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Student competency, autonomy, and relatedness in a practice-oriented engineering program: An application of self-determination theory

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Abstract

For engineering students, how might three basic needs—competency, autonomy, and relatedness—promote intrinsic motivation among students? In this **research** **paper**, two studies are presented which assess satisfaction and relationship of these basic needs among students in a project-based, undergraduate-only engineering program. In study one, a quantitative study, we surveyed students ($N = 162$) using the Situational Motivation Scale and the Basic Need Satisfaction Scale (BNSS). The results of study one are consistent with previous research showing strong correlations between the three basic needs and intrinsic motivation. In study two, a qualitative study, we analyzed in-depth phenomenologically based interviews ($N = 9$ participants resulting in 756 pages of single-spaced transcripts) using the BNSS as a heuristic framework to identify instances when students express satisfaction or frustration of competency, autonomy, and relatedness. Study two illustrates when and how supportive contexts and behaviors contribute to feelings of competency, autonomy, and relatedness. These studies expand research on SDT by showing ways in which engineering students develop feelings of competency, how specific needs-supportive actions contributed to feelings of competency, and the roles of autonomy and relatedness in the development of competency.

Keywords: Motivation, Makerspaces, Competency, Autonomy, Relatedness, Student wellness

Introduction

"Do you want to watch?"

I turn my attention to Jesse, a sophomore engineering student wearing a leather jacket that's at least two sizes too big for her. She has a welding helmet tucked under one arm and another in her outstretched hand. I instinctively take the helmet from her as my brain works to catch up. Realizing this student is inviting me, a researcher who is new to the fabrication lab, a chance to observe her at the welder I respond, "yes, that would be great!"

"Cool, let's get a jacket for you," she says and leads me to the back of the room where a large metal cabinet holds protective gear. It's just one of many identical cabinets around the room, most of which are filled with hand tools like screwdrivers, chisels, and every size drill bit you could ever need. Now properly suited up I follow her past the table saw and the drill press to the divided off section of the room where the welder is stationed. While other sophomores look lost trying to figure out what tool they need and which cabinet it might be in, Jesse navigates the fabrication lab with confidence.

The fabrication lab is one of several makerspaces in the engineering department of this large, comprehensive, mid-Atlantic public university where engineering students can work on curriculum-required building projects or just hang out with other engineering students. Other makerspaces in the engineering department serve different functions. The prototype lab is filled *with craft materials that make useful aids for conceiving and communicating designs. There's another makerspace with 3D printers that is a popular spot for students to study while the machines work quietly in the background. Aside from students in these spaces, there are staff moving about and making themselves available to answer questions about fabrication or to occasionally get a novice builder out of a jam. I frequent this space too as one of a group of researchers working to unravel how learning happens in makerspaces like the fabrication lab.*

Jesse fiddles with some clamps adjusting and readjusting until the welder cooperates with her explaining to me how the welder needs to be grounded. She pauses her explanations as she handily welds pieces of a bicycle frame into place. Afterwards I have so many questions. How did she get interested in welding? How did she learn? I know the basic training for the welder is widely available but not many of the students use the welder. Why her? Why this?

Through conversation I learn that Jesse was introduced to welding by her grandfather. She had many opportunities to weld and use other tools growing up which was a big factor in choosing this engineering program. This undergraduate-only engineering program aims to prepare its students for a changing landscape of engineering that requires engineers to be adept creators, problem-solvers, and collaborators. Here students learn engineering through the practice of engineering and as Jesse tells me, "all I want to do is build stuff." That made this program, with fabrication projects built into engineering coursework, an ideal choice for her.

As she goes on to explain how she developed the skills needed to accomplish her current project, a theme emerges. When she has a question about materials, she talks to staff member Joseph. When she is deciding between a few techniques, she'll chat with Dr. Paul. It becomes apparent that at every step of the way, relationships play an important role in this students' desire and ability to weld. From early relationships that nurtured her desire to build, to current relationships that keep her moving forward, and future relationships she plans to develop as she shares her vision with me for a welding club for women, her connections to others is significant to her learning. This is a highly-motivated, engaged student who feels a strong sense of belonging in the engineering spaces, and the more she shares, the more it appears relatedness is relevant to the motivation she feels.

Conversations and observations like this one inspired the two-study series described in this **research paper**. We began with a simple question about how relatedness impacts motivation, and more importantly, what educators can do to cultivate an environment that encourages student motivation? Self-Determination Theory (SDT) provides the most appropriate research landscape from which to investigate these phenomena. SDT, a theory of human motivation constructed on/over 50 years of empirical and applied research, asserts that the satisfaction of three basic, universal psychological needs, relatedness, competency, and autonomy, is necessary in the development of intrinsic motivation [1], [2], and "self-determination theory specifies that need-supportive contexts should lead to highly self-determined student motivation" [3]. Further, intrinsic motivation, the desire to engage in an activity because it is interesting and enjoyable to the individual, is linked to student wellness and academic achievement [1]. In other words, the environment created by educators and the actions of educators likely support or thwart feelings of competency, autonomy, and relatedness in students. The satisfaction or frustration of these needs impacts student motivation and wellness.

Equipped with the SDT framework we began with a quantitative study to uncover the relationships of the three basic needs to intrinsic motivation among the student population of this practice-oriented engineering program. A series of in-depth interviews (collected for the wider research project on learning in makerspaces) allowed us to gain insight from a qualitative perspective into how the three basic needs work together and play off each other. We discerned the importance of competency in particular to the formation of intrinsic motivation and identified specific aspects of a practice-focused engineering program that contributes to feelings of competency according to student descriptions of their experiences–insights that are useful for designing need-supportive programs in engineering education and beyond. A picture also emerged of how competency, autonomy, and relatedness function together and a tentative model is presented below. It was *relatedness* that inspired this project, and our approach offers nuanced insight into the functions of relatedness, particularly its contributions to feelings of competency.

Self Determination Theory

Self-Determination Theory (SDT) is a theory of human motivation. Prior to the development of SDT, human motivation was largely considered a binary of intrinsic or extrinsic motivation. This view of motivation was complicated by researchers Edward Deci and Richard Ryan who, beginning in 1971 with the examination of external rewards on intrinsic motivation [4], identified the significance of autonomy versus control in motivation. A person is autonomously motivated when they are doing something under their own volition, willingness, or choice; when someone experiences controlled motivation, they are engaging in an activity because it is demanded of them, and they feel they must, to avoid punishment, or for a reward [2]. Intrinsically motivated action is autonomous whereas extrinsically motivated action may vary in the amount of autonomy that is felt. For example, work may be demanded and/or controlled, but also highly beneficial or aligned with an individual's values impacting the amount of autonomy that is experienced. Decades of research helped clarify a spectrum of motivation ranging from most controlled and external to most autonomous and internal [2]: external regulation, introjection, identification, integration, and intrinsic motivation (for more description of each type of motivation see [5]). Motivation that is autonomous and internalized is called self-determined motivation. A lack of motivation altogether is amotivation. Our two studies focus on the most self-determined form of motivation: intrinsic motivation. “When people are intrinsically motivated they play, explore, and engage in activities for the inherent fun, challenge, and excitement of doing so” [6].

SDT has long posited that more self-determined forms of motivation are associated with improved well-being, learning outcomes, and performance [7], [8]. A meta-analysis of 344 samples was conducted to parse out which forms of self-determined motivation are linked to which positive outcomes [1]. From their findings, intrinsic motivation was related to academic achievement. Intrinsic motivation was also positively associated with all surveyed indicators of well-being: satisfaction, positive affect, vitality, enjoyment, and social-emotional functioning. Further, intrinsic motivation was the only motivation type to “significantly and negatively relate to globally defined maladaptive outcomes,” such as, anxiety, depression, and boredom [1].

The value of intrinsically motivated students is well-established in SDT research which prompts the questions of how to encourage intrinsic motivation. SDT proposes that the satisfaction of autonomy, competence, and relatedness is essential to well-being and function [9]. Autonomy is the feeling that your actions are self-endorsed or that you have the power to make decisions about what you're doing. Competency refers to the feeling that you've done something well or are capable of accomplishing the task at hand. Relatedness is the feeling of being connected to others and knowing that you are cared about. That these three identified needs are universal (even across varying cultural contexts) and linked to both well-being and intrinsic motivation has been affirmed in countless studies [1], [3], [10], [11], [12], [13]. According to a recent meta-analysis of 144 SDT studies, competence is the strongest predictor of self-determined motivation [3]. Other meta-analyses show autonomy as either closely following, equal to, or greater to competence when it comes to predicting intrinsic motivation [14], [10], and here it appears that context matters; competence is the strongest predictor of intrinsic motivation in classroom settings, followed by autonomy. Relatedness is positively associated with intrinsic motivation but weakly when compared to competence and autonomy [3].

From the earliest studies examining environmental factors on motivation to the most recent meta-analyses affirming the relationships between the three basic needs and intrinsic motivation, it has been understood that teachers, parents, employers, or anyone in a position to require or inspire effort from others, could either support or thwart intrinsic motivation through their actions and the environments they create. Although SDT has been widely applied (psychotherapy, behavior modification, physical education, workplaces) our focus is on the role of SDT in student experiences and need-supportive actions of instructors. Studies have shown that rewards, deadlines, competition, controlling contexts, and evaluation all have the power to undermine intrinsic motivation and well-being [15]. Conversely, intrinsic motivation, engagement, and wellbeing are supported in classrooms that promote autonomy [11], [16]. [17] used SDT research to design a needs-supportive computer engineering course. Despite previous research emphasizing autonomy support, it was relatedness that was most frequently mentioned in student interviews evaluating the course. The researchers noted that team projects promoted relatedness, and relatedness contributed to the development of competency. From this study, an area of ambiguity emerges. The vast majority of need-supportive interventions have focused on promoting autonomy, but it was relatedness that rose to prominence for [17]. Our studies address this ambiguity around the functions of relatedness and examine which aspects of a project-oriented program support or thwart competency, autonomy, and relatedness.

Study 1: Quantitative Evaluation of Motivation and Basic Needs Assessment

Our first study is designed to assess students' feelings of competency, autonomy, and relatedness, how the basic needs relate to one another, and how they relate to intrinsic motivation. This study, which uses the *Basic Needs Satisfaction Scale* and the *Situational Motivation Scale*, is one of many similar studies used to evaluate motivation and satisfaction of basic needs among students from elementary school to college. It stands out from this backdrop of supporting research by examining motivation among engineering students in a practice-centered program. We expected competency, autonomy, and relatedness to be positively associated with intrinsic motivation–as previous studies have found. For the sake of exploration, we also wanted to check for differences in male versus female students and in White versus non-White students. The appropriate research questions and hypothesis then are as follows:

RQ1: What are students self-reported autonomy, competence, relatedness, and intrinsic motivation in a practice-centered program?

H1: Autonomy, competence, and relatedness will be positively associated with intrinsic motivation.

RQ2: Are there differences in terms of gender (male vs. female) and race/ethnicity (White vs. non-White) in autonomy, competence, relatedness, and intrinsic motivation?

Study 1: Method

There are an average of 400 students enrolled in the engineering department. Engineering students were invited via email to participate in the survey. Some students were given an opportunity to complete the survey during class time but were reminded that the survey was voluntary and optional. For completing the survey, students could enter to win a $25 gift card.

Participants (N = 162) ranged in age from 18 to 23 (M = 19.5, SD = 1.58). Participants were mostly male (74.1%), followed by female (25.9%). No participants identified as any other gender than male or female. Most participants identified as White or Caucasian (85.8%), followed by Asian (6.9%), Black or African American (5.6%), Hispanic/Latino (3.1%), and Native American (0.6%). The ratios of male to female and White to non-White in the sample is comparable to the total population. Participants reported working on anywhere from 1 to 25 projects (M = 4.87, SD = 3.12, Median = 4, Mode = 3), reported an average number of 2.84 of projects involving making (SD = 2.68, Median = 2, Mode = 3, Range = 0-25).

All items were measured on a 7-point Likert scale (1 = corresponds not at all to 7 = corresponds exactly). See Table 1 for a zero-order correlation matrix for study variables. The current study used a modified version of the basic needs satisfaction scale [18]. Autonomy was measured with six items (e.g., "I feel like I am free to decide how to do things in this program," α = .65, M = 4.39, SD = 0.87). *Competence* was measured with six items (e.g., "People tell me I am good at what I do in this program," α = .69, M = 4.92, SD = 0.87). *Relatedness* was measured with nine items (e.g., "I get along with people in this program," α = .83, M = 5.24, SD = 0.82). Participants were asked to think about a recent project and were asked why they engaged in this project. *Intrinsic motivation* was measured with four items (e.g., "Because I think this project is interesting," α = .89, M = 4.75, SD = 1.39) from the Situational Motivation Scale [19].

Study 1: Results

RQ1 sought to examine reported autonomy, competence, relatedness, and intrinsic motivation of students in a practice-centered program. Results revealed that students had relatively high levels of all four variables: (a) autonomy (M = 4.39, SD = 0.87), (b) competence (M = 4.92, SD = 0.87), (c) relatedness (M = 5.24, SD = 0.82), and (d) intrinsic motivation (M = 4.75, SD = 1.39).

Table 1: Zero-Order Correlation Matrix for Study Variables

Variables	1	2	3	4	5	6	7	8
1. Autonomy	----							
2. Competence	.57**	----						
3. Relatedness	.50**	.55**	----					
4. Intrinsic Motivation	.40**	.46**	.33**	----				
5. Gender	-.07	-.17*	-.28**	-.13	----			
6. Race/Ethnicity	-.03	.00	-.09	.01	.23**	----		
7. # of Projects	-.01	-.08	.08	.03	-.05	-.04	----	
8. # of Making Projects	.01	-.07	.05	.06	-.04	.03	.77**	----

Gender was coded 0 = female, 1 = male. Race/ethnicity was coded 0 = non-White, 1 = White.

In order to test H1, bivariate correlations between autonomy, competence, relatedness, and intrinsic motivation were examined (see Table 1). Results revealed significant correlations between students' reported intrinsic motivation and autonomy ($r = .40$, $p < .01$), competence ($r = .46$, $p < .01$), and relatedness ($r = .33$, $p < .01$).

RQ2 examined potential differences in reported autonomy, competence, relatedness, and intrinsic motivation in terms of gender (male vs. female) and race/ethnicity (White vs. non-White). To test RQ2, a series of independent sample *t*-tests were conducted. Female students reported higher relatedness ($M = 5.63$, $SD = 0.65$) than men ($M = 5.11$, $SD = 0.82$), $t(1, 160) = 3.68$, $p < .001$. Female engineering students also reported higher competence ($M = 5.18$, $SD = 0.79$) than men ($M = 4.86$, $SD = 0.86$), $t(1, 160) = 2.14$, $p = .034$. Male and female students did not differ in autonomy or intrinsic motivation. White and non-White students did not differ in autonomy, competence, relatedness, or intrinsic motivation.

Study 1: Discussion

Our findings are consistent with a recent meta-analysis [3] demonstrating the same pattern showing strong correlations between the three basic needs (autonomy, competence, and relatedness) and intrinsic motivation. All three variables were associated with intrinsic motivation. In particular, competency and autonomy stood out as strongly, positively associated with intrinsic motivation with competency taking the lead as the strongest positively associated basic need to intrinsic motivation. Relatedness was associated with intrinsic motivation, albeit less strongly than autonomy and competence. Female engineering students self-reported higher relatedness and competency than men. No differences between White and non-White students in respect to these four factors (autonomy, competence, relatedness, and intrinsic motivation) were observed. There was nothing surprising about our quantitative findings, but it gave us a strong and useful foundation on which to assess how students experience competency, autonomy, and relatedness.

Study 2: Qualitative Assessment of Basic Needs

Our quantitative study proved to be informative and drew our attention to competency as key in the formation of intrinsic motivation. Although in-line with similar quantitative studies, the seeming demotion of relatedness in relevance to intrinsic motivation (compared to competency and autonomy) left us with questions about the function of relatedness in this practice-oriented program. Noting the strong correlations between all three basic psychological needs, we wanted to examine how each basic need is or is not felt by the students and then unpack the interplay between the basic needs, all of which informs the following research questions:

RQ1: How are students experiencing the satisfaction or frustration of competency, autonomy, and relatedness?

RQ2: What does qualitative data reveal about the interplay of competency, relatedness, and autonomy?

Study 2: Method

Students were recruited through snowball sampling with the researcher approaching faculty, staff, and students to get suggestions for and invite students to participate who fit the criteria for the study. Students fit the criteria if they were over 18 years old, enrolled in the engineering program, and frequently used and/or spent time in the engineering makerspaces. Nine students were interviewed using a phenomenologically based interviewing (PBI) [20], semi-structured interview protocol. Each series of interviews consisted of three interviews up to 90 minutes long. The first interview focused on early experiences in making and what drew the student to this program. The second interview focused on making experiences in the program. In the final interview, participants reflect on their journey up to this point and their identity as a maker. There were five men and four women interviewed. Three of the nine students self-identified as part of a racial or ethnic minority; the remainder were white. Four students were sophomores at the time of the interview or had just completed their sophomore year and not yet begun their junior year. One was a junior, and the remaining four were seniors. Interviews were audio recorded and transcribed.

The qualitative data were analyzed by the first author using an a priori coding scheme based on the *Basic Needs Satisfaction Scale* to identify references to competency, autonomy, and relatedness. A coding manual based upon the *Basic Needs Satisfaction Scale* was created to define coding rules for each item based upon the Likert-type measures in the survey. For example, a students' statements related to competency were coded when students described feeling capable, feeling accomplished, learning new skills, having opportunities to demonstrate their capabilities, and reported on how other people think they are doing in the program. Using methods of constant comparison, the researcher examined each transcription line by line to identify and code student discussions of the themes. After all the interviews were analyzed, each of the nine areas coded were further analyzed to identify common themes in order to provide a more nuanced understanding of students' experiences. A complete codebook for the first round of analysis is included as the Appendix. The second round of analysis separated the data by the three basic needs and used inductive methods of constant comparison to provide in depth insights into how students' feelings of competency (and each subsequent topic) functions and is experienced.

Study 2: Findings and Discussion

Using the BNSS as criteria to identify when students describe feelings of competency, autonomy, and relatedness in the qualitative interviews, then examining these references by topic and in the context of these conversational, in-depth interviews, we gained insight from students' perspectives into when and how each of these basic needs is experienced, and importantly when they are discussed together. These student perspectives shed light on the nuanced relationships between competency, autonomy, and relatedness, and in the section below, we elaborate on those insights first by topic (competency, autonomy, then relatedness) and then in consideration for how they work together, i.e. how relatedness in autonomy-supportive space builds competency.

Contributions to Competency

Competency was the most frequently identified topic in the qualitative data. This is not surprising, in part because the questions in the interview protocol lent itself to encouraging students to describe their accomplishments and skills as makers. The students described experiences and aspects of their learning environment that contributed to feelings of competency: experiential knowledge, recognition, social comparison, success, and self-sufficiency. Importantly, student descriptions of competency prior to the program, in the program, and expectations going forward indicate that competency both builds and is dynamic being constantly evaluated by students.

Experiential knowledge contributes to feelings of competency. Students' pathways into feeling competent in makerspaces start long before they enter an engineering program [21]. Students' experiential knowledge is reported by students as important to bolstering their confidence in making, citing how opportunities to use tools prior to college contributed to feelings of confidence in the makerspaces and how experiences in the makerspaces build confidence in making. For example, Jesse, a White, female sophomore who really enjoys working with tools, notes her time working with tools at home prepared her for the tool training in the makerspaces:

> I just remember the tools training we did freshman year with the trebuchets–I was sort of helping everyone out, because they're trying to use the jigsaw and they're like, "Ah!" and I'm like, "I've been doing that for years." So, I would say it gave me confidence, definitely. I could go in there and I was like, "Oh, I already know how to do that." And it also made me feel kind of powerful helping out guys in the woodshop.

Comparing one's skill level to others and helping others gives students an additional opportunity to favorably evaluate their competence. Jesse was in a position to do so based on her prior experiences working with tools which she notes builds confidence in the makerspaces.

Other students note that their experiences in the makerspaces leave them feeling more confident. As Jacob, a White, male, honor student notes, "I think my confidence has grown more than my abilities, but I definitely have a much better idea of the kind of things I need to do or, I don't have to ask as many questions... I have the hang of things much better than when I started." Finally, as

Hunter observes, experiences in the makerspaces can contribute to feelings of confidence as the students move beyond the makerspaces and into careers:

> In terms of a career, I guess I won't be as naive. When I go into something, I won't have to make those same stupid mistakes that some new guy would make because I've been there and done most of that stuff already, which this program has been really helpful in. Not necessarily that it's made me make those mistakes, but I've done so much that they've happened and if you don't learn from them, they're actually a mistake, but if you learn from them, it's good. So I guess it makes me more confident going into an actual career.

Hunter is a fifth-year student who expresses considerable frustration over the academic issues that have made his journey take longer than four years but whose frustrations are mitigated by opportunities to design and fabricate. As Hunter notes above, confidence comes from experience, and experience necessarily includes failures and learning from those failures. Notably, Hunter cites a process of learning as key, rather than a specific skill or skill set as an outcome of their experiences in this project focused program. Other students also describe competency as something much broader than learning a specific skill or tool. For example, Jacob notes that he is learning "a kind of intuition about materials and their properties."

Success contributes to competency. "Seeing it come together," as is often described by the students, is the competency affirming experience of successfully building something in a project focused engineering program. As Thomas, a White, male sophomore who is excited about engineering and entrepreneurship puts it, "gradually seeing the progress and finally seeing what you envisioned on paper as a hard copy, you can finally get the weight off your shoulders and be proud with your team and see what you've done and look at the journey you took." Here, Thomas references an affective theme that emerged from the students' narratives related to competency: pride. Pride is an outcome of competency. "With a mechanical background, if you can fix anything, that kind of gives you a sense of pride," says Hunter. Another outcome of competence, frequently relating to the affirming experience of "seeing it come together," is confidence. Pride and confidence are two affective outcomes of successful, competency-building experiences.

Affirming communication contributes to feelings of competency. Students made reference to affirming communication, i.e. interactions with others that expressed students' success related to a project, program overall, or leadership role, when describing themselves as competent. For example, Jesse proudly describes: "[The head of the machine shop] said this was one of the best-fitting pieces, so I was very proud." When students described their accomplishments in the interviews, it was common for them to cite the statements of others that recognized their successes and work as further evidence of competency. For example, Lauren, a senior student who is active in the engineering makerspaces, stated, "Probably one of my greatest achievements, I organized that entire bike lab." She then goes on to note, "and actually [my professor] said, not to me but to my parents, he's like, 'yeah, I've never seen that bike lab so organized in my entire time doing this project.' So that was cool," In this instance, Lauren is not only experiencing pride in the quality of her work, but the recognition she received from her professor affirmed her understanding of herself as competent.

Students compare themselves to peers when ascertaining their competency. Students also expressed that opportunities to demonstrate capabilities to others was an important affirming experience that reinforced feelings of competency. Importantly, it is not just the student's successful performance of capabilities, but the comparative successes and accomplishments that elevate or diminish one's perceptions of their own competence. Social comparisons are made with one's peer group – in which students ask themselves "How do I measure up against my peers?" As students evaluate their competency by comparing themselves to one another, statements that indicate a student might be ahead of their peers constitutes an affirming experience. For example, Thomas notes after the opportunity to present a freshman project to the entire engineering department, "I had seniors coming by saying [my project was] better than some of the [senior] projects that came out of this." Students also experienced social comparison with peers when they were invited to assist another student, the implicit message that they are seen as competent and skilled. Jesse reflected on this, "Sometimes people ask me to help them with stuff and that makes me feel good."

Students who take the initiative are well-positioned to build competency. Some students describe a willingness to take the initiative, or as Jesse describes it, "being a go-getter," as a quality that facilitates the development of competency. For example, Thomas states,

> There seems to be a lot of people that I'll talk to in this engineering department, they'll be like, 'I don't know that technical skill. I can't do that project.' And for me it's more of just having that motivation and taking that step forward. Yes, the unknown can be scary if it's a field you haven't touched or anything like that. Just jump into it, see what you can do with it.

Jesse adds to this by defining a go-getter: "Just taking the bull by the horns and doing things on your own, I guess. Even if you're nervous or you don't know what to do, you've just got to start working on it so you eventually know what to do and do it." Hunter agrees that there are opportunities to develop competency in the program but that the students must take some initiative stating, "you're paying for the opportunity to be educated. They won't just give it to you, you've got to go out and get it." Initiative described by the students above is not a given, importantly student accounts articulate how varied qualities of the engineering program contribute to or constrain the students motivation and ability to be a "go-getter."

Self-sufficiency is considered an indicator of competency. Consistently through the interviews, students use self-sufficiency as a measure of competency. For example, Lauren states, "I think students are more likely to take pride in their work and say, 'Hey, instead of just buying this from a hardware store, we designed and built it, or we designed and sent it off to the machine shop'," indicating the pride that she takes in the work she does in the machine shop. David seems to agree when asked what it is about hand tools which appeals to him stating "I like seeing that I've done the work as opposed to a machine." As Hunter states, "I do like being self-sufficient. That first year, the machine shop was hard cause you always have to be asking permission for stuff and how do you do this? But then once you reach a level of that self-sufficiency, everything just becomes so much faster and you're able to do so much more work and you can then outwork everyone else." The way the students describe self-sufficiency indicates that it both contributes to feelings of pride and that it is a measure by which they understand their own competency. Can they do a task independently? If so, they have considerable competency in that area as noted by Logan, "The more independent you are and the more skills you have, the more freedom you have because you're able to use those different traits to your advantage."

There is a complexity to self-sufficiency, however, that emerges when we explore the topic of relatedness. While it is true the students feel more competent when they are able to complete a task independently, it is not necessarily the case that needing help or guidance lessens feelings of competency. Indeed, a network of support and meaningful relationships emerges as one antecedent for developing competency.

Autonomy

Student accounts related to experiences of autonomy show that it is facilitated by freedom over and within learning spaces. Likewise, students experienced feelings of autonomy related to freedom of choice in how projects are completed. There is a strong sense of ownership conveyed by students when they talk about the engineering spaces and projects. Time constraints and pressure in the program presented obstacles to autonomy. By examining when students describe feelings of autonomy, we gain further insight into when and how opportunities to build competency are presented.

Students experience autonomy when they have freedom of movement in the spaces. Accounts demonstrated that feelings of autonomy were facilitated by students' perceptions of having liberty in the physical spaces of the engineering department. The project-focused engineering department is designed to provide a variety of multi-modal spaces with varying degrees of expectations for how the spaces can be used. For example, the fabrication lab which holds a welder and assorted power tools has greater restrictions for how the space can be used than the room equipped with assorted craft supplies for making models. However, even in the spaces with greatest restrictions and expectations, students express considerable freedom in how they use and conduct themselves in the spaces. For example, the machine shop where mills and lathes are stationed is described by Erin, a White, female senior and machine shop apprentice, this way, "it's so goofy, and it's amazing. Last year, we would prank each other all the time." Other students who work in the machine shop describe it as laid back, casual, and fun, being careful to note that safety is still the number one priority in that space.

In other makerspaces, the function of the room may be more broad or undefined. As Thomas notes, "One of the most helpful things is we have a lot of rooms that don't have equipment-specific stuff within them." Thomas posits that this helps him feel more creative. Jesse similarly relates freedom in the spaces to the ability to take the initiative and try new things stating, "[The makerspaces] are very student-friendly, so you can just kind of go in and do your thing." Faith, a Black, female senior holding multiple leadership positions in student organizations, sums it up this way, "I think the makerspaces are really important because they provide a space without intention. You can try as much as you can to be like, 'This is how this space should be used.' But it's kind of a free-for-all space versus a classroom." Of course, there are limits to the autonomy students have in the makerspaces. Hunter expresses frustration that students cannot be in the spaces at any time of day or night and on weekends.

Autonomy is supported when students have ownership and freedom to make project choices. Student descriptions highlight the importance of a wide range of choices they are free to make as they work towards completion of a project; this freedom within and over their projects is an important theme in students' experiences of autonomy (or lack thereof). For example, Jesse talks about a freshman project in which she was instructed to build a ukulele. The instructions for that project allowed for a lot of variation in how the work was completed. Jesse describes the variability and openness of the project, "It was really cool because there were a lot of different ukuleles. Some people made it out of soap bottles. Some people bought ukulele kits and just glued it together. Some people hand-made them." As students progress through the program, guidelines for projects do get more constraining as they are determined by the needs of a client and the resources available, but the liberty to make choices in manufacturing remains across projects. As Jacob states, "there's very rarely one right way to do things."

Access to persons with more expertise is necessary to support autonomy. Students consistently cite the importance of having access to experts – faculty and staff – toward their agency and self-control over projects. As students describe the multiple pathways and options in a project and the choices in proceeding, they frequently cite conversations with faculty, staff, and other students that help guide their decision making. For example, David, a Hispanic sophomore student who likes spending time in the engineering makerspaces, notes getting help with manufacturing decisions as valuable, "A few upperclassmen have already done this project, so we kind of asked them, like, 'What do you think is the best way to attach this or attach that?' and they gave us a few pointers and actually helped." Interactions like this one are so frequently referenced in the decision-making processes of students suggesting that access to persons with greater manufacturing expertise is a necessary quality of a project-based program that facilitates feelings of autonomy.

In seeming tension with the students' desires to demonstrate competency through self-sufficiency, sensemaking conversations with faculty, staff, and other students in the engineering department is the most often cited reason the students give for choosing one tool or technique over another. Consider Lauren, who relishes the opportunity to make decisions for herself but still needs the support and guidance of those with expertise:

> It was a challenge because I was working alone but was also a great reward because I truly was able to make all the decisions and not have somebody else trying to make them for me. [Faculty and staff in the engineering department] helped when I got hung up on something specific, but it was really my design and my hard work that made the bike a reality which was really cool.

Here, Lauren notes that she was never truly alone in a bike building project because she had access to people who could help her along the way. Importantly, then, autonomy is not experienced in isolation, as helping interactions are reported as necessary for developing both competency and autonomy. We revisit the value of these experts and their role in decision making in the next section on relatedness.

Negotiating Autonomy vs. Constraint

Students desire autonomy. Students frequently made references in their speech to their perceived desire for autonomy as an ideal state. For example, when talking about hopes for a career, Logan, a White male sophomore, says, "I feel like I would be most comfortable in a place where there's not much limitation. The same way that we do in class, where we follow the design process from start to end, I would want to do something like that in my future career where I can actually be the one who designs it and fabricates it." This ideal of autonomy is linked to the character of makerspaces themselves and the people who use them, Faith states, “the makerspace is for people that don't like rules.” Many of the students interviewed echoed similar sentiments of craving self-control over the process or creative liberty and disliking imposed constraints. However, even as students reveal a desire for personal liberty in their project work, they all recognized and described the boundaries of autonomy.

Students can have too much autonomy and feel unsupported. Importantly, autonomy is an ongoing negotiation, rather than a static state. Students, therefore, describe experiences in which they actively navigate varying degrees of constraint, including too much or not enough autonomy. When students described situations in which they had too much autonomy, they described it as having too little direction and not enough support. For example, Logan describes an assignment with which students in his class struggled. “We were supposed to follow the design process, but we weren't given any information about what we were supposed to be doing or anything. We were just given what our deliverables were supposed to be.” Others similarly described the struggles of a group project that lacked clear faculty guidance. Lauren opines, “I think our advisor is a bit too lax. I think he thinks we're great, but we're like, kind of not. I would say we need more help than he's given us.” In this case, the help Lauren seems to desire is in the form of guidance and accountability.

Time constraints and pressure infringe on autonomy. If too much autonomy is experienced as a lack of support and direction, not enough autonomy is experienced as feeling pressured. Students reveal that pressure in the program comes from high expectations of professors, impending deadlines, and grades. For example, Thomas describes the intense night before a major deadline stating, “We were there until like 5:00 AM, and I had, trying to put the gear into the right place, I had just little bruises slots all down my hands from pushing that gear into place and holding it there, so that I had battle scars.” When students describe a desire to engage in more personal projects, they often cite pressures from the program, namely time constraints, as a limiting factor. Autonomy then, is a freedom of choice within a field of constraint.

Relatedness

Students interviewed often use words like *community*, *family*, and *home* to describe the engineering department, suggesting strong feelings of relatedness. Feelings of relatedness, according to the students, are facilitated by experiences that encourage deeper engagement, the small size of the program, and relationships with faculty and staff themselves. In the same way that prior experiences impact feelings of competency, student narratives reveal that meaningful relationships played an important role in the series of decisions that led to their enrollment in the engineering program. For example, Thomas notes that helping his dad work on cars increased his interest in making, the amputation of someone close to him got him interested in biomedical engineering and having a relative graduate from this university got him interested in this school in particular. Long before the students enter this program, relationships are playing a pivotal role in what they do. Once in the program, relationships continue to shape the students’ journey and outcomes.

Relatedness, as described by students, is tied to the culture of the engineering program. Students use positively valanced language to describe the climate and its emotional character. For example, Jesse describes the department as “welcoming,” and David says the people in the department are “supportive.” All the students interviewed expressed similar feelings of relatedness in the program. Some students described having built relationships with many others in the program such as professors, staff, upperclassmen, and teammates, while others described feeling well connected to just a few key people in the program. Whether students described their relationships as many or few, all attributed their success in part to relationships with others who provided help and guidance.

Relatedness is designed into the program and modeled. Relatedness in the engineering department is encouraged through programs that promote deeper engagement. For example, an orientation program allows students to gather in the department the summer before their first year and participate in challenges and activities that familiarize the students with the space and people. As Jesse noted, “I went to the orientation camp. I met a lot of the upperclassmen from that, so that kind of—and a lot of students my age, too, but that also helped with coming into new spaces because I knew upperclassmen so I felt pretty cool.” Relatedness is also modeled by faculty and staff. As Jesse continues to explain what it is about the program that makes it feel like family, noting both a program (the leadership program) that is a designed part of engineering, and how faculty and staff model relatedness:

> I just feel like it's very family. The professors are all really nice and they all actually care. I think the professors set the tone. Them being there for you, in a way it kind of helped with the students being the same way. And then I think the leadership program integrating the upperclassmen into the underclassmen from day one freshman year, I think that helped a lot too because then you get to meet the upperclassmen and that kind of set the tone.

This excerpt reflects the sentiments of other students who, when describing the community of the department, make references to programs in the department that promote integration of students. Importantly, this example along with others showcase the manner in which faculty model features of relatedness that the students then emulate.

Students experience relatedness through personal relationships with faculty and staff. More significant than the co-curricular activities and organizations built into the engineering department are the relationships students build along the way with faculty and staff, particularly in the form of mentoring. For example, Hunter describes his relationship with a professor he worked with both in and out of the classroom this way, “from the beginning he kind of took me under his wing and showed me what his thought of what engineering should be.” The small size of the program helps create opportunities for students to get to know faculty and staff personally and most of the students interviewed referenced the size of the engineering program as something that attracted them to the program or as a benefit of the program that contributes to their success. As Faith states, “I needed my teachers to know me as a human person, and so I couldn't go to a large school.”

A recurring theme in the student interviews is that small classes and a small program make it easier for students to get to know their professors, and importantly for the professors to get to know them as well. Faith attributes feeling supported and not marginalized as a Black, female engineering student to the fact that professors and peers know who she is personally, “because the program is so small, people know my ambitions, people know my work ethic, people know how much I can get done, people know how I think, people know what I say, people know what I wear. People know me as a person regardless of if I show them or not." Feelings of relatedness in this engineering program are demonstrably generated both by the faculty and staff who have designed a program that facilitates community and by the students themselves who take advantage of these opportunities to become deeply engaged. The students interviewed for this study crave relationships with their professors and peers; they want to know and be known.

Students experience relatedness in the form of peer support. Students identified interactions with peers as a source of relatedness and support in the program. As Thomas notes, "Everybody kind of knows everybody, so we just like, say hey and sometimes we help each other on projects and stuff like that or ask advice." While describing their making experiences, many students note that other students in the makerspaces are there to make suggestions or lend a helping hand. The students also help one another with homework and exam preparation as Thomas describes: "Sunday I texted, I said, "if anyone wants to work on materials and mechanics come to the junior/senior studio" and eight people showed up and we just sat there and helped each other at work on materials and mechanics." Most of the students interviewed acknowledge cooperative behavior among their peers as a benefit of the program, but notably a minority of students describe a preference to stick to themselves. Even these students, however, describe close connections to a few of the faculty and staff that helped them be successful.

Relatedness makes the physical spaces of the department accessible and comfortable. The relatedness students feel with peers and mentors makes the autonomy-supportive physical spaces of the engineering department places where students can be themselves. As David describes, "Here, it's kind of like you're open to creativity, but in those other areas [of the university] I'm closed off, like I'm not familiar with the people I'm around. So, it's almost like a part of me shuts off, but here I'm very open." Further, Jacob describes a sentiment shared by many of the students that the more time you spend in the spaces, the more comfortable you'll feel there: "Not just like the actual work itself, but just like being in those spaces, you get more comfortable with them. It just kind of starts to become a hang out spot where you'll do your homework, or just chill with friends or whatever."

The comfort students feel is described as being both in the space and with the people in the space which end up being important for understanding how relatedness contributes to autonomy and competency. Peer and mentor support play an important role in student experiences and facilitate developing competency. Like Lauren who got stuck during a bike building project and relied on the help of a mentor to get her unstuck or Jacob who flourished in the machine shop where he always felt comfortable asking questions, student narratives describe relatedness as a mediator between the challenges of the engineering program and skills development. This phenomenon was noted by [17] who found that relatedness was frequently referenced in student interviews as a pathway to competence building, e.g. by learning from peers in team projects and feeling comfortable asking for clarification from teaching assistants who were approachable. A limitation of that study was a self-selected group of students whose experiences may not be generalizable.

Similarly, it may be that the students who were approached for this study and agreed to participate are students who experience greater feelings of relatedness than others in the engineering program. Seeing the same phenomenon bare out in both studies strengthens the assertion that relatedness facilitates competency by providing students, not just an *opportunity* to get help if they need it, but with caring mentors the students feel comfortable going to.

General Discussion

Intrinsic motivation is positively associated with academic achievement and well-being and "significantly and negatively" related to maladaptive outcomes [1]. According to SDT, the satisfaction of basic needs is directly related to intrinsic motivation and wellness. Quantitative and qualitative data collected in Study 1 and Study 2 support the relationship between autonomy, competence, relatedness, and intrinsic motivation. Study 1 highlights the importance of competency as the strongest positively associated psychological need to intrinsic motivation and Study 2 illustrates how competency is not static but something that is being evaluated by students as they navigate the program. Study 1 confirms the correlation of basic psychological needs, and Study 2 illustrates the interplay of these needs. From these insights emerges a tentative model for building competency. We can also address our original inquiries into the functions of relatedness and suggest qualities of a need-supportive learning environment.

Taking the Initiative, a model of competence building

This practice-focused engineering program provides an interesting lens through which to view SDT and more specifically the development of competence as a contributor to intrinsic motivation. Central to the design of this program are makerspaces where tools and various equipment are provided that students will need to complete making projects in the course of their engineering education. All students are required to contribute to the design and fabrication of coursework projects, but not all students get the same skill-building benefits of the autonomous makerspaces. According to student narratives, the willingness to put oneself out there and take the initiative is key to skills-building in the makerspaces. Based on the results described above, we present this model demonstrating how relatedness, autonomy, and competence facilitate initiative which in turn develops competence.

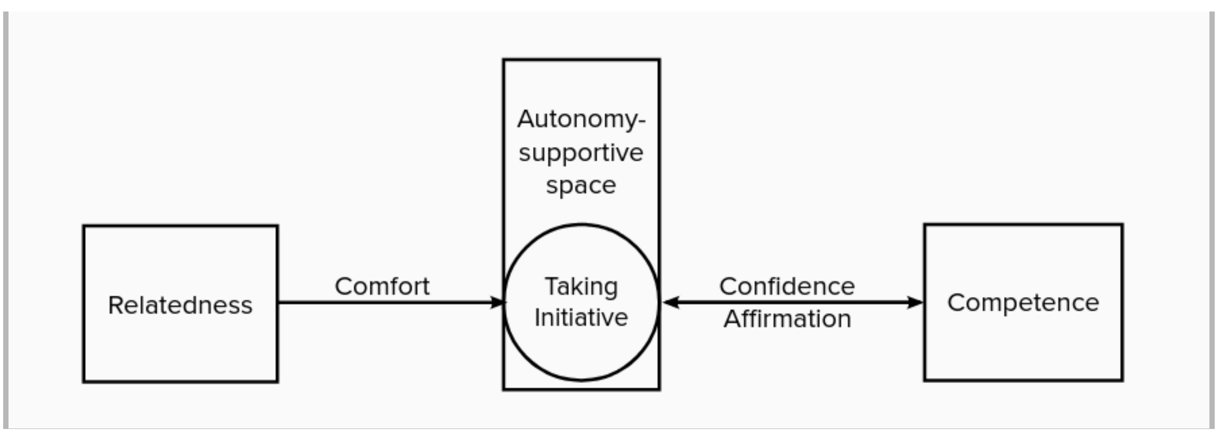

Figure 1. Building Competency: A Model of Basic Needs Satisfaction

For students to be able to take the initiative, there needs to be spaces where students are free to be creative and try new things (autonomy). Students need to be comfortable in those spaces and with the other people there (relatedness), and they have to have a sense of their own capabilities to use the tools provided (competency). Once in the spaces, affirmations in the form of success, comparison, and positive communication support student's developing feelings of competency. As noted by students, increased time in the autonomy-supportive makerspaces also increases relatedness as students develop bonds with the other people who frequent those spaces.

Revisiting relatedness

As was the case in [17], in our qualitative study, students brought up examples of relatedness even when not prompted and illuminated ways that relatedness contributes to competency. In our qualitative findings, there is nothing to suggest that relatedness is any less important than competency or autonomy to student wellbeing and achievement in the program. On the contrary, there are times when it stands out as perhaps most important, as is the case when students are under the most pressure and are the least sure how to proceed. However, as with other quantitative research [3], autonomy and competence were more strongly related to intrinsic motivation than relatedness. By providing qualitative and quantitative data from the same population we can put these outcomes in conversation with one another and gain a more nuanced understanding of the role of relatedness in competency-building that contributes to self-determined motivation.

The desire to be self-sufficient was salient in the self-evaluation of competency to the group of students who were interviewed, but it is not clear if that is particular to that group of students, the culture from which they emerge, or is more broadly generalizable. It may be that even though competency, autonomy, and relatedness are all necessary for the development of intrinsic motivation, that a tension exists between self-sufficiency, a marker of competency, and relatedness. Decision making in particular highlights this tension as students describe a desire to be in a position to make their own choices but frequently cite conversations with faculty, staff, and upperclassmen as guiding them through the decision-making process. Students need the guidance of people with more expertise but feel competent when they are able to be self-sufficient or help others with their expertise.

Creating a basic needs-supportive learning environment

Students come into the program with perceptions of their own competency based on experiences and perceptions of aptitude. However, unlike expertise development which is considered a linear progression from novice to expert [22], competency exists as a question being asked over and over again. Student narratives reveal how this question is asked, by novel and challenging experiences, and answered, by affirmations such as successful completion of a project and recognition for a job well done. Relatedness and autonomy both facilitate opportunities for competence to grow. Relatedness enables students to ask questions and seek help on their making projects and increases their comfort in the spaces. Increased comfort asking questions and being in the makerspaces may make it easier for students to try new things and take the initiative, which is an aspect of building feelings of competency. Importantly, the makerspaces in particular provide an autonomy-supporting context in which students feel a sense of ownership over their work and choices.

These are the characteristics identified by student narratives as the qualities of a practice-focused engineering program that contribute to the basic psychological needs of competency, autonomy, and relatedness. We think these insights can be applied broadly to a variety of learning environments. For example, students who are developing expertise are moving towards increased independence in their work but that is a product of a process that proceeds, a process of trying, struggling, asking questions, and trying again. Students need spaces where they can struggle and even fail safely with the knowledge that help is available. Likewise, our research demonstrates that the key to balancing autonomy-support and structure (both being necessary for student success) is access to knowledgeable and approachable mentors.

Limitations

The use of both quantitative and qualitative data in our study allowed for a more sophisticated understanding of students' perceptions of autonomy, competence, relatedness, and intrinsic motivation in a practice-centered program. For both the quantitative and qualitative data, selection effects may influence study findings. For instance, the target participants for the qualitative study were students who frequent the engineering makerspaces. Participants in the in-depth interviews were approached by the researcher and asked to participate but not all students who the researcher approached agreed to participate. It is possible that the interviewed group of students share qualities that make some of their experiences different from the population of engineering students at this university. The students interviewed, though, represented as diverse a group as possible within the population with regard to gender, race, ethnicity, and as the interviews later revealed–personality, ambitions, and prior experiences.

Conclusion

Student performance and wellness are improved when students are intrinsically motivated [1]. According to SDT, the satisfaction of three psychological needs (competency, autonomy, and relatedness) promotes intrinsic motivation [23]. We conducted two studies to assess the satisfaction of these basic needs among students in a practice-focused, undergraduate-only engineering program. The autonomy-supportive design of this engineering program was shown to contribute to the development of competency by availing students with many opportunities to take initiative and demonstrate self-sufficiency. Relatedness contributed to the development of competency by providing a safety net of accessible experts and mentors and increasing comfort in the engineering spaces, both important antecedents of taking initiative. These studies expand research on SDT by showing ways in which engineering students develop feelings of competency, how specific needs-supportive actions contributed to feelings of competency, and the roles of autonomy and relatedness in the development of competency.

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Appendix: Codebook for analysis

Competence

I do/do not feel competent or capable in this program.	if there was a project the required machining for the Capstone, you know I can do that, but then if it also required welding and um soldering and some electrical work- I was up a creek and I probably wouldn't have done it... but now you know I can do almost all of that- woodworking, metal working, welding, soldering- all within 100 feet of each other.
Other people do/do not think I am doing well in this program.	And actually Dr. Richards said, not to me but to my parents, he's like, "yeah, I've never seen that bike lab so organized in my entire time doing this project." So that was cool.
I am/am not learning interesting new skills.	"I'm gaining an insight into just to how things work, how understanding the natural world, I guess in a nutshell I'd have to say like understanding the natural world around me. I mean a lot of it's just for fun, but it also serves the function of familiarizing myself with manufacturing processes, how different types of systems work, how they integrate with each other and that kind of thing."
I do/do not feel a sense of accomplishment.	I'm just like "I made that, she's riding my bike!" And so before the bike got painted, it was late September, last year, and I was riding around the engineering building and of course the bike was just a little bit small for me, but people were looking at me and I'm just like, "See y'all don't know I built this bike, this is mine." That was really cool.
I do/do not get to demonstrate my capabilities.	And then, some people's ukuleles sounded great, some of them didn't, some of them weren't very loud, some of them were really funny. Mine was funny, because it was like, "dink, dink, dink,"

Relatedness

I like/do not like people in this program.	"Everyone's really nice. There's a couple people that are kind of closed off but even they're pretty nice and helpful."
I get along with/do not get along with people in this program.	"I think it's just the fact that we're the minority of the percentage, and we might be like, scared of judgment, but in the end we kind of stick together."
I keep to myself/do not keep to myself in this program.	"So I was the person who was telling everybody what I needed from them in order to make this successful. And then they were the most important part, since they actually made it happen. So that was crucial. I couldn't have done it without them."
People do/do not care about me in this program.	"Describe the culture here. Oh, it's good ... good for me. Describe the culture here. I don't know ... easygoing, helpful, supportive."
The people in this program are/are not my	"Not just like the actual work itself, but just like being in those spaces, you get more comfortable with them. It just kind of starts to become a hang out spot where you'll do

friends.	your homework, or just chill with friends or whatever, so. So there is that kind of social aspect to it."
My feelings are/are not taken into consideration in this program.	"Henry is the kind of person I'd go to if I'm about to break down, because there's moments where you're about to break down, so I always kind of go to him."

Autonomy

I am/am not free to decide how to do things in this program.	Interviewer: Do you have the autonomy in these situations to be like, "Appreciate what you said, but if I have to make 50 of these. I'm doing it this way." Participant H: Yeah. I feel like as long as you get the correct results and it doesn't hurt the machine and all that, you're good. So if you have one way to think about it that isn't what they think about, but it's still gonna work, they're like, "Fine, do it."
I am/am not free to express my ideas and opinions in this program.	"we would say something that was kind of like constructive criticism and then they would change the wording so it sounded better. The professor would say it to Jill and we would hear what she's saying, and then Jill would write down what she was saying. We were like, "That's not what I said.""
I feel/do not feel pressured in this class.	"There was the night before the alpha. I had been trying to do this with the bike. We were until like 5:00 AM and I had, trying to put the gear into the right place, I had just little bruises slots all down my hands from pushing that gear into place and holding it there, so that I had battle scars. So that part was not as fun."
I can/cannot be myself in this program.	Here, it's kind of like you're open to creativity, but in those other areas [of the university] I'm closed off, like I'm not familiar with the people I'm around. So, it's almost like a part of me shuts off, but here I'm very open.
I have to do what I'm told/ I can choose what to do in this program.	"I think the makerspaces are really important because they provide a space without intention."