basis. Depending on their project needs, students could procure supplies, tools, and materials from sources outside the classroom; make use of equipment in other shop and lab spaces on campus; or design and fabricate custom experimental setups.
- *Physical environment.* The instructor typically planned 1-2 hours each week for structured discussion and shared in-class activities. The remaining time (~4 hours/week) was open project time, during which student teams decided where they would work, and how they would make use of the physical lab-studio classroom spaces. Student teams could choose to work outside of the scheduled lab-studio space, e.g., in machine shops or hallway lounge areas.

### B. Instruments, Data Collection, and Analysis

Student responses in the courses were measured using three instruments based on self-determination theory. Learners' sense of autonomy was measured with an adapted version of the Basic Psychological Need Satisfaction (BPNS) in General Scale, a 21-item, Likert-scaled (1=not at all true, 7=very true) questionnaire that gauges individuals' sense of competence, relatedness, and autonomy in a given setting, such as a college course [1,33,34].

Students' sense of instructor autonomy support was measured using the Learning Climate Questionnaire (LCQ) [22]. The LCQ is a 15-item, Likert-scaled (1=strongly disagree, 7=strongly agree) instrument that serves as a combined measure of different forms of instructor autonomy support, including procedural autonomy support (e.g., *I feel that my instructor provides me choices and options*) and cognitive autonomy support (e.g., *My instructor encouraged me to ask questions* and *My instructor tries to understand how I see things before suggesting a new way to do things*) [13], as well as social-emotional forms of autonomy support (e.g., *I feel understood by my instructor and I feel that my instructor cares about me as a person*). Williams and Deci showed high internal consistency for a single autonomy support factor represented by the sum of the 15 LCQ survey items [35].

Learner motivations in course activities were measured by the Situational Motivation Scale (SIMS), an instrument developed and validated by Guay et al. [36]. The SIMS is a 16-item Likert-scaled (1 = corresponds not at all; 7 = corresponds exactly) self-report instrument that maps state, or situational, motivation to Deci and Ryan's self-determination continuum [1]. The SIMS measures four types of motivation along the self-determination continuum: amotivation, external regulation, identified regulation, and intrinsic motivation. Guay et al. reported adequate internal reliability of each SIMS subscale, as well as construct validity of the four-factor structure of the SIMS [36]. In their study of learner motivations in college STEM courses, Stolk et al. reported good internal consistency of the SIMS subscales and confirmed the four-factor structure of the SIMS instrument [4].

Data were collected via web-based deployment of the surveys. In each course, the SIMS, BPNS and LCQ were administered near the start and end of the academic term. In addition, the SIMS was administered periodically as a measure of situational motivations in the project work. Survey response totals were N=69 for the BNS and LCQ, and N=126 for the SIMS. Descriptive statistics were compiled for all SIMS, BPNS, and LCQ subscale measures. SIMS data were also used to calculate the self-determination index (SDI) [37], a single number that represents students' overall levels of autonomous versus controlled types of motivation, by weighting SIMS subscale means by their position on the self-determination continuum. SDI is calculated as: 2×(intrinsic motivation) + 1×(identified regulation) – 1×(external regulation) – 2×(amotivation). Pearson correlations were calculated to examine associations among the study variables.

TABLE II. DESCRIPTIVE STATISTICS AND INTERCORRELATIONS FOR SUBSCALE VARIABLES.

| Subscale | *M* | *SD* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. BPNS - Competence | 5.19 | 0.98 | -- | .42** | .67** | .64** | -.44** | -.25* | .41** | .33** | .47** |
| 2. BPNS - Relatedness | 5.45 | 0.87 | | -- | .55** | .42** | -.14 | -.10 | .08 | .14 | .16 |
| 3. BPNS - Autonomy | 5.69 | 0.64 | | | -- | .74** | -.46** | -.39** | .35** | .43** | .55** |
| 4. LCQ - Instructor Autonomy Support | 5.44 | 0.69 | | | | -- | -.50** | -.31** | .38** | .45** | .56** |
| 5. Amotivation | 1.84 | 0.74 | | | | | -- | .34** | -.38** | -.40** | -- |
| 6. External Regulation | 3.79 | 1.15 | | | | | | -- | -.25** | -.40** | -- |
| 7. Identified Regulation | 5.01 | 1.00 | | | | | | | -- | .66** | -- |
| 8. Intrinsic Motivation | 5.25 | 1.06 | | | | | | | | -- | -- |
| 9. Self-Determination Index (SDI)† | 8.04 | 4.38 | | | | | | | | | -- |

Notes. **Correlation is significant at the $p < 0.01$ level. *Correlation is significant at the $p < 0.05$ level. †Calculated from SIMS subscale values (correlation not applicable).

## IV. RESULTS AND DISCUSSION

Descriptive statistics and correlations for all study variables are shown in Table II. The survey results indicate that students in the courses expressed a relatively high level of satisfaction of all three basic psychological needs. BPNS and LCQ responses suggest that the course environments supported a strong sense of autonomy and high perceived instructor autonomy support among students. On average, students adopted autonomous or self-determined motivations, with high ratings for both value- or importance-based drive (identified regulation) and interest- and enjoyment-based drive (intrinsic motivation), moderate levels of external regulation, and low levels of amotivation.

Correlations among the study variables generally followed the trends predicted by theory [1]. As predicted by SDT, student autonomy and autonomy support showed significant positive correlations with identified regulation and intrinsic motivation, the two internalized or autonomous forms of motivational engagement [1]. Amotivation and external regulation show the expected negative correlations to both autonomy and instructor autonomy support. Notably, of the three basic needs, autonomy showed the strongest correlation to intrinsic motivation ($r = .43$, $p < .01$), suggesting that autonomy may have played a particularly important role in prompting the most highly internalized motivations among students in the project-based courses. Students' perceptions of instructor autonomy support showed a similarly high correlation to intrinsic motivation ($r = .45$, $p < .01$). Fig. 3 summarizes the positive relationship between self-determination and autonomy ($r = .55, p < .01$), and Fig. 4 illustrates the correlation between self-determination and students' perceptions of instructor autonomy support in the classroom ($r = .56, p < .01$).

Results suggest that the autonomy framework may offer practical utility value to instructors seeking to make strategic and intentional choices to promote student autonomy in certain aspects of the learning experience. As illustrated in the Fig. 2 autonomy breakdown, the project-based courses were by no means entirely student self-directed. Rather, the courses supported autonomy in specific areas, with levels ranging from low to high student control. Projects carried an overarching theme such as end-of-life sustainability challenges of single-use plastics or e-waste, but students chose how they would connect the overarching themes to real-world engineering products and social or environmental impacts (applications, context) of personal interest. For example, under the single-use plastics theme, one team choose to examine the recyclability of plastic biowaste, and another team examined the eco-impact of single- and multi-use plastic grocery bags. In the e-waste project, one team studied the reduction in materials usage tied to advancement of LED light bulb technologies, and another team measured the heavy metals in e-cigarette vape juice. As predicted by self-determination theory [10,11], the study data suggest that enabling students to pursue topics of personal interest or relevance within a larger shared theme worked well as an autonomy-supportive strategy. After they selected their topic, students had significant choice and control in *how* they approached their projects (learning strategies), including specifying the questions they wished to explore and shaping the details of their exploratory pathways. At the same time, all projects were required to address broad learning goals established by the instructor, and all projects made use of a shared set of technical and contextual topics (course content) from the instructor-assigned weekly readings and activities.

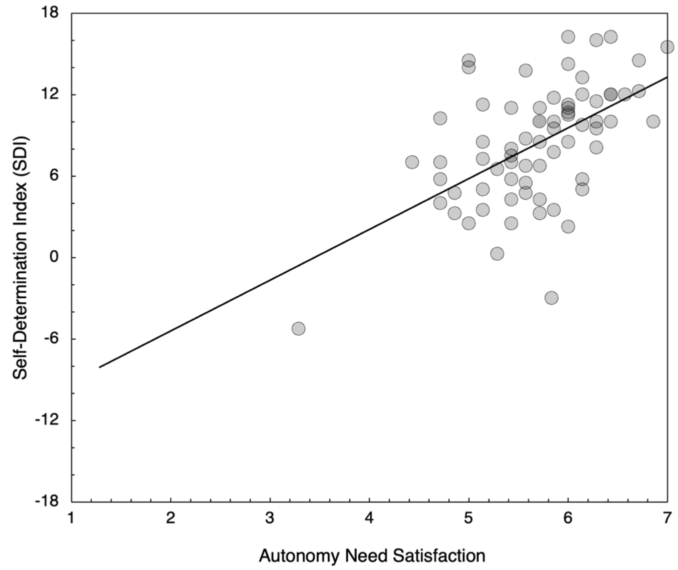


Fig. 3. Relationships between students' mean self-determination index (SDI) value and autonomy need satisfaction. Motivations were measured with the SIMS, and autonomy was measured with the BPNS instrument. N=69.

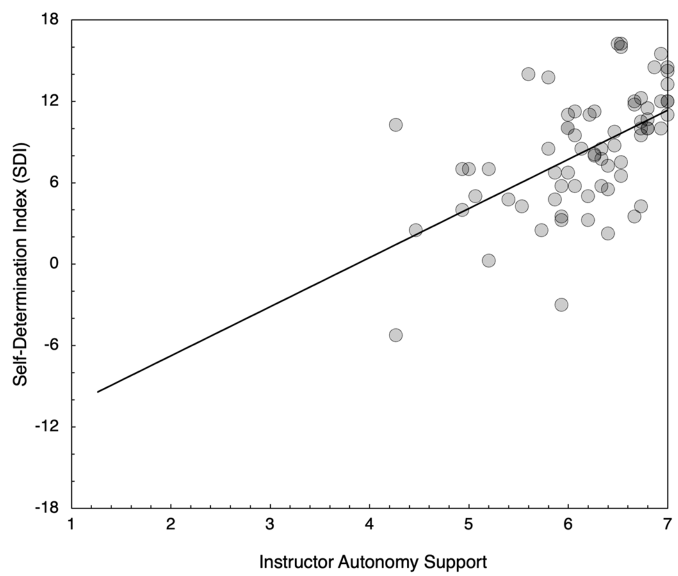


Fig. 4. Relationships between students' mean self-determination index (SDI) value and perceived instructor autonomy support. Motivations were measured with the SIMS, and autonomy support was measured with the LCQ. N=69.

The high levels of autonomy in choosing project deliverables sparked interesting student responses, and provided practical insights about the ways students respond to implied instructor constraints. For the first project in each class, the instructor provided a set of shared style and content guidelines for project deliverables but encouraged project teams to be creative in their deliverable design and format, and to think about how they might best share their project findings and insights with the class. The style guidelines emphasized clarity in the topic or theme, coherent visual style and flow of ideas, balance between text and visuals, and high quality data visualization. At the culmination of their first project, most project teams chose to create a poster in either scientific or infographic style. Only a few teams in each class opted to create deliverables other than a poster. For the final project in each class, the instructor did not provide a deliverable style guide. In contrast to the first project where most teams created a poster, students responded to the final project with diverse array of creative project deliverables, including physical displays, interactive games and demos, websites, booklets or zines, videos, written reports, and slide decks. The instructor's style specifications might have oriented students toward posters as a default deliverable – an implied constraint. Removal of the style guide in the final project may have freed students to consider creation of alternative deliverables, effectively bolstering their sense of autonomy support. Another possible explanation for the greater expression of creativity in the final project deliverables is the building of autonomy support and internalized motivations throughout the semester, as evidenced by the LCQ and SIMS data.

Individuals' sense of relatedness in the courses was moderately high, perhaps tied to the collaborative team-based learning environment and the fact that students hold nearly complete control over their team structure, roles, and peer interactions in the projects. Surprisingly, relatedness showed no significant correlations to motivations. Given that most of the assignments in the courses are team-based, it is possible that students viewed connections to their peers in project team settings as more of a baseline or normal condition for learning in the course, and less of a motivation-influencing variable. Additional research is needed to understand the lack of relatedness-autonomy connection.

Students' lack of control over grading and due dates does not appear to have negatively affected their motivations. External regulation levels are moderate and intrinsic motivations are high, despite the fact that the courses use a letter grading system and address a general (non-major) graduation requirement. Given that cognitive autonomy in the form of self-evaluation [13], and organizational autonomy in the form of due date or schedule management [13] are not typically part of college courses, students simply might not expect any choice or control in these areas. It could also be that students view the project assessments as a form of autonomy support, given the instructor's use of competency-based rubrics that enable individualized feedback and appraisal of each team's strategies and deliverables as unique expressions of the learning goals. Given the importance of self-evaluation in self-regulated learning, and the connection of intrinsic motivations to SRL [16,18], it may be worthwhile examining how opportunities for self-reflection, self-evaluation, and due date management affect students' sense of autonomy and influence autonomous motivations in the courses. Reducing the reliance on instructor assessments and providing self-evaluation opportunities may boost students sense of autonomy as well as their sense of competence, which is currently rated lowest among the three basic psychological needs.

## V. SUMMARY

This paper reviews the literature on learner autonomy and instructor autonomy support, examines the potential benefits of autonomy support to student learning, and argues that development of detailed and concrete theory-to-practice tools may help college instructors create courses that intentionally support students' sense of choice, control, and freedom in learning. The learner autonomy framework developed for this study encourages course designers to shift away from instructor control and toward student autonomy support, by offering a menu of options for enabling learner choice and control at varying levels across different aspects of the learning experience. The framework provides a tool for analysis of existing course designs, design of new courses and projects, and communication between faculty and students regarding choices and constraints in assignments. Application of the framework to undergraduate project- based courses suggested good alignment between instructors' intentional design for autonomy-supportive learning, and students' autonomy need satisfaction, sense of instructor autonomy support, and positive motivations. Furthermore, application of the framework demonstrated that fully self-regulated or self-directed learning is not necessary to kindle a strong sense of learner autonomy and positive motivational engagement. Provided students are able to find personally meaningful, interesting, and relevant choices in some areas, other aspects of the learning experience may be constrained by instructors without ill effects on psychological need satisfaction and motivations.

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