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Experimentation Over Traits: Hierarchical Predictors of Entrepreneurial Intention in Engineering Education

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Abstract*– Entrepreneurial intention is widely used as a central outcome in entrepreneurship education in engineering; however, less attention has been paid to how different predictors operate when ordered according to their proximity to entrepreneurial action under uncertainty. This study proposes and tests a layered explanatory model in which entrepreneurial intention is progressively explained through variables ranging from distal structural factors to proximal behavioral mechanisms. A questionnaire was administered to 497 third-year engineering students from three departments at a Chilean university. Measures included entrepreneurial intention, experimentation (as an effectuation-related behavior), cognitive flexibility-adaptability, polychronicity, openness, extraversion, demographic variables, work experience, and family entrepreneurship background. Hierarchical regression analyses revealed a progressive increase in explained variance across five theoretically ordered blocks: demographic variables (R^2 = .045), experiential background (R^2 = .124), personality traits (R^2 = .24), cognitive-temporal mechanisms (R^2 = .307), and, finally, experimentation (R^2 = .435). Experimentation emerged as the strongest predictor (β = .52, p < .001), while polychronicity maintained significance in the final model. Personality traits, gender, age, and innovation training were not significant once proximal mechanisms were incorporated. The findings support a progressive explanatory structure in which entrepreneurial intention is primarily associated with mechanisms proximate to behavioral engagement under uncertainty, rather than with traits or distal conditions. These results have direct implications for curriculum design in engineering, suggesting that formative experiences centered on iterative experimentation and parallel coordination of activities may play a decisive role in strengthening entrepreneurial intention.

Keywords—entrepreneurial intention, effectuation, polychronicity, engineering education, hierarchical regression.

I. Introduction

In the contemporary training of engineers, entrepreneurship has ceased to be an "alternative path" and has become a legitimate—and increasingly necessary—way to respond to productive challenges characterized by uncertainty, technological acceleration, and the permanent transformation of markets [1], [2]. In these contexts, value creation depends not only on mastering technical tools, but also on the ability to reconfigure limited resources, learn from imperfect feedback, and act with incomplete information [3], [4]. For this reason, innovation and entrepreneurship education in engineering has acquired a strategic role, particularly in ecosystems such as Chile's, where coordination among universities, industry, and support networks has grown steadily, and where training programs are expected to contribute to the development of scalable technology-based ventures [5].

Nevertheless, there is a recurring tension in the way entrepreneurship education is evaluated and designed. A significant portion of the empirical evidence in engineering education uses entrepreneurial intention as a central outcome—a robust cognitive predictor of entrepreneurial behavior in classical models [6], [7]—and recent studies have synthesized the main cognitive and motivational drivers of that intention through integrative reviews and meta-analyses [8]. However, the literature also warns of a persistent gap between intention and action, particularly among student populations, suggesting that not all formed intention is equally viable, stable, or transferable to real behavior under uncertainty [9], [10]. This raises a more demanding pedagogical question than merely measuring "interest in entrepreneurship": what mechanisms—cognitive, temporal, and behavioral—make entrepreneurial intention more robust and actionable in engineering students?

Part of the difficulty lies in the fact that curricula tend to operate under prediction and planning logics, characteristic of well-structured problems; whereas technology entrepreneurship, in its most authentic form, more closely resembles ill-structured problems, where prediction is limited and control emerges from iterative action [3], [4]. At this juncture, effectuation theory offers a decisive conceptual inflection: as opposed to causation (defining objectives, planning, and predicting), effectuation describes a decision-making logic in which the future is constructed through the use of available means, progressive commitments, and iterative experimentation under uncertainty [4], [11]. This shift—from prediction to non-predictive control—is not merely a descriptive framework for the expert entrepreneur; it is, potentially, a pedagogical logic: if entrepreneurial intention is to be more than a declarative disposition, it must be anchored in behaviors that make it possible to act without requiring complete certainty from the outset [11], [12].

In parallel, research in entrepreneurial cognition has shown that action under uncertainty requires specific cognitive and metacognitive mechanisms. The situated metacognition model of the entrepreneurial mindset suggests that cognitive adaptability allows individuals to monitor, regulate, and reconfigure thinking strategies in response to changing feedback [13]. Similarly, cognitive flexibility is associated with the ability to abandon fixations, shift interpretive frames, and generate alternatives in dynamic and complex tasks [14]. However, even these capacities may prove insufficient if they are not translated into forward-moving behavior under conditions of ambiguity; in fact, education that emphasizes only "thinking better" may produce students capable of analysis without necessarily learning to act.

Finally, there is a frequently undertheorized component in traditional intention models: the temporal dimension. Entrepreneurship is inherently temporal because it demands the overlapping coordination of interdependent activities (technical development, user validation, network building, team leadership), often without clear linear sequences. In this framework, polychronicity—understood as a dispositional temporal preference for structuring time in a non-sequential manner—emerges as a plausible mechanism for alignment between individual preferences and the demands of the entrepreneurial role [15]–[17]. For engineering students, whose academic trajectory tends to be organized around monochronic logics (sequentiality, fixed deadlines, discrete tasks), polychronicity could act as a critical factor of vocational congruence, strengthening intention when such temporal preference is present and aligned with the perceived demands of entrepreneurship [15], [17].

Accordingly, this study proposes that entrepreneurial intention in engineering students is better understood not as a direct outcome of isolated traits, but as the product of a progressive explanatory architecture: from distal variables (context and background), through predispositions, to cognitive-temporal mechanisms and, crucially, proximal behavioral actions under uncertainty. Specifically, the objective of this paper is to empirically examine, in third-year engineering students in Chile, the relative weight and explanatory order of (i) experiential exposure, (ii) personality traits, (iii) cognitive flexibility/adaptability, (iv) polychronicity, and (v) experimentation as a representative behavior of effectuation logic, with respect to entrepreneurial intention [4], [11]–[14], [18].

Unlike purely correlational approaches, this paper seeks to identify which variables operate as the most proximal activators of intention, thereby providing an interpretive basis with direct curricular implications for the design of formative experiences that privilege iterative experimentation, early validation, and non-sequential temporal coordination, in line with contemporary approaches to entrepreneurship education in engineering [5], [19], [20].

II. Theoretical Framework

This section reviews the theoretical foundations underlying the layered explanatory model proposed in this study. It proceeds from the role of entrepreneurial intention as a central construct in engineering education, through the cognitive and decision-making mechanisms associated with action under uncertainty, to the temporal dimension of the entrepreneurial role. Each layer of the review corresponds to a conceptual level of the model, building toward a synthesis that formalizes the architecture examined empirically in the sections that follow.

A. *Entrepreneurial Intention as a Central Cognitive Construct in Engineering Education*

Entrepreneurial intention has been established as one of the most widely used cognitive predictors for approaching entrepreneurial behavior, particularly in educational contexts where observing real action is difficult and costly. Classically, intention is understood as a deliberate mental state that directs attention, evaluation, and behavior toward the creation of a new initiative [6]. In the Theory of Planned Behavior (TPB), intention results from attitude toward the behavior, subjective norm, and perceived behavioral control [21]; in entrepreneurship, competing models have consistently shown that intention is an immediate antecedent of action [7]. In engineering education, this centrality has made it a frequent indicator for assessing the impact of entrepreneurship- and innovation-oriented courses and programs [19].

Nevertheless, intention does not fully capture the phenomenon. Evidence reveals a persistent intention-action gap among student populations [9]. This does not invalidate the construct; rather, it suggests that not all intention is equally robust in the face of contexts that penalize prediction: technological uncertainty, resource constraints, and non-linear trajectories—conditions typical of technology entrepreneurship [3]. From this perspective, the relevant question for engineering education is not only whether students report intention, but what psychological architecture renders that intention viable and resilient when the environment is uncooperative with planning.

B. *Entrepreneurial Mindset in Engineering Education: Between Pedagogical Orientation and Mechanisms*

Interest in the entrepreneurial mindset has grown steadily in engineering education, driven by the need to train professionals capable of creating value in dynamic scenarios [2]. Initiatives such as KEEN have disseminated the Entrepreneurial Minded Learning (EML) approach, pedagogically operationalized through the "3Cs" (curiosity, connections, and creating value) [22], [23]. This framework provides a powerful educational grammar: it orients instructional design toward questions, connections, and value, and has been adopted to align technical learning outcomes with entrepreneurial capabilities [24], including its articulation with related pedagogical approaches such as design thinking in engineering education [25].

However, there is a tension: EML functions as a pedagogical compass rather than a mechanistic explanation. Critical reviews suggest that, while useful, EML does not in itself specify the cognitive and decision-making processes through which students form a robust entrepreneurial intention and, eventually, take action [5], [20]. In other words, EML defines where to look; the theoretical challenge is to specify how intention is built when prediction becomes a luxury.

C. *Entrepreneurial Cognition and the Metacognitive Turn: Thinking in Motion*

The "cognitive turn" shifted the focus from entrepreneurial traits toward the mental processes involved in opportunity recognition and decision-making under ambiguity [26]. But in environments where change is rapid, static cognitive structures are insufficient: cognition must become mobile. In this vein, Haynie et al. propose a situated metacognition model of the entrepreneurial mindset, in which cognitive adaptability is understood as the capacity to monitor and regulate thinking in accordance with environmental feedback [13]. This situated metacognition does not seek to "have the right answer" from the outset; it seeks to sustain judgment when information is incomplete. Complementarily, cognitive flexibility describes the ability to abandon fixations, shift interpretive frames, and generate alternatives in the face of ill-structured problems [14]. In the training of engineers—frequently trained to tackle well-defined problems with optimal solutions—these capabilities are especially relevant for navigating toward contexts where solutions are discovered (or constructed) in the process.

However, even flexibility and adaptability can remain "latent capacities" if they are not translated into an organizing principle for acting when prediction fails.

D. *Effectuation as a Decision-Making Logic: From "Predict to Act" to "Act to Control"*

Effectuation theory offers an inflection point: as opposed to causation—predefined objectives, planning, prediction—effectuation proposes a logic in which the future is controlled in a non-predictive manner through available means, alliances, and iterative action [4], [11]. In practical terms, this is not about denying thought; it is about reordering the sequence: action produces information, and information reconfigures action. Chandler et al. operationalize effectuation as a multidimensional construct, identifying dimensions such as experimentation, affordable loss, and flexibility, enabling its quantitative study [12]. Subsequently, this line of work has been extended to the field of engineering education through the development of instruments aimed at assessing effectual logic in students, strengthening the empirical measurement of the entrepreneurial mindset in formative contexts [27].

This step is crucial for engineering education because it translates common pedagogical practices (prototyping, early validation, iteration) into a coherent theoretical framework. Recent empirical evidence indicates that effectual components—particularly experimentation—show substantial associations with entrepreneurial intention, by strengthening the perception of feasibility and control under uncertainty [28]. This suggests that the most resilient intention is born not only from wanting to become an entrepreneur, but from having practiced a logic in which error becomes data and iteration becomes method.

E. *Temporal Orientation and Polychronicity: Matching Preferences with Entrepreneurial Role Demands*

Despite the fact that entrepreneurship is inherently temporal, the temporal dimension has been undertheorized in traditional intention models. The entrepreneurial role demands overlapping coordination of interdependent activities (technical development, validation, networking, leadership), with sequences that are often non-linear. Polychronicity is defined as a dispositional temporal preference for organizing time in a non-sequential manner, allowing for the overlap and parallel coordination of interdependent activities or roles [16]. Its relevance emerges when interpreted as an alignment mechanism: under the person-vocation fit framework, congruence between individual preferences and role demands strengthens vocational attitudes and decisions [17]. Cox et al. propose that polychronicity may mediate the relationship between cognitive capabilities (flexibility/adaptability) and entrepreneurial intention, acting as an indicator of congruence with the structural demands of entrepreneurship [15].

For engineering students, this mediation is particularly plausible: the academic trajectory tends to be organized around monochronic logics (sequentially, fixed deadlines, discrete tasks), which may inhibit the expression or development of polychronic preferences; however, when such preferences are present, their alignment with the perceived demands of entrepreneurship may substantially strengthen intention [15], [29]. Polychronicity, thus, is not cognitive "multitasking," but rather a preferential temporal architecture that can make entrepreneurship feel "inhabitable."

F. *Personality Traits as Amplifiers: Predisposition Without Activation*

The literature recognizes associations between certain personality traits—such as openness to experience and extraversion—and entrepreneurial intention [30], [31]. Openness is linked to tolerance for novelty and exploration; extraversion to social interaction and network mobilization. Nevertheless, when cognitive and decision-making mechanisms more proximal to action are introduced, the evidence converges on the finding that traits operate primarily as amplifiers, rather than as primary causes [28]. From an educational standpoint, this is decisive: if traits are not the proximal driver, then curricula can be designed to foster trainable behaviors and mechanisms even in students with diverse dispositional profiles.

G. *Synthesis and Articulation of the Layered Model*

The reviewed literature converges on a fundamental point: entrepreneurial intention in engineering students is better explained as the result of an integrated configuration of mechanisms, rather than as a consequence of isolated traits. In this paper, that integration is formalized as a layered model ordered by conceptual proximity to entrepreneurial action under uncertainty:

- Distal variables (age, gender, disciplinary affiliation), which provide context but typically explain a limited fraction of variance in intention [9].
- Experiential exposure (work experience and family background), which introduces normalization and situated learning [32].
- Dispositional traits (openness and extraversion), which predispose but do not necessarily activate [30], [31].
- Cognitive-temporal mechanisms (flexibility/adaptability and polychronicity), which enable reframing and temporal coordination congruent with the entrepreneurial role [13], [17].
- Proximal behavioral mechanism (experimentation as a component of effectuation), which operationalizes iterative action under uncertainty and is therefore

expected to be the strongest predictor of entrepreneurial intention [11], [28].

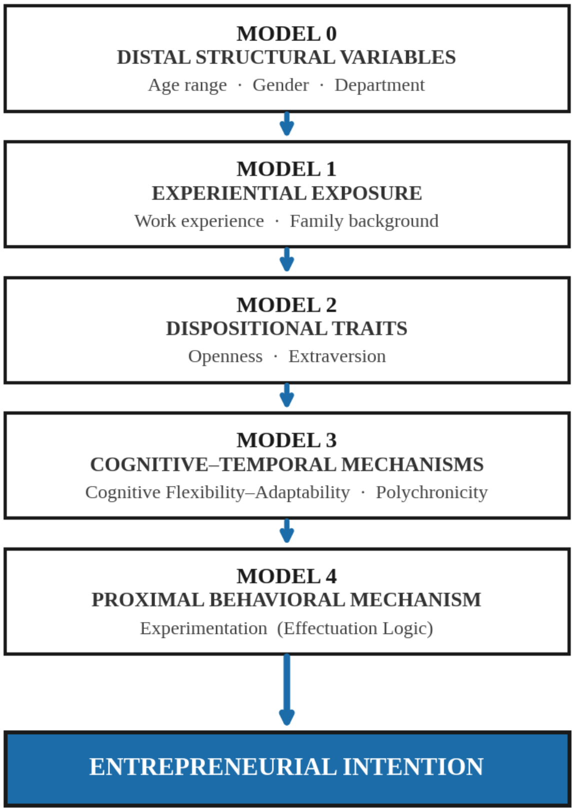

Fig 1. Hierarchical predictor model of entrepreneurial intention in engineering students

This ordering is not merely descriptive: it expresses a theoretically motivated explanatory thesis. If entrepreneurship occurs where prediction fails, then the most robust entrepreneurial intention is not derived solely from attitudes or traits, but from the internalization of an effectual action logic that allows one to move forward without requiring complete certainty [4], [11]. From this perspective, the contribution of the study consists in empirically evaluating this incremental explanatory pattern, clarifying which variables explain intention as increasingly action-proximal predictors are incorporated successively.

The model organizes predictors into five levels ordered by their conceptual proximity to entrepreneurial intention. A progressive incorporation of predictors from distal structural conditions toward proximal behavioral mechanisms is proposed, with experimentation—as a component of effectuation logic—emerging as the strongest predictor of entrepreneurial intention. Polychronicity is incorporated as a temporal alignment mechanism that modulates congruence between individual preferences and the demands of the entrepreneurial role, while dispositional traits operate as contextual rather than primary determinants.

III. Methodology

This quantitative study used a cross-sectional survey design. The sample included 497 undergraduate engineering students from a private university in Chile, enrolled in three departments: Industrial Engineering (41.0%), Computer Science (30.6%), and Earth Science (28.4%). Participants ranged in age from 19 to 42 years ($M = 22.47$, $SD = 3.22$); 49.1% were 19–21 years old, 36.0% were 22–24 years old, and 14.9% were 25 or older. Regarding prior experience, 21.3% reported none, 12.7% reported having completed a professional internship, 48.9% reported dependent employment, and 17.1% reported involvement in their own entrepreneurial ventures. Regarding family entrepreneurial background, 64.0% reported at least one relative with entrepreneurial experience, 26.8% reported none, and 9.2% reported not knowing.

Data were collected through a structured questionnaire comprising 29 Likert-type items (1 = strongly disagree to 5 = strongly agree) and brief sociodemographic and academic questions. Entrepreneurial intention was assessed with five items from [18]. Experimentation was measured with five items adapted from [34]. Openness and extraversion were each captured with four items from [28]. Polychronicity was measured with three positively worded items adapted from [15], and cognitive flexibility–adaptability with eight items from [15]. Confirmatory factor analyses supported the proposed six-factor structure, and internal consistency ranged from .57 to .92 (McDonald's ω) and from .57 to .91 (Cronbach's α) (Table I). Because this represents an initial, exploratory implementation of the instrument—and some coefficients (notably for openness and polychronicity) were modest—the scales will be refined in subsequent data collections to strengthen reliability and measurement quality.

TABLE I. Internal Reliability of the Instrument's Scales

Dimension	N° Items	ω	α
Entrepreneurial Intention	5	.92	.91
Experimentation	5	.82	.82
Openness	4	.65	.64
Polychronicity	3	.57	.57
Cognitive flexibility-adaptability	8	.81	.78
Extraversion	4	.82	.75

Faculty members administered the questionnaire during regular class sessions. Participation was voluntary and began with informed consent; students were informed about confidentiality, provided with contact details for questions, and completed the survey via Microsoft Forms. Data were anonymized and stored securely.

Analyses were conducted in JASP. We briefly reviewed descriptive statistics and screened the data (distributions, outliers, and univariate normality using skewness and kurtosis) as a preliminary step before the main analyses. Next, we examined bivariate associations using Pearson correlations. To address the research questions, we estimated a series of blockwise hierarchical linear regression models with entrepreneurial intention as the dependent variable. Predictors were entered in five theoretically ordered blocks: M_0 included sociodemographic controls; M_1 added family background in entrepreneurship and work-related experiences; M_2 introduced personality traits (openness, extraversion); M_3 incorporated cognitive and temporal factors (cognitive flexibility–adaptability, polychronicity); and M_4 added the effectuation-related behavior of experimentation. At each step, we examined changes in explained variance (ΔR^2) and interpreted standardized regression coefficients (β) using a significance level of $\alpha = .05$. Model assumptions were evaluated through inspection of residual plots, multicollinearity diagnostics (tolerance, variance inflation factors), and influence statistics, and we computed bias-corrected and accelerated (BCa) bootstrap confidence intervals based on 1,000 resamples to assess the robustness of the estimates. Additionally, to screen for common method bias, we conducted Harman's single-factor test by submitting all 29 items to an exploratory factor analysis constrained to one factor; results are reported in the limitations section.

IV. RESULTS

Using a five-point scale, students rated all six dimensions above the midpoint, reflecting generally positive profiles across the measures. As shown in Table II, the highest scores were for cognitive flexibility-adaptability ($M = 4.19$, $SD = 0.47$), openness ($M = 4.13$, $SD = 0.58$), and experimentation ($M = 4.12$, $SD = 0.59$), indicating frequent use of flexible thinking strategies, effective behaviors, and a generally open attitude. Extraversion also scored relatively high ($M = 3.95$, $SD = 0.63$), followed by entrepreneurial intention ($M = 3.72$, $SD = 0.92$). Polychronicity received the lowest mean score ($M = 3.34$, $SD = 0.69$), suggesting a more moderate preference for non-sequential time management and multitasking.

Regarding the distributional assumptions, all variables exhibited negative skewness (ranging from −0.23 to −1.52), indicating a tendency toward higher scores, and positive kurtosis (from 0.87 to 7.02), suggesting moderately leptokurtic distributions, especially for cognitive flexibility and experimentation. Nonetheless, skewness values stayed well below an absolute value of 2, and kurtosis estimates were at or under 7, ranges generally deemed acceptable for considering variables as roughly normal in large samples. With a sample size of roughly $N = 497$, these slight deviations from normality are unlikely to significantly bias the analyses, justifying the use of parametric procedures.

TABLE II. DESCRIPTIVE DATA OF THE SCALES

Dimension	Mean	Std. Dev.	Skewness	Kurtosis
Entrepreneurial Intention	3.715	0.924	-0.787	0.872
Experimentation	4.124	0.594	-1.524	5.786
Openness	4.133	0.582	-1.040	3.385
Polychronicity	3.343	0.691	-0.234	1.977
Cognitive flexibility-adaptability	4.187	0.470	-1.343	7.020
Extraversion	3.949	0.627	-0.893	3.074

Taken together, these descriptive results indicate that the variables showed sufficient variability and acceptable distributional properties to support the subsequent inferential analyses. On this basis, a series of linear regression models was estimated to examine the extent to which sociodemographic, academic, and individual characteristics contributed to explaining entrepreneurial intention. Results are presented in Table III and Table IV.

In Model 0, which included only sociodemographic and program variables (age group, gender, and department), the regression was significant, $F(5, 491) = 4.67$, $p < .001$, explaining 4.5% of the variance in entrepreneurial intention ($R^2 = .045$). Students enrolled in programs belonging to the Department of Industrial Engineering reported higher entrepreneurial intention scores than those in Earth Sciences ($B = 0.34$, $p < .001$), and women scored slightly lower than men ($B = −0.21$, $p = .040$). Age group and the Department of Computer Science did not reach statistical significance in this baseline model.

Model 1 added family history of entrepreneurship and work-experience categories. The model remained significant, $F(5, 486) = 10.953$, $p < .001$, and R^2 increased to .124 ($\Delta R^2 = .079$). In this block, the effect associated with the Department of Industrial Engineering remained positive and significant ($B = 0.28$, $p = .005$), while the gender effect was reduced to a marginal level ($p = .053$). Having salaried work experience became a significant positive predictor ($B = 0.22$, $p = .036$), and prior experience running students' own entrepreneurship showed the largest coefficient in the model ($B = 0.73$, $p < .001$). Students without a family background of entrepreneurship scored significantly lower in entrepreneurial intention ($B = -0.219$, $p = .020$).

In Model 2, openness and extraversion were added. The model explained 24% of the variance, $R^2 = .24$, with a significant improvement over Model 1, $\Delta R^2 = .111$, $F(2, 484) = 35.138$, $p < .001$. Once personality traits were included, salaried work experience was no longer significant ($p = .153$), and the effect of having a family background of entrepreneurship became non-significant ($p = .082$). In contrast, the positive effect of pursuing a program in the Department of Industrial Engineering remained robust ($B = 0.35$, $p < .001$). Entrepreneurial job experience remained a strong predictor ($B = 0.62$, $p < .001$). Both openness ($\beta = .42$, $p < .001$) and extraversion ($\beta = .19$, $p = .005$) emerged as significant positive correlates of entrepreneurial intention, indicating that personality traits captured part of the variance previously attributed to work experience and a family history of entrepreneurship.

TABLE III. FIT INDICES FOR HIERARCHICAL REGRESSION MODELS PREDICTING ENTREPRENEURIAL INTENTION.

Model	M_0	M_1	M_2	M_3	M_4
R^2	0.045	0.124	0.235	0.307	0.435
R^2adj	0.036	0.108	0.218	0.289	0.418
ΔR^2	0.045	0.079	0.111	0.072	0.127
ΔF	4.667	10.953	35.138	25.261	108.343
p	< .001	< .001	< .001	< .001	< .001

Model 3 incorporated the cognitive dimensions of the instrument, *cognitive flexibility-adaptability,* and *polychronicity*. This model explained 31.2% of the variance, $R^2 = .307$, again with a significant increase relative to Model 2, $\Delta R^2 = .072$, $F(2, 482) = 25.262$, $p < .001$). In this specification, pursuing a program within the Department of Industrial Engineering has been identified as a significantly positive predictor (B = 0.37, $p < .001$), and students enrolled in programs in the Department of Computer Science also exhibited higher entrepreneurial intention compared to those in the Department of Earth Sciences (B = 0.23, p = .018). Entrepreneurial job experience remained strongly associated with *entrepreneurial intention* (B = 0.53, $p < .001$). *Polychronicity* emerged as a significant predictor ($\beta = .36$, $p < .001$), indicating that students who prefer coordinating multiple tasks report higher *entrepreneurial intention*. *Openness* remained significant, with the standardized coefficient attenuated ($\beta = .16$, p = .002), whereas extraversion became non-significant (p = .081). The other addition to the model, *cognitive flexibility-adaptability*, did not reach significance (p = .089).

Finally, Model 4 added *experimentation* as a behavioral component of effectuation. This final model showed the best fit, explaining 43.7% of the variance in entrepreneurial intention ($R^2 = .435$, $\Delta R^2 = .127$, $F(1, 431) = 108.343$, $p < .001$). When *experimentation* was entered, its standardized coefficient was the largest in the model ($\beta = .52$, $p < .001$), and *polychronicity* remained a significant positive predictor ($\beta = .22$, $p < .001$). Entrepreneurial job experience continued to be strongly associated with *entrepreneurial intention* (B = 0.40, $p < .001$), and being enrolled in a Department of Industrial Engineering program remained significant (B = 0.22, p = .008). In contrast, the effects of *openness* and was no longer significant (p = .351) after controlling for experimentation, suggesting that part of their association with *entrepreneurial intention* operates through more proximal entrepreneurial behaviors. *Cognitive flexibility-adaptability*, which had been nonsignificant in Model 3, became a small but significant negative predictor in Model 4 ($\beta = -.14$, p = .012), consistent with a suppression effect when experimentation is included.

We performed additional diagnostics to evaluate the robustness of the final regression model (M4). Multicollinearity was assessed using tolerance and variance inflation factor (VIF) statistics; tolerances ranged from approximately .61 to .98, and VIF values were between about 1.02 and 1.62, well below standard thresholds (e.g., VIF < 5), indicating that correlations among predictors did not compromise numerical stability or bias the regression estimates. To further evaluate the stability of the coefficients, we applied nonparametric bootstrapping with 1,000 bias-corrected and accelerated (BCa) resamples. The bootstrap estimates were very similar to the original coefficients, and the 95% BCa confidence intervals for Department of Industrial Engineering, own entrepreneurial experience, *cognitive flexibility-adaptability*, *polychronicity*, and *experimentation* did not include zero, while intervals for the remaining predictors did. This pattern replicates the significance results of the parametric model and supports the robustness of the substantive conclusions drawn from M4.

TABLE IV. FINAL HIERARCHICAL REGRESSION MODEL COEFFICIENTS FOR PREDICTING ENTREPRENEURIAL INTENTION.

	B	beta	t	p	Collinearity Statistics	
					Tol.	VIF
(Intercept)			-0.222	.824		
age (22-24)	0.118		1.651	.099	0.972	1.029
age (>25)	-0.078		-0.869	.385		
gender (women)	-0.045		-0.595	.552	0.931	1.074
Dept (Industries)	0.219		2.683	.008	0.939	1.065
Dept (Informatics)	0.089		1.104	.270		
work_exp (internship)	0.014		0.002	.998	0.953	1.049
work_exp (dependent)	0.105		1.215	.225		
work_exp (entrep.)	0.401		3.628	< .001		
family_entrep (no)	-0.099		-1.280	.201	0.967	1.034
family_entrep (no data)	0.044		0.382	.702		
Openness		0.045	0.934	.351	0.709	1.410
Extraversion		0.013	0.301	.763	0.814	1.228
Cognitive		-0.140	-2.517	.012	0.614	1.629
Polychronicity		0.222	5.634	< .001	0.869	1.151
Experimentation		0.521	10.33	< .001	0.678	1.476

V. DISCUSSION

The results of this study support a central argument: entrepreneurial intention in engineering students is not explained primarily by traits or structural conditions, but is progressively better explained as predictors increasingly proximal to action under uncertainty are incorporated into the model. In the hierarchical model, explained variance increases in a stepwise fashion from distal variables to behavioral mechanisms, and the most pronounced jump occurs when experimentation is incorporated ($\Delta R^2 = .127$), reaching a total R^2 of .435 in the final model. This pattern should not be read as an incremental sum of "factors," but as a pattern consistent with the theoretical architecture proposed: variables closer to behavioral engagement under uncertainty contribute the most to explaining entrepreneurial intention [3], [4], [11].

A. *From Distal to Proximal: Evidence for a Progressive Activation Model*

At the most distal level, the baseline model (age, gender, and department) explains a limited fraction of entrepreneurial intention (R^2 = .045), consistent with studies that have identified gender as a variable associated with entrepreneurial intention, though insufficient in itself to explain substantive differences in the decision to become an entrepreneur [33]. This has two implications: first, it confirms that intention is not "determined" by structure; second, it suggests that the pedagogical focus should shift toward trainable mechanisms. Intention, in the cognitive tradition, is understood as a deliberate state that directs action [6] and is formalized in frameworks such as the TPB [21] and competing entrepreneurship models [7]. However, the intention-action gap documented among students [9] warns that intention does not always translate into behavior, especially in environments that penalize exhaustive planning and demand operating with incomplete information [3]. In this context, a "well-formed" intention is not only one that is declared, but one that is sustained in the face of friction and uncertainty: one that possesses internal mechanisms for moving forward.

The second block—experiential exposure—substantially increases explained variance (R^2 = .124). Personal entrepreneurial experience appears early as a strong predictor and remains significant through the final model, which is consistent with the idea that contact with real practices reconfigures what is perceived as feasible, reduces normative ambiguity, and provides non-simulated feedback. Experience, in this sense, does not "teach prediction"; rather, it reduces friction and enables learning through iteration, approximating students to the control logic that characterizes entrepreneurial action under uncertainty [3], [4].

When dispositional traits (openness and extraversion) are incorporated, the model increases to R^2 = .24. This result is consistent with literature associating these traits with entrepreneurial intention [30], [31]. However, the important finding is not that traits "matter," but how they change when action proximity is introduced: extraversion loses significance in the cognitive-temporal block, and openness ceases to be significant when experimentation is incorporated. This pattern supports an explanatory reading: traits predispose and amplify, but do not necessarily predict intention when proximal mechanisms are controlled [28]. In pedagogical terms: it is not enough to "have" openness; what is decisive is "translating" that openness into iterative behavior.

The fourth block, with cognitive-temporal mechanisms, raises the explanation to R^2 = .307 and produces two conceptually relevant results. First, polychronicity emerges as a significant predictor and, crucially, remains significant even after experimentation is incorporated. This point avoids the simplistic reading that "everything" reduces to a single behavior. Polychronicity, understood as a temporal preference for organizing time in a non-sequential manner and coordinating interdependent activities or roles in parallel [16], may operate as a vocational alignment mechanism: when the individual's preferred temporal structure matches the perceived demands of the entrepreneurial role, entrepreneurial intention is strengthened [17]. Cox et al. propose precisely this reading of polychronicity as an alignment mechanism that may mediate relationships between cognitive capabilities and intention [15]. The persistence of its effect in the final model suggests that intention is associated not only with "running experiments," but also by perceiving that one can inhabit entrepreneurship as a temporal practice: sustaining role simultaneity, iteration, and parallel coordination without requiring a rigid sequence.

Second, cognitive flexibility/adaptability does not reach significance in the block preceding experimentation, but becomes a small, significant negative predictor when experimentation is incorporated ($\beta = -.14$), consistent with a suppression effect. This is a nuanced result and, when properly interpreted, a highly fertile one: it does not suggest that flexibility is "detrimental," but that its meaning changes when the proximal behavioral mechanism is controlled. Situated metacognition and cognitive adaptability involve monitoring, regulating, and strategically reconfiguring thinking in the face of changing feedback [13]; cognitive flexibility involves shifting frames and generating alternatives in the face of ill-structured problems [14]. However, in the absence of a behavioral anchor, flexibility may translate into an expansion of the option space without decisional closure—that is, into exploration that prolongs deliberation. In environments of radical uncertainty, entrepreneurship requires precisely the opposite: committing to a reasonable course of action under incomplete information and learning in the process [3], [4], [11]. In pedagogical terms, this finding suggests that "thinking better" does not substitute for "doing"; when flexibility is not channeled into test-learn-adjust cycles, it can become a sophisticated substitute for action.

The fifth block—experimentation—constitutes the model's inflection point. When incorporated, total R^2 rises to .435 and experimentation emerges as the strongest predictor ($\beta = .52$). This result is coherent with effectuation: when the future is not predictable, the entrepreneur does not wait for certainty to act, but acts to generate information and build non-predictive control [4], [11]. The operationalization of effectuation as a multidimensional construct, and the centrality of experimentation as a quantifiable practice, have made it possible to empirically demonstrate its relevance in formative contexts [12], [28]. In our case, experimentation is not only associated with intention: it reorders explanatory attribution, absorbing part of the variance that previously appeared to belong to traits such as openness. This supports the idea of proximal activation: entrepreneurial intention consolidates when students have a method for moving forward without complete prediction; that method is iterative experimentation.

B. *Curricular Implications: Designing Action Architectures and Temporal Architectures*

If entrepreneurial intention is progressively better explained as predictors more proximal to action are incorporated, then curriculum design should not focus on "promoting attitudes" or "stimulating interest" in the abstract, but on constructing pedagogical conditions that produce experimentation and train temporal coordination congruent with the entrepreneurial role. Put differently: the curriculum must cease to be a pedagogy of traits (or motivation) and become a pedagogy of mechanisms.

First, the trait absorption pattern suggests that the formative return will likely be greater when priority is given to designing experiences that compel students to act under uncertainty in a safe and structured manner, rather than attempting to "develop profiles." This is consistent with competency development approaches for an entrepreneurial mindset that emphasize trainable and observable capabilities [5]. The curricular objective shifts from "identifying entrepreneurs" to cultivating practices: formulating hypotheses, testing quickly, learning, and iterating. In operational terms, this implies evaluating evidence of learning through iteration (what was tested, what was observed, what was adjusted), rather than only the final quality of a deliverable.

Second, the persistent relevance of polychronicity indicates that it is not sufficient to include projects or teamwork; it is necessary to design polychronic learning structures. Polychronicity is not equivalent to attentional multitasking, but to parallel coordination of interdependent roles and/or activities [16]. Therefore, a curricular intervention consistent with the model should incorporate simultaneous flows: technical development in parallel with user validation and network building; rotating roles that require coordinating interdependencies; and milestones that allow iteration without rigid sequentiality. This not only approximates students to the temporal reality of entrepreneurship but also strengthens perceived vocational fit—a mechanism that, from the person-vocation fit framework, can reinforce intentions [17].

Third, the finding on flexibility suggests a pedagogical caution: training "cognitive skills" without requiring action may produce analytical sophistication without entrepreneurial commitment. Consequently, flexibility and situated metacognition should be trained as capabilities in service of action-feedback-adjustment cycles [13], [14]. A simple and powerful design might consist of turning each experiment into a "learning event": after each trial, a structured reflection is required (assumption, evidence, implication, next step), so that flexibility translates into data-guided reconfiguration rather than inert expansion of the option space.

Fourth, the fact that certain traditional variables (including traits and other background factors) lose weight when experimentation is introduced suggests that innovation or entrepreneurship courses may not be sufficient if they are not built on an action architecture. This must be stated with caution: the finding does not imply that training does not matter; it implies that the form that training takes matters more than its mere existence. Effectuation, understood as a pedagogical logic, offers a clear criterion: if the course does not compel students to act with available means, accept affordable losses, and learn through iterative experimentation, it is likely to strengthen discourse but not activation [4], [11], [12].

C. *Interpretive Closure: From Intention as Declaration to Intention as a Consequence of Practice*

In sum, the pattern of results supports a progressive explanatory model in which entrepreneurial intention emerges as a consequence of an integrated configuration: experience that reduces friction, dispositions that predispose, cognitive-temporal mechanisms that enable the inhabitability of the role, and, at the core, a behavioral practice that produces control under uncertainty: experimentation. This reading is coherent with the distinction between causation and effectuation: when prediction is limited, the most robust intention is not the one that is exhaustively planned, but the one that is sustained through iterative action that generates information, evidence, and commitment [4], [11]. For engineering education, the principal implication is clear: if we seek to develop entrepreneurial intention that does not collapse in the face of uncertainty, we must design curricula in which students not only "learn about" entrepreneurship, but learn to "control" the future through action, in rapid cycles of testing and learning.

D. *Limitations and Immediate Research Agenda: Moving from an Explanatory Model to Causal Evidence*

This study has several limitations that should be considered when interpreting its findings. First, the cross-sectional design does not permit causal inference; consequently, the layered model should be understood as a plausible and operationally useful explanatory architecture for curriculum design, rather than as a demonstrated causal chain. The language of "layers" and "progressive explanation" reflects the theoretical ordering of predictors by conceptual proximity to action, not an empirically demonstrated sequential process. Future research should employ longitudinal or quasi-experimental designs to test whether the proposed ordering reflects actual developmental or temporal sequences in the formation of entrepreneurial intention. Second, the reliability of certain scales is modest: polychronicity ($\alpha/\omega \approx .57$) and openness ($\alpha = .64$) fall below conventional thresholds for established instruments, although these values may be considered acceptable for short scales in an initial, exploratory implementation [35]. Nevertheless, these coefficients warrant caution in interpreting the specific magnitude of effects involving these constructs, and the scales should be refined and revalidated in subsequent data collections. Third, because all variables were self-reported and collected at the same time, common method bias (CMB) cannot be entirely ruled out. To assess this risk, Harman's single-factor test was conducted: an exploratory factor analysis constraining all 29 items to a single factor revealed that this factor accounted for only 26.8% of the total variance, well below the 50% threshold conventionally used to flag CMB concerns. While this result suggests that CMB does not pose a severe threat to the findings, it does not eliminate the possibility entirely; future studies should consider procedural and statistical remedies such as temporal separation of predictor and criterion measures, marker variable techniques, or multi-source data collection designs. These limitations notwithstanding, they open a direct and valuable research agenda: designing curriculum interventions based on effectuation (iterative experimentation, early validation, polychronic structures) and evaluating them through longitudinal or quasi-experimental designs that permit testing mediation (e.g., whether openness operates through experimentation) and observing the consolidation of entrepreneurial intention over time [4], [11], [28]. The contribution of this paper is, precisely, to have charted the map: if we want robust intention, we must intervene in the proximal mechanisms most strongly associated with it.

VI. Conclusions

This study examined entrepreneurial intention in engineering students through a hierarchical model organized according to the conceptual proximity of predictors with respect to entrepreneurial action under uncertainty. The results reveal a consistent pattern of incremental explanatory contribution: explained variance increases in a stepwise fashion from distal structural variables to proximal behavioral mechanisms, reaching its greatest increment when experimentation is incorporated as a component associated with effectuation logic. These findings support the thesis that entrepreneurial intention, in formative contexts, is consolidated primarily when students internalize practices that allow them to act, learn, and adjust in contexts of uncertainty and incomplete information [4], [11].

In the explanatory domain, the model offers three main contributions. First, it demonstrates that structural and experiential variables explain an initial proportion of intention, but their relative weight diminishes when mechanisms more proximal to action are incorporated. Second, it provides evidence that dispositional traits—while relevant in intermediate models—lose significance when experimentation is introduced, suggesting that part of their association with intention operates through concrete iterative behaviors. Third, it identifies that polychronicity maintains significance even in the final model, indicating that temporal orientation constitutes an independent and complementary component in the formation of entrepreneurial intention, possibly linked to the alignment between individual preferences and the structural demands of the entrepreneurial role [15]–[17].

From the perspective of engineering education, these results suggest that strengthening entrepreneurial intention depends less on interventions focused exclusively on general attitudes or personal profiles, and more on the systematic design of formative experiences that integrate trainable mechanisms of action under uncertainty. The structured incorporation of iterative experimentation cycles, early validation, and feedback-based learning may contribute to consolidating a more robust entrepreneurial intention that is potentially transferable to future entrepreneurial behavior [4], [11], [12]. Likewise, the relevance of the temporal dimension suggests that curriculum design should consider work structures that require parallel coordination of interdependent activities and roles, approximating students to organizational dynamics characteristic of technology entrepreneurship.

This study presents limitations that should be considered. Its cross-sectional design prevents the establishment of causal relationships between the identified mechanisms and entrepreneurial intention. Furthermore, the moderate reliability of the polychronicity scale indicates the need to continue refining its measurement in educational contexts. Consequently, future research should advance toward longitudinal or quasi-experimental designs that allow evaluation of whether curriculum interventions explicitly based on experimentation and non-sequential temporal coordination generate sustained increases in entrepreneurial intention and, eventually, in effective entrepreneurial behavior.

In summary, the principal contribution of this study lies not only in identifying predictors of entrepreneurial intention, but in proposing and empirically validating an explanatory order organized by proximity to action. This conceptual architecture provides a solid foundation for guiding curriculum design decisions in engineering education, contributing to a more precise understanding of the mechanisms through which entrepreneurial intention can be fostered and strengthened in formative contexts.

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