Using Self-Determination Theory to Understand Engineering Student Motivation During Innovation Projects

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***Abstract*— While prior studies on student innovation have examined cognitive and social aspects, recent studies have demonstrated the important role motivation plays in the engineering student experience of innovation, particularly in dealing with the unique challenges innovation presents. However, motivation can be observed in diverse ways and at diverse levels. Using Deci & Ryan's Self-determination Theory, this study examined five levels of motivational regulation (external, introjected, identified, integrated, and intrinsic) that engineering students experienced during innovation projects. The results suggest that students overall expressed more instances of intrinsic and integrated regulation compared to introjected and external motivation. Individual students experienced a variety of regulation types, often developing towards higher level regulation over time. These results suggest that innovation projects trigger complex modes of motivation among engineering students.**

Keywords—innovation; motivation' self-determination theory; component; engineering projects

I. Introduction

Innovation involves working through novel and complex problems; developing deep expertise in key areas; applying broad knowledge to new contexts; and managing a host of technical, human, societal, and business aspects. Not surprisingly, successful innovators are often viewed as highly driven people who are intrinsically motivated to solve new problems, take risks, and change the world [1,2].

While prior studies on student innovation have examined cognitive and social aspects that affect students' abilities to innovate [3–6], few have explored the important role motivation can play, and how engineering students may differ from their expert counterparts. These few studies have begun to indicate potential differences between engineering students and expert innovators, most notably a lack of self-efficacy related to innovation competencies [7,8], limited perceived opportunity to be innovative within engineering [3,9], and primarily extrinsic motivation for innovating during their engineering design projects [10].

In this study, we build on previous work by exploring the mechanisms through which engineering students become motivated to participate in and engage with specific tasks/activities during their innovation projects. We use Deci & Ryan's [11] Self-Determination Theory and the underlying micro-theory of Organismic Integration as a theoretical grounding and investigate students' rich and authentic accounts of their innovation experiences. More specifically, we ask:

- Which types of regulation (intrinsic, integrated, identified, introjected, and external) do engineering students experience during their innovation projects?
- How do students experience these types of regulation during their innovation projects?

II. Theoretical Framework

Motivation is the regulation of processes that influence people in energizing, directing, and sustaining behavior [12]. Self-Determination Theory describes motivation as a process of satisfying one's needs for autonomy, competence, and social relatedness [11]. The underlying micro-theory of Organismic Integration [11] describes the process by which individuals internalize previously extrinsically motivated activities as they come to address needs for autonomy, competence, and social relatedness.

Rather than presenting motivation as either extrinsic or intrinsic, Self-Determination Theory and Organismic Integration present motivation as a spectrum from purely extrinsic to purely intrinsic, with three intermediate stages that are increasingly intrinsically regulated based on the degree to which an individual has internalized the motivated behavior [11]. We briefly describe each type of regulation identified by Deci and Ryan, from most extrinsic to most intrinsic. We later operationalize these concepts in the Methods section (Table 2).

External Regulation – Motivation based on earning externally granted rewards (e.g., money, grades) or avoiding externally meted punishments (e.g., fines, suspensions). The most extrinsic (least autonomous) form of motivation.

Introjected Regulation – Motivation to increase one's feelings of self-worth based on external perceptions. More intrinsic than external regulation, but still highly extrinsic (externally controlled) because of reliance on external perceptions of the self.

Identified Regulation – Motivation to attain a personally meaningful outcome that is partially internalized (e.g., achieve a tentative goal). More intrinsic than introjected, but still somewhat extrinsic because the individual has not entirely accepted the desired outcome as one's own.

Integrated Regulation – Motivation to attain a personally meaningful outcome that is strongly internalized (e.g., achieve a life goal; follow personal or professional values). The most intrinsic form of extrinsic motivation due to the personal importance of the desire outcome.

Intrinsic Regulation – Motivation to perform an activity solely for the experience it provides (e.g., knowledge gains, achieving a personal best, or experiencing sensory stimuli). The most intrinsic form of regulation.

While Self-Determination Theory and the regulation spectrum described therein have underpinned several studies in engineering and technical education, most of these studies have utilized established student self-report surveys (e.g., [13]) and have not explored connections to engineering innovation. In this study, we explore aspects of Self-Determination Theory in the verbal descriptions of engineering students that focus on their experiences with engineering innovation. We apply this theoretical framework to identify the types of regulation engineering students experience, but also remain open to the complex instances and situations that may represent these well-established concepts in this novel context.

III. Literature Review

Previous literature has suggested that expert innovators are often intrinsically, rather than extrinsically, motivated to innovate. Dyer and colleagues [1], for example interviewed a critical mass of successful professional innovators, who followed their intrinsic tendencies to question, observe, associate, network, and experiment. These innovators often noted a strong personal desire to challenge preconceptions, make change, and make their unique marks on the world. Griffin and colleagues [2] found that serial engineering innovators were motivated to innovate by the opportunity to solve problems and follow the processes they associated with innovation. As such, the innovative activity of creative thinking is also viewed as its own reward in many corporate cultures [14].

Studies on student learning, however, tend to focus on cognitive factors rather than motivational factors necessary to innovate. Research on engineering students' experiences with, perceptions of, and approaches toward innovation show some potential misalignment between student tendencies and motivation among expert innovators. For example, both observation and interview studies found undergraduate engineering students who were unwilling to engage with ambiguity and novel solutions during engineering design activities [3,5,7]. In part, these results may reflect the educational environments which engineering students can perceive to devalue innovative aspects of engineering such as creativity [8,9].

In one study exploring innovation-related motivation of engineering students, Linnerud and Mocko [10] surveyed 20 mechanical engineering students on the reasons they pursued innovative solutions during engineering design projects. These students ranked earning high grades, identifying elegant solutions, and developing contacts with and impressing industry sponsors as the most motivating factors. The first and third factors represent highly extrinsic motivation (e.g., external regulation based on grades and professional opportunities). The second factor, however, would tend to align with expert motivation (e.g., intrinsic regulation). These results indicate a potentially complex motivational space connected to engineering student innovation. In the current study, we further explore this space by identifying and detailing the types of intrinsic and extrinsic regulation engineering students experienced during a variety of innovation projects.

IV. Methods

We used a summative, latent approach to content analysis [15] to identify whether and how engineering students experienced five types of regulation (external, introjected, identified, integrated, and intrinsic) during their innovation projects. A summative approach to content analysis involves analyzing specific elements within a dataset based on an extant theoretical framework. A latent approach to content analysis goes beyond exploring the content in a quantitative way (e.g., frequency counts) and seeks to add detail and meaning to content instances. This approach, thus, allowed us to explore the presence of motivational structures based on the well-established Self-Determination Theory, but also to explore unique ways these structures manifested within the engineering student innovation context.

A. Participants

Eight engineering students participated in this study. We selected these participants from a larger pool of 33 students to maximize variation along three factors: academic major, innovation project experience, and general approach to innovation. Table 1 provides a demographic snapshot of the participants.

B. Data Collection

The eight students each participated in a two-hour semi-structured interview focused on their experiences with and conceptions of engineering innovation. The interviews occurred in six stages: participant background, initial definition of innovation, experiences during innovation projects, comparison of innovative and non-innovative projects, general conceptions of innovation, and closing thoughts. The longest and most thorough portion covered the participant's experiences during innovation projects, and formed the basis for investigation in this study. Typically, participants detailed one or two of their engineering innovation projects. Participants were prompted to discuss project events and timelines, processes and design behaviors, their roles and contributions, rationale for decisions and actions, and several other key aspects. The semi-structured nature of the interview allowed for rich and flexible accounts of the participants'

TABLE I. PARTICIPANTS BY MAJOR, YEAR IN SCHOOL, GENDER, AND INNOVATION EXPERIENCE

Pseudonym	Major	Year in School	Gender	Innovation Experience
Chris	Nuclear	Masters	Male	• Founded and led a multiyear entrepreneurial project • Focus on groundbreaking technology
Dylan	Biomedical	Senior	Male	• Innovation in senior design and research-based internship • Focuses on incremental technological innovation with societal and humanistic implications
Ella	Industrial	Junior	Female	• Client-driven, international, co-curricular innovation projects • Focuses on meeting multiple stakeholder needs through innovation
Esteban	First-Year	First-year	Male	• Personal projects both in class and in spare time • Market-oriented, new product development focus to innovation
Hannah	Chemical	Sophomore	Female	• Innovation in a service learning project • Focuses on technical creativity while meeting user needs
Matt	Mechanical	Senior	Male	• Innovation curricular and co-curricular projects • Innovation as an opportunity to complete hands-on, design-build-test work and explore new problems
Sarah	Chemical	Senior	Female	• Innovation mostly in her numerous service learning projects • Human-centered focus to incremental innovation
Tony	Industrial	Senior	Male	• Client-driven senior design project • Systematic, process-oriented technological innovation

innovation experiences, allowing us to identify salient regulation instances and explore them in detail. All interviews were audio-recorded and transcribed.

C. Data Analysis

We first parsed the interview transcripts to cover only the sections in which participants discussed their innovation project experiences. Two researchers then began coding using an a priori framework consisting of the five types of intrinsic and extrinsic regulation. Initial coding lasted three rounds as the researchers coded portions of the data, discussed disagreements, and refined the codebook. Refinements were focused on wording the codes to improve clarity and reliability within the study context (e.g., responding to border cases) while remaining consistent with established descriptions of the constructs the codes represented [11,16]. During this process, we also established a two-item protocol for establishing a codable instance (i.e., an instance of the participant experiencing one of the five types of regulation). First, the instance must have described an action or behavior the participant pursued in the context of an authentic innovation project (and not a hypothetical action the participant might take). Second, the action or behavior must have been attributable to a specific type of regulation (rather than a post-hoc evaluation).

Once the codebook was finalized (see Table 2), we began a round of axial coding. We identified 70 codable instances per the two-item protocol above. Two researchers coded each of these instances and agreed at an acceptable rate of 86% (Cohen's $\kappa = .82$). The two researchers then reconciled coding disagreements and compiled the 70 instances of regulation. We then counted the frequency of each code and qualitatively analyzed the instances of each regulation type for patterns and variation to provide a rich picture of how engineering students experienced regulation during their innovation projects.

TABLE II. CODING PROTOCOL FOR TYPES OF SELF REGULATION

Code	Description	Example
External regulation	Participant is inclined to pursue or perform a behavior or action based on the possibility of external rewards and/or punishments. This type of regulation is externally controlled.	Participant produces many ideas during idea generation because it is required to earn a good grade or is part of the externally-determined project requirements.
Introjected regulation	Participant is inclined to pursue an action based on a desire to avoid negative or promote positive feelings of self-worth. This type of regulation is mostly externally controlled because the importance of the action/behavior is based on the judgment of others.	Participant performs a series of experiments and modifications to perfect a design and set self apart from classmates, prove someone else wrong, or otherwise enhance own ego.
Identified regulation	Participant is inclined to pursue an action because he or she finds its potential outcome(s) important or desirable. This type of regulation is not externally controlled, but not entirely internalized because the outcome has not been entirely integrated into the individual's self-system. Such values may be situational, indirect, or emerging.	Participant pursues a design, that while not intrinsically interesting, will likely meet the clients' stated needs. Meeting the specific clients' needs may not be an overarching goal for the participant, but it seems important in the context of the project.
Integrated regulation	Participant is inclined to pursue an action because its potential outcome is strongly aligned with the individuals' goals or values. This is the most potent form of extrinsic regulation because the aligned goals/values are completely internalized and part of a comprehensive self-system.	Participant engages with menial tasks because the eventual outcome of these projects would be to help those in need, a critical, previously solidified goal of his or her engineering work.
Intrinsic regulation	Participant is inclined to pursue an action for its own sake, independent of value-alignment or external factors. The action is inherently appealing to or enjoyable for the participant based on curiosity or thrill of learning/exploration (i.e., knowledge), satisfaction of creating something or outperforming oneself (i.e., accomplishment), and/or sensory stimuli.	Participant enjoys idea generation for the feeling of freedom, expression, and creativity.

V. Results

Content analysis indicated that participants experienced most or all of the five types of regulation during their innovation projects, and did so in a variety of different ways. Table 3 presents a overview of regulation types, including the total number of instances and cases (i.e., participants) and most frequent manifestations of each regulation type. In the following sections, we further detail these examples in the context of innovation projects that participants described.

TABLE III. Common Occurrences of Each Regulation Type

Regulation Type	Number of…		Common Occurrences of Regulation
	Instances	*Cases*	
External	12	6	• Initial desire to earn a good grade, many money, or produce future opportunities • Performing specific, monotonous tasks or taking undesirable approaches because they were required by an instructor or supervisor
Introjected	5	4	• Demonstrating abilities to earn external recognition • Attempting to prove others (especially authorities) wrong • Taking an action to avoid blame for a potentially disastrous outcome
Identified	16	7	• Performing difficult or boring tasks because they are important to project success • Constraining project work or avoiding exciting but high-risk approaches to ensure feasibility and desirability to stakeholders
Integrated	19	6	• Overarching and enduring engagement with project due to alignment with goals and/or identity (e.g., helping people, technological innovation, professional development) • Internalized self-identification with the project
Intrinsic	18	8	• Participating in projects to explore new areas or interesting topics • Taking desired approaches to design behaviors • Experiencing enjoyable, innovation-related activities (e.g., idea generation, physical prototyping) • Seeking new experiences or interesting topic areas • Exploring new possibilities and thresholds of personal achievement

A. *External Regulation*

Six of the participants described instances of external regulation during their innovation projects (12 total instances). During many of these instances, the potential for external rewards provided participants the initial motivation to engage with their innovation projects. These rewards included grades, money, jobs, or tangible objects they could earn by fulfilling or exceeding the requirements of the project. In many instances, external regulation was paired with more intrinsic forms of regulation to support the engagement needed to innovate. For example, Dylan noted that his initial desire to do well on his senior design project came from a pairing of desire to earn a good grade (external regulation) and his desire to help people (integrated regulation).

> *The beginning of the project it was just, "What can we do to get an A? And can we actually put something together?" And then, once we actually got an idea that was feasible, it was more about, "Okay, let's do it for the purpose of helping and getting hopefully the literature validation." But to be honest with you, yeah, initially you always have to think I terms of what's going to get us the best grade. If it's regardless of the device, but if we could both help the community and get us a grade that would be in a perfect world get which, ideally, we have right now. (Dylan, Senior, Biomedical Engineering)*

In other instances, participants followed instructions, suggestions, or requirements from authority figures (such as instructors, supervisors, and clients) without explicit rewards or punishments attached to these behaviors. These instances included participants accepting design decisions and following general approaches outlined by others. Several instances also involved participants completing tasks in which they found little (personal or innovation-related) value or enjoyment. For example, Hannah described following her supervisor's documentation requirement, which she thought interfered with more important creative and hands-on activities.

> *A lot of it was just recording, and it was kind of taking our time. We have this big design document that we—So, obviously, we wanted to record what went on. Each failure, why it went wrong, things like that. But a lot of it was like, "this is our project partner," they wanted us to learn personally about them, and it was just like, "I want to do the design, I want to ..." Well, you need to know about the project partner to figure out what they want for the design, obviously, but it was hard to communicate and do all that. So, we were wasting our time more doing the design document about the school and things like that instead of ... creatively thinking and designing and building. (Hannah, Sophomore, Chemical Engineering)*

B. *Introjected Regulation*

Four participants described five total instances of introjected regulation during their innovation projects. These instances varied substantially. Esteban and Dylan were motivated to exceed expectations in order to showcase their talents and earn the admiration of other students and prospective employers. Chris noted checking an experimental setup with his project supervisor before proceeding to avoid guilt for any disastrous consequences. Chris, along with Matt, also described the opposite: performing a task to prove an authority wrong. For example, Chris noted that he was often driven by ego during his project to develop a novel radiological energy source.

Ego. Yeah. I'm right. Everyone else is wrong. Just, it didn't work this way and then I'll show my professor and he'll be like, "Ah, I still don't think there's a way to do it." And I'm just like, "Oh yeah? Well, I'm going to prove you wrong." And then I'll go try other things. I would say that comes into play a lot. It's just there's, I'm going to find some way to make this work, and then, "Oh, this didn't work? Doesn't matter." I'm still going to find some way to make it work and just keep trying. (Chris, First-Semester Masters Student, Nuclear Engineering)

Like many instances of external regulation, introjected regulation was often paired with more intrinsic forms of regulation. For example, Chris' and Matt's egoistic approaches to prove others wrong were often aligned with their unique, novel, and personally preferred (i.e., intrinsically regulated) methods of ideation, experimentation, and prototyping. Matt's experience with introjected and intrinsic regulation came when he and his team attempted to build a part for their motorized longboard using a novel machining method. The shop supervisor hesitated to allow them to proceed, which supplemented Matt's desire to experience prototyping in his preferred way with a desire to prove to the supervisor that his proposed method would work.

I guess that was more of an effect of us trying to do our own thing, and do something that no one else has done. But the cause was: no one else has done it. The head ME shop person was actually trying to, I don't want to say actively discourage us from doing it, but he didn't necessarily like how we were designing it. And we still were able to get it designed, and get it built, and make it work. It was a little bit of a, "You're saying we can't, but yes we can!" attitude in there, too. (Matt, Senior, Mechanical Engineering)

C. *Identified Regulation*

Seven participants described 16 instances of identified regulation during their innovation projects. These typically stemmed from a desire make their projects successful, either in terms of objective design criteria or from the perspectives of key stakeholders. Participants came to value project success beyond the tangible rewards of external regulation and the ego enhancements of introjected regulation. This value was not yet part of their core self-concept, but was specific to the project itself, stemming from a growing situational attachment to the solution they were developing and/or the people for whom they were developing that solution.

Identified regulation manifested in two key ways. First, participants accepted the necessity of otherwise boring or overly challenging tasks as long as they contributed to project success. For example, Tony described how he and his team performed, but did not enjoy the "number crunching" phase that preceded the more exciting ideation phase while Hannah described an intense study of the concept of gravity because it allowed her to "start innovating what I wanted to do with the project." Second, participants took feasibility-oriented approaches and mitigated their desires to create globally novel solutions (especially when such solutions were beyond the scope of the project) to ensure that they could deliver effective solutions within time, resource, and contextual constraints. For example, Sarah described her approach to adapt rather than reinvent as a strategy to ensure project success.

In the process of designing that robotic arm, we had an innovative mindset to say that we don't need to recreate. We can improve… In this case, it was: we could take something that was already existing and adapt it and improve it to fit the need that we needed it to fit, and then deliver it, much faster and more effectively. The innovation there comes in the idea of adapting and improving, and then getting something done a lot faster compared to starting from scratch and having to work through the entire process and probably not be successful. (Sarah, Senior, Chemical Engineering)

D. *Integrated Regulation*

Six participants described 19 total instances of integrated regulation during their innovation projects. As with identified regulation, participants were often inspired to complete unenjoyable or overly challenge tasks, or more generally engage with their innovation projects, to ensure overall project success. Here, though, motivation was not limited to the project itself, but responded to a more internalized goal or value that the participant was able to achieve through project success. For example, Ella described her motivation as extending beyond the product itself and how developing a successful innovation provided value for a host of project stakeholders.

It was about more than just the product itself. It was also about all of the implications that solving this problem had for everyone involved with the product. It makes a better product for the consumer. It would make the, in this particular case, the cleanup process for all of the operators much easier. It would improve the profits of the company because the waste would not be as high. It was not just the product that was affected. It was also everybody tied to the product, and the process of making that product. (Ella, Junior, Industrial Engineering)

Integrated regulation provided participants the impetus to initially contribute to their innovation projects and continue to engage with these projects in thorough and meaningful ways, due to evident connections to their personal and professional goals. Common examples included (1) helping others through effective and appropriate design solutions, (2) building skills and expertise that would contribute to their desired career trajectories, and (3) contributing to innovative and groundbreaking solutions. Dylan, for example, described how his goal of helping others contributed to his major selection, but more specifically, his choice to pursue an innovation project to develop a less invasive implantable device for left ventricular conditions.

I just have always been very community conscious, I want to leave the community in a better place then where it started, I want to make sure that whatever I do create or oversee that there's no, but not no, but I can minimize the negative impact it had on those around me. And if I can create to help anyone, whether it's one or a million, I want to go about that. That's kind of a big part that made me also *want to do biomedical engineering. I mean working with the human anatomy, there's so many things that break down. I mean that's just natural. That's how life is. Things break down but you can also increase quality of life through product creation and product generation. So, in terms of creating a device that can then be placed in an individual to give them a higher quality of life then what they could have already gotten, I mean that was a big drive for it. (Dylan, Senior, Biomedical Engineering)*

Chris provided a singular example of how attachment to the specific project resulted in integrated regulation rather than identified regulation. As he described below, experimental failures created substantial cognitive and financial challenges, beyond the point at which he had seen many potential innovators give up. Yet his desire to see his project succeed provided the motivation to continue. This represented integrated rather than identified regulation due to Chris' overall attachment to the project, which he demonstrated throughout the interview. Chris' situation was unique among the participants in this study because he had been working on his project for over six years, compared to the typically semester- or yearlong projects described by other participants. Deci and Ryan [11] proposed that integrated regulation occurs as individuals internalize behaviors and actions that were initially more extrinsically regulated. Thus, Chris may provide an example of how integrated regulation can supplant identified, and potentially even the more extrinsic forms of regulation (e.g., Chris was initially urged to pursue the project by a high school science teacher, potentially representing external regulation), with long-term, continued involvement.

For me it's just like, you just have to keep at it. It's not easy to try and then fail fifteen times in a row and then try again on the sixteenth time because you're like, "Ugh, this is dumb, I'll just go get a job for Steel Dynamics or something like that." ... It's just: I'm going to find some way to make this work. And then "Oh, this didn't work? Doesn't matter. I'm still going to find some way to make it work" and just keep trying. (Chris, First-Year Masters Student, Nuclear Engineering)

E. Intrinsic Regulation

Intrinsic was the most pervasive, but also varied, type of regulation observed in this study. All eight participants experienced intrinsic regulation during their innovation projects, describing 18 total instances. These examples spanned the three types of intrinsic regulation described by Vallerand [16]: to know (e.g., from curiosity), to accomplish (i.e., to achieve personal milestones), and to experience stimuli (e.g., enjoyable activities).

Due to the personal nature of intrinsic motivation, the objects of these instances of regulation often differed between participants. Several participants noted that they were drawn to their innovation projects due to their focus on interesting topics or because they provided new and potentially challenging experiences. While this theme remained consistent among participants, the topics and experiences varied widely based on individual interests and backgrounds. For example, Dylan chose a project centered on cardiology while Chris chose to focus on converting radiation to electricity. Participants also took specific approaches and engaged with specific tasks in ways they alone found enjoyable and stimulating. Once again, preferences differed from participant to participant, and were often made possible by specific aspects of the project context. For example, Matt took an exploratory approach to prototyping because he enjoyed it and his project, in his mind, allowed for the more exploratory approach.

It was the type of prototyping that I liked, and that worked with me. When you're prototyping, it's not always supposed to work. Sometimes it's not supposed to work, and you're supposed to figure out how it didn't work. With our prototyping, it was like, "Well, let's quick sketch it out. Let's cheaply build some part. Let's see if it works." ... As for other projects where it wouldn't work, definitely larger scale and more expensive, it would obviously not work, which is why when we're doing the practical utility platform, our frame is all CAD modeled, before we start building anything. (Matt, Senior, Mechanical Engineering)

Other elements of intrinsic motivation remained more consistent between participants and often aligned with motivation structures typically associated with innovation projects. First, participants enjoyed engaging with the generative tasks and activities commonly associated with innovation: open-ended idea generation, rapid prototyping, and experimentation. Second, participants were interested in solving challenging problems in novel ways. While professional innovators are typically portrayed as intrinsically motivated by a desire to make their mark on the world [1], participants in this study often took this approach due to their curiosity at what was possible and to explore the extent of their capabilities (i.e., it was more developmental). Hannah, demonstrated a combination of curiosity and desire for personal achievement in her approach to designing an educational gravity well for an elementary school classroom, which differed from the more traditional approach their supervisor extolled, notably that a gravity well should be circular.

We were like, "we want to create our own thing, we want to do this, we want to make it a square. This isn't working." ... We saw a better design. We saw a way that it could be much better than the way that he thought. Better in our eyes. Maybe he thought it was better in his eyes to do that, of course. So, he was only using his little corner of the box, and we wanted to use the whole box that we were given. So, we saw that there were other corners of the box, and we wanted to reach out and use all the space that we were given, and he was just stuck in his one corner. So, we saw that there were possibilities, so we wanted to jump on them and see if we could make the best product possible for our project partner. (Hannah, Sophomore, Chemical Engineering)

VI. Discussion and Conclusions

In this study, we investigated five types of regulation engineering students experienced during their innovation projects and how each of those types of regulation manifested in this unique context. We found instances of each type of regulation among the verbal descriptions of at least half of the participants. Further, we found a variety of ways each regulation type manifested. These findings suggest a complex and nuanced motivation space among engineering students participating in innovation projects that may differ between individual students and learning/project contexts, and from previously held understandings of student and expert motivation to innovate (e.g., [1,2,10]) in several key ways.

First, traditional educational reward structures (e.g., grades) may not be sufficient to support student innovation. This conflicts with Linnerud and Mocko's [10] findings, which indicated that earning "A" grades was a key motivator of innovative engineering design work. However, in this study, external regulation only supplied initial motivation to engage with project work (which would later pair with more intrinsic forms of regulation to support innovation) and complete routine or boring tasks. Participants tended to not associate purely external regulations with innovation.

Second, as with expert innovators, intrinsic regulation was especially important to the engineering students in this study. Each participant described at least one instance of intrinsic regulation related to innovation and often described these instances as critical to their innovation experiences. Yet, while expert innovators' intrinsic regulation often stems from consistent causes [1,2], students' intrinsic regulation showed to be more varied (e.g., individual topic and procedural interests). Thus, attempting to tap into intrinsic motivation to innovate on a course design project may be challenging because it would require the instructor to identify the range of potential intrinsic motivators and address each of these within the project description. Flexibility in key areas may support, but not necessarily guarantee, such goals. Still, instructors should strive to support intrinsic regulation due to its power to support positive engagement with innovation among engineering students.

Third, identified and integrated regulation provided the most consistent and robust pathways to engagement. The most prominent form of identified regulation demonstrated participants' growing attachment to their projects. As participants contributed to their projects and began to internalize responsibility for their projects' success, they became more motivated to engage deeply with innovation work. Integrated regulation served a similar purpose, responding to altruistic, creative, and professional values and goals. By making these connections evident to students and allowing them to achieve feelings of ownership and responsibility for their project outcomes (e.g., through autonomy and relatedness), instructors might be able to inspire greater motivation to innovate for a variety of engineering students.

The manifestation of identified and integrated regulation as key aspects of engineering students' engagement with innovation projects may add new insights to previous results that engineering students have been risk averse and/or devalued the importance of creativity in engineering innovation [3,7,9]. In this study, identified regulation often led directly to a feasibility orientation. Participants felt connected to project success and strove to achieve this through ensuring a functional deliverable. Integrated regulation based on helping others served a similar purpose. Thus, engineering students who decline to generate and pursue novel solutions may do so not because they are inherently risk averse or entirely devalue creativity. They may simply be *more* extrinsically motivated toward feasibility within the specific project context. Several participants still acknowledged intrinsic and integrated regulation related to the creative side of innovation, so further study of these potentially competing motivational factors is warranted.

Ultimately, this study reflects the unique experiences of eight engineering students from different majors and years in school, and with different engineering design experiences and approaches to innovation. Thus, educators and researchers must interpret these findings and suggestions with careful consideration of similarities and differences to their own contexts. In our future work, we plan to expand this investigation to new student populations and contexts, while further unpacking the roles and manifestations of identified and integrated regulation within student innovation experiences as well as how engineering students respond to the complex interplay of different motivational factors they experience during their innovation projects.

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