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The Role of Intrinsic Motivation in Student Imagination: A Comparison Between Engineering and Science Majors*

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The current study analyzed how learning resources and human aggregates moderate the effect of intrinsic motivation on the imaginative capabilities of undergraduates. The differences between the moderation models of engineering and science majors were also compared. We administered a survey at seven universities across different regions in Taiwan. Our participants were divided into two groups: the first group consisted of 473 science majors, whereas the second group consisted of 478 engineering majors. Structural equation modeling was used to test all the proposed hypotheses. The results demonstrated that imaginative capabilities became highest when students had high intrinsic motivation, learning resources, and human aggregates. The major difference between the engineering and science groups was the moderating effect of intrinsic motivation and learning resources on initiating imagination. In other words, the initiating imagination for those engineering students who are insensible to learning resources was strongly stimulated when their intrinsic motivation remained high. The other critical difference was the moderating effect of intrinsic motivation and human aggregates on transforming imagination. In other words, transforming imagination for those engineering students who are insensible to human aggregates was strongly stimulated when their intrinsic motivation remained high. Practical implications of the study are discussed and research limitations are explained.

Keywords: engineering education; human aggregates; imaginative capability; intrinsic motivation, learning resources; science education

1. Introduction

Student motivation regarding science learning tends to decrease during adolescence [1, 2]. Vedder-Weiss and Fortus indicated that school culture influences student perceptions of teaching emphases and peer goals [3]. Numerous studies have also suggested that learning resources, such as learning activities and materials, exert a positive influence on intrinsic motivation and knowledge acquisition in science education [4]. Future research on education should account for the interplay between student motivation, human aggregates, and learning resources. In this study, *learning resources* measures the degree to which participants have perceived that the instructional materials and activities in their learning environment stimulated their imagination, whereas *human aggregates* assess the extent to which an organizational culture and the characteristics of its inhabitants influence the inhabitants' imagination. We used *human aggregates* interchangeably with school culture.

A distinction exists between scientists and engineers. Scientists seek cognitive knowledge, whereas engineers aim for practical ends [5]. To achieve their ends, both scientists and engineers require substantial imagination [6]. Murphy, Peters, and Marginson contended that cultivating imaginative capabilities should be viewed as the cornerstone of learning because a basic discovery requires high levels of creative thinking [7]. Swirski indicated that how we envision and contribute to our educational, social, and cultural landscapes is limited only by our imaginative capabilities [8]. Imagination in learning environments frames educational activities and facilitates innovative assessments, allowing students to explore, question, and clarify the diversity surrounding them.

Although numerous educators seem to agree that imagination is at the root of how humans modify their material world, Van Eijck and Roth found that the process by which this scientific imagination in

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education occurs has rarely been conceptualized [9]. Therefore, we examine how learning resources and human aggregates moderate the effect of intrinsic motivation on imaginative capabilities, and compare the moderating effect of science majors with that of engineering majors.

2. Literature

2.1 Science, engineering and imagination

Theodor von Kármán made the following distinction between scientists and engineers: "The scientist seeks to understand what is; the engineer seeks to create what never was" [10]. According to the National Society of Professional Engineers, science refers to knowledge based on observed facts and tested truths, which are arranged in an orderly system that can be validated and communicated to other people. Engineering refers to the creative application of scientific principles used to plan, build, direct, guide, or manage systems to maintain and improve our daily lives [11]. Bybee explained that both practices can be compared according to the question asked, the model used, the investigation implemented, the solutions made, and the information communicated [12]. Although engineering and science have different goals and methods, most engineers and scientists move freely back and forth along the continuum of discovering truth in nature and developing beauty in innovations [10]. Imagination can be perceived as a creative faculty of the mind and a precondition of discovery and innovation [13, 14]. Scientists and engineers need substantial imagination to achieve their ends [5, 6].

Holton asserted that it is remarkable how little consensus has developed on how scientific imagination functions [6]. However, numerous scholars have devoted themselves to studies related to scientific imagination over the past decade. For example, Taylor, Jones, Broadwell, and Oppewal suggested a strong need to teach science students critical thinking and inspire their creative imagination [15]. Al-Balushi argued that a reliable mental model of the atom is required to conduct advanced cognitive processes for the mental exploration of chemical phenomena. The mental images experienced by students are shaped by their imagination, mode of attention, and images in their memory [16]. In addition, Maeyer and Talanquer emphasized that it is important for science students to develop and apply analytical methods of reasoning and evaluate the effectiveness of intuitive heuristics in various contexts [17].

In contrast, engineering scholars appear to be more enthusiastic regarding imagination, creativity and innovation than scientific scholars are [18, 19]. For example, Pritchard urged engineering educators to focus on the positive side of practice and address questions of imaginative capabilities [20]. Coeckelbergh and Wackers concluded that engineers need imagination to transcend their expertise-specific perspectives, thereby improving the robustness of their organizations and enabling them to be better prepared for crisis situations [21]. Daly, Yilmaz, Christian, Seifert, and Gonzalez encouraged engineering students to incorporate design heuristics into their practice [22]. Genco, Hölttä-Otto, and Seepersad experimentally investigated the innovation capabilities of engineering undergraduates [23].

Liu and Noppe-Brandon argued that imagination is the ability to conceive new realities and possibilities (p. 19) [24]. Moreover, they contended that imagination can unfold in processes that are conscious and deliberate, as well as in those that are unconscious and intuitive (p. 12). In addition, the authors indicated that imagination fundamentally involves forming associations and analogies between things that did not previously appear to be connected (p. 182). These three assertions imply that the imagination can be categorized into three types of ability. Based on this study by Liu et al., Liang and Chia empirically categorized imaginative capability into three types: *initiating*, *conceptual*, and *transforming* [25]. *Initiating imagination* refers to the ability to explore the unknown and productively originate novel ideas. *Conceptual imagination* refers to the ability to mentally grasp the core of a concept by using personal intuition and sensibility, and to formulate effective ideas by using concentration and dialectics to achieve a goal. *Transforming imagination* refers to the ability to crystallize abstract ideas and reproduce what is known across various domains and situations.

2.2 Relationships between learning resources, human aggregates, intrinsic motivation, and imaginative capability

Learning resources and human aggregates are critical dimensions of a campus environment [26, 27]. Numerous studies on engineering and science education have indicated that institutional integration plays a critical role in student imagination, learning, and success [28, 29]. In addition to learning resources and human aggregates, institutional integration includes students. Prior research has indicated that intrinsic motivation is closely associated with creative behavior [30]. Numerous scholars have also indicated that intrinsic motivation influences learning and imaginative capability in both engineering and science education [31, 32, 33].

Studies of engineering and science have stressed the importance of learning resources. For example, Dede and Barab suggested leveraging the advantages of emerging technologies in science learning [34]. Olympiou and Zacharia revealed that using a combination of physical and virtual manipulatives enhances student conceptual understanding [35]. Bultitude and Sardo observed that students were inspired by science events in unusual locations through three elements: the involvement of "real" scientists, the informality of the surroundings, and the opportunity to re-engage participants with scientific concepts outside the context of formal education [36]. Allendoerfer et al. added that participating in various outside communities that offer engineering students opportunities to belong is the most productive approach to studying [37].

Human aggregates not only create features in an environment that reflect varying degrees of consistency [27], but also affect student thinking, restrict their behaviors, create campus culture, and create a stable image of an educational institution [38]. Roehrig, Kruse, and Kern demonstrated that teacher beliefs regarding teaching and supportive institutional culture strongly influence the implementation of science curriculum reform and student attitudes to learning [39]. Gislason indicated that educational culture is closely related to student thinking and learning [27]. Yueh, Jiang, and Liang further concluded that human aggregates can be used to significantly predict the imaginative capability of both engineering and science majors [40].

In our study, *intrinsic motivation* assesses the influence of personal satisfaction (rather than external rewards) on participant imagination[0]. Numerous scholars have noted the close relationship between intrinsic motivation and creative behavior [30, 41]. Rosenbaum explained that what a person imagines and plans to do next influences his or her performance [42]. Gungor, Erylmaz, and Fakoglu found that *achievement motivation* highly influenced achievements in the study of physics, whereas *motivation in physics* had a negative impact on achievement [31]. Jones et al. concluded that expectancy for success in engineering predicted achievement more than identification with engineering [32]. Based on these studies, we hypothesize the three following relationships:

H1: *Learning resources* predict the three types of imaginative capability.
H2: *Human aggregates* predict the three types of imaginative capability.
H3: *Intrinsic motivation* predicts the three types of imaginative capability.

2.3 Relationships between learning resources, human aggregates, and intrinsic motivation

For the relationship between intrinsic motivation and learning resources, Kember, Ho, and Hong indicated that several supportive conditions enhance student motivation, namely allowing students to choose their own courses, learning activities, and the assessment of learning activities [43]. Bamberger and Tal suggested that free choice of learning activities deepens engagement in student learning and motivates students to connect the activity to their own life experiences and prior knowledge [44]. Perrot, Gagnon, and Bertsch further confirmed the moderating effect of learning activity on inductive reasoning, which is closely related to imaginative capability [45].

For the relationship between intrinsic motivation and human aggregates, Walczyk, Ramsey, and Zha contended that institutional culture is a major obstacle to using learner-centered instruction in college science classrooms, resulting in negative effects on undergraduate learning and motivation [46]. Demir suggested that a collaborative school culture has a moderating effect on collective teacher efficacy, which is closely associated with student motivation and achievement [47]. Recent studies in the field of organizational behavior have shown that organizational culture moderates the effect of intrinsic motivation on work performance [48, 49].

Deci, Koestner, and Ryan conducted a meta-analysis, and concluded that intrinsic motivation on the part of students results in develops learning activities that are more interesting, provides more choice, and ensures that tasks are optimally challenging, thereby promoting student creativity, cognitive flexibility, and conceptual understanding of learning activities [50]. Consequently, we propose the following two hypotheses:

H4: *Learning resources* moderate the effect of *intrinsic motivation* on the three types of imaginative capability.
H5: *Human aggregates* moderate the effect of *intrinsic motivation* on the three types of imaginative capability.

3. Method

3.1 Participants and procedures

We tested the hypotheses with data from seven universities in Taiwan. The sizes of the universities are similar, and they are all located in urban areas. Five are teaching-intensive private universities, and the other two are research-intensive public universities. Participants ranged from 18 to 23 years in age and were divided into two groups. The first group (science majors) consisted of 473 undergraduates enrolled in physical, chemical, mathematical, and biological science programs. The second group (engineering majors) consisted of 478 undergraduates from electrical, chemical, mechanical, and computer engineering programs. The science group participants included 358 men and 115 women; 35.9% were freshmen, 33% were sophomores, 20.3% were juniors, and 10.8% were seniors. The engineering group participants included 367 men and 111 women; 34.1% were freshmen, 29.9% were sophomores, 24.7% were juniors, and 11.3% were seniors.

We requested the participants to complete a questionnaire containing the measurements included in this report. All participation was voluntary and anonymity was guaranteed. All university surveys were conducted based on the same procedure, and included tutorial groups that were accompanied by their class instructors. In this manner, the problems participants faced when answering the questions could be resolved immediately. The survey took approximately 15 minutes to complete, and was administered either during or immediately following regular class time. The participants were allowed to review the results of their responses.

3.2 Measurements

Imaginative capability. We used the 29-item imaginative capability scale to measure student imagination [25]. The participants were instructed to determine the level of agreement with each item of imaginative capability. The scale was scored on a 6-point Likert scale ranging from 1 (*strongly disagree*) to 6 (*strongly agree*). Example items include "I often have unique ideas compared to others," "I often have a rich diversity of ideas," and "I like to explore the unknown through a variety of experiences" (initiating imagination); "I can express abstract ideas by using examples from daily life," "I can transfer similar ideas to various situations," and "I can integrate different points of view into my way of thinking" (transforming imagination); and "I can continue to focus on a project until the ideas are formed," "I constantly revise my ideas to reach satisfactory results," and "I can come up with an approach to meet the teacher's requirements" (conceptual imagination).

Learning resources, human aggregates, and intrinsic motivation. Based on the environmental influence scale proposed by Chen et al. [40] and the psychological influence scale proposed by Yeh et al. [33], we adopted the subscales of learning resources (6 items), human aggregates (5 items), and intrinsic motivation (3 items), in which respondents were asked to determine the level of influence each item had on their imagination. The respondents answered on a 6-point scale ranging from 1 (*strongly disagree*) to 6 (*strongly agree*). Some example items of learning resources include "Learning facilities and tools (such as computers and lab equipment)," "Dynamic audiovisual materials (such as videos and computer-assisted learning)," and "Off-campus activities (such as internships and corporation visits)." Example items of human aggregates include "Schoolmate characteristics," "Common practice on campus," and "Institutional culture." Example items of intrinsic motivation include "Interest in the class assignment" and "Curiosity for the content topic."

3.3 Confirmatory factor analysis

In this study, the factorial validity of the factor structures was tested using LISREL (Version 8.80) by performing confirmatory factor analysis with maximal likelihood estimation. Regarding imaginative capability, the three-factor solution yielded a good fit for both science (χ^2 = 1441.24, df = 374, $p < 0.005$, RMSEA = 0.079, SRMR = 0.072, CFI = 0.96, NFI = 0.95, TLI = 0.96) and engineering

Table 1. Confirmatory factor analysis of imaginative capability

Variable	Imaginative Capability					
	Science group			Engineering group		
Item/Factor	Initiating Imagination	Conceptual Imagination	Transforming Imagination	Initiating Imagination	Conceptual Imagination	Transforming Imagination
1	0.78	0.52	0.71	0.71	0.56	0.65
2	0.81	0.63	0.79	0.79	0.65	0.73
3	0.75	0.66	0.83	0.71	0.66	0.76
4	0.79	0.55	0.79	0.76	0.65	0.75
5	0.77	0.61	0.62	0.64	0.70	0.64
6	0.78	0.59	0.60	0.70	0.70	0.71
7	0.68	0.55	0.62	0.63	0.61	0.72
8	0.65	0.50	0.72	0.68	0.52	0.70
9	0.69	0.70		0.62	0.66	
10		0.73			0.69	
11		0.75			0.68	
12		0.69			0.69	
Composite Reliability	0.919	0.880	0.892	0.893	0.897	0.889

Table 2. Confirmatory factor analyses of intrinsic motivation, learning resources, and human aggregates

Variable	**Imaginative Capability**					
	Science group			**Engineering group**		
Item/Factor	**Intrinsic Motivation**	**Learning Resources**	**Human Aggregates**	**Intrinsic Motivation**	**Learning Resources**	**Human Aggregates**
1	0.88	0.68	0.67	0.82	0.71	0.70
2	0.91	0.54	0.84	0.90	0.74	0.81
3	0.54	0.74	0.82	0.59	0.80	0.86
4		0.62	0.79		0.61	0.72
5		0.80	0.72		0.78	0.58
6		0.67			0.72	
Composite Reliability	0.832	0.836	0.879	0.821	0.871	0.857

groups (χ^2 = 1341.21, df = 374, p < 0.005, RMSEA = 0.075, SRMR = 0.056, CFI = 0.97, NFI = 0.95, TLI = 0.96). Table 1 shows the factor loadings and composite reliability results. Construct validity was determined based on convergent and discriminant validity. The results indicated that each factor achieved convergent validity (factor loading > 0.5) and discriminant validity (1 > φ > –1).

Regarding intrinsic motivation, learning resources, and human aggregates, the three-factor solution yielded a good fit for both science (χ^2 = 250.45, df = 74, p < 0.005, RMSEA = 0.072, SRMR = 0.067, CFI = 0.96, NFI = 0.95, TLI = 0.95) and engineering groups (χ^2 = 256.96, df = 74, p < 0.005, RMSEA = 0.073, SRMR = 0.076, CFI = 0.97, NFI = 0.95, TLI = 0.96). Table 2 shows the factor loadings and composite reliability results. Construct validity was determined based on convergent and discriminant validity. The results indicate that each factor achieved convergent validity (factor loading > 0.5) and discriminant validity (1 > φ > –1).

4. Results

4.1 Structural model

We employed structural equation modeling (SEM) to test the proposed hypotheses, and examined the moderating effects based on the suggestions provided by Frazier, Tix, and Barron [51]. The results indicated that the moderation models were initially supported, but not all variables were significantly associated with the three types of imaginative capability. We removed the paths that were less significant in both groups, and revised the structural models. We retained the significant paths as being significant in one group, but not in the other.

The trimmed model for the *science* group showed a model fit comparable to that of the initial model (χ^2 = 13030.78, df = 2,754, p < 0.005, RMSEA = 0.072, SRMR = 0.080, CFI = 0.93, NFI = 0.91, TLI = 0.93), accounting for substantial variance in conceptual imagination (R^2 = 0.27), initiating imagination (R^2 = 0.17), and transforming imagination (R^2 = 0). The standardized path coefficient of intrinsic motivation to initiating imagination was 0.33, whereas that of learning resources to initiating imagination was 0.19. Both intrinsic motivation (0.38) and human aggregates (0.31) predicted conceptual imagination, partially supported H1, H2, and H3.

Our data also showed that the interaction of human aggregates and intrinsic motivation exerted a significant effect on conceptual imagination (–0.12), but had an insignificant effect on transforming imagination (–0.01). The interaction of learning resources and intrinsic motivation did not have a significant effect on the three types of imaginative capability, disproving H4 and partially supporting H5. Fig. 1 shows the structural model of the *science* group. In the following figures, the solid line refers to a significant effect, whereas the dotted line refers to an insignificant effect.

The revised model of the *engineering* group showed a model fit comparable to that of the initial model (χ^2 = 12214.11, df = 2754, p < 0.005, RMSEA = 0.070, SRMR = 0.080, CFI = 0.95, NFI = 0.92, TLI = 0.94), accounting for substantial variance in conceptual imagination (R^2 = 0.69), initiating imagination (R^2 = 0.71), and transforming imagination (R^2 = 0.96). The path coefficient of intrinsic motivation to initiating imagination was 0.42, whereas that of learning resources to initiating imagination was 0.18. Both intrinsic motivation (0.44) and human aggregates (0.27) predicted conceptual imagination, partially supporting H1, H2, and H3.

The results also showed that the interaction of human aggregates and intrinsic motivation exerted significant effects on both conceptual imagination (–0.14) and transforming imagination (–0.19). The interaction of learning resources and intrinsic motivation had a significant effect on initiating imagination (–0.09). In other words, both H4 and H5 were partially supported (see Fig. 2).

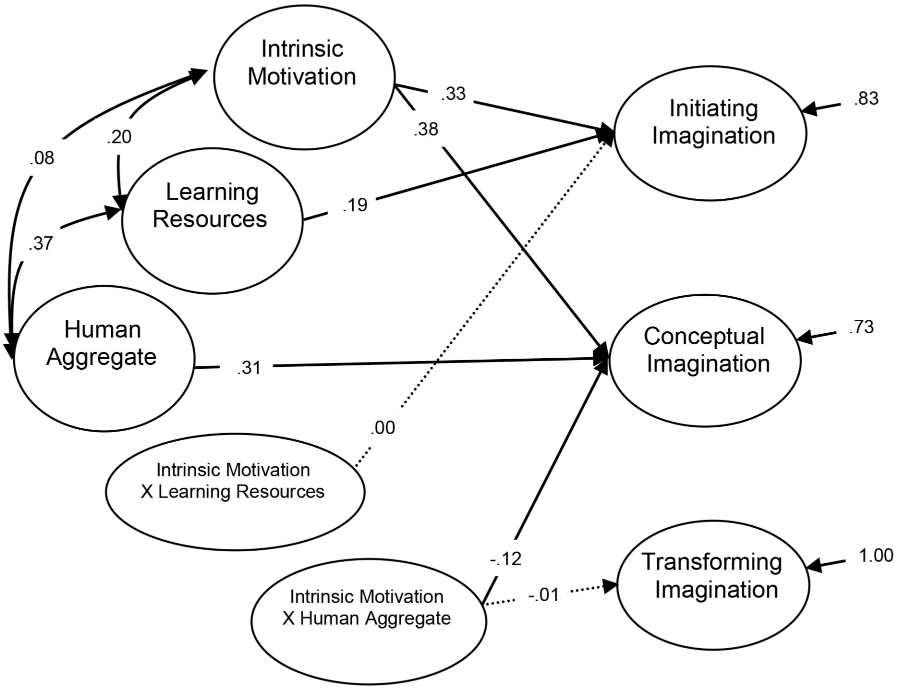

Fig. 1. Moderation model of the *science* group (n = 473).

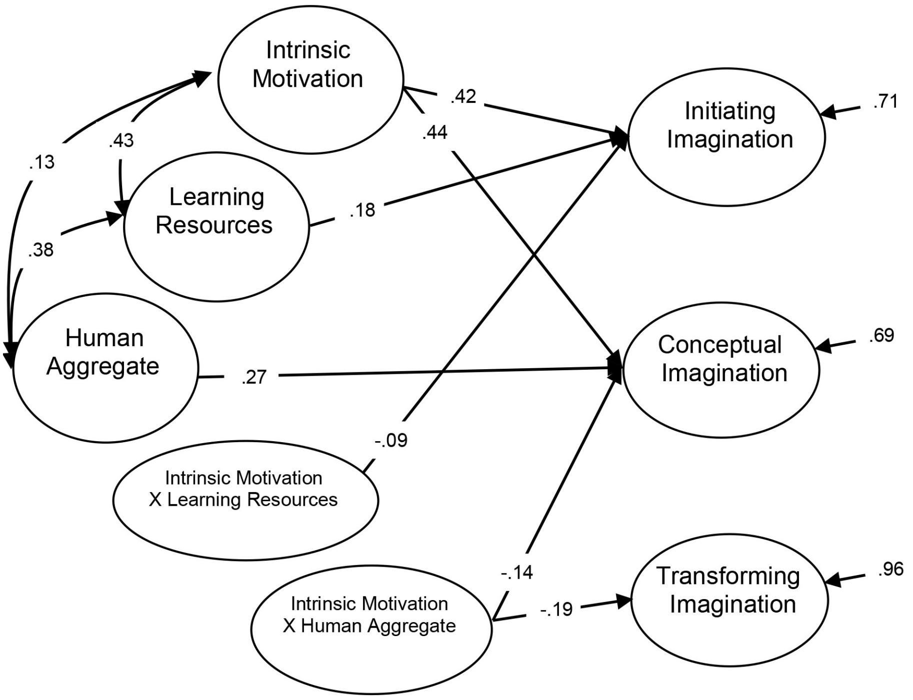

Fig. 2. Moderation model of the *engineering* group (n = 478).

4.2 Moderating effects

We hypothesized that the moderation models between engineering and science students would differ. The SEM analyses showed these two models to be similar, but the effects of each variable differed. To further examine the form of interaction for interpreting the moderating effects, we calculated simple slopes and regression lines for each moderator level [52]. We plotted regression lines for high [1 standard deviation (*SD*) above the mean], average, and low (1 *SD* below the mean) influence levels of human aggregates and learning resources as recommended by Cohen, Cohen, West, and Aiken [53]. A high human aggregate refers to a student whose imagination is highly (+1 *SD*) influenced by human aggregates, whereas an average human aggregate represents the average human aggregate level of influence, and a low human aggregate represents a low level (–1 *SD*) of human aggregate influence.

For *initiating imagination*, the results of simple slope analysis revealed no moderating effect of learning resources on the relation between intrinsic motivation and initiating imagination in the science group (Fig. 3.1). However, the moderating effect in the engineering group was significant. Fig. 3.2 shows that intrinsic motivation was more strongly associated with initiating imagination for high learning resources than those at average and low levels. When intrinsic motivation was low, high learning resources had a greater effect on initiating imagination. When intrinsic motivation was high, the moderating effects between different levels of learning resource influence on initiating imagination narrowed.

For *conceptual imagination*, our data showed that the moderating effects resulting from intrinsic motivation by human aggregates were significant in both engineering and science groups. Intrinsic motivation was more strongly associated with conceptual imagination for high human aggregates than those at average and low levels. Fig. 4 shows the slope of low human aggregates to be steeper than that of high human aggregates. This implies that the moderating effect of intrinsic motivation by human aggregates for low human aggregates is greater than high human aggregates.

Our results also showed no joint effect of intrinsic

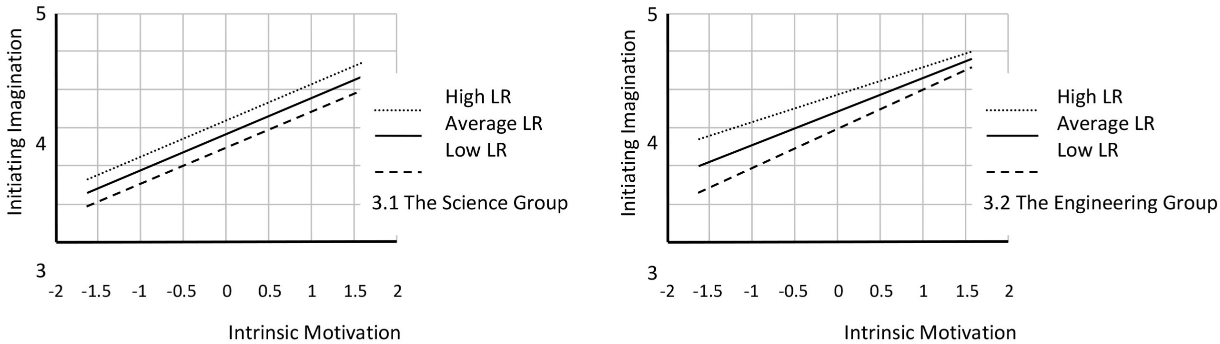

Fig. 3. Plot of intrinsic motivation and learning resources on initiating imagination.

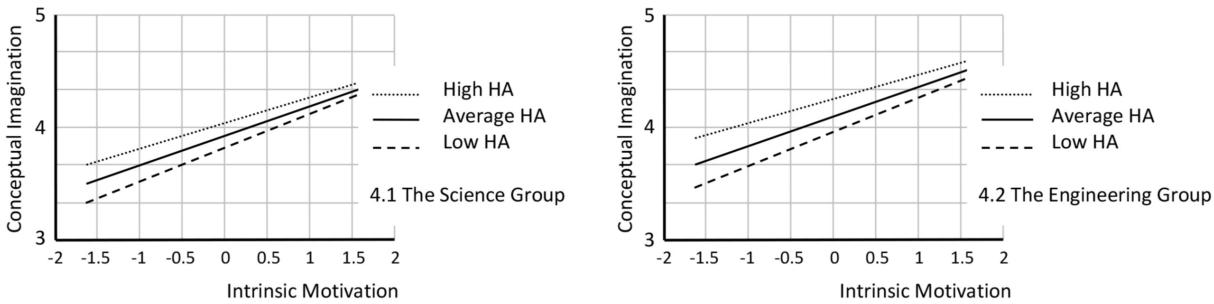

Fig. 4. Plot of intrinsic motivation and human aggregate on conceptual imagination.

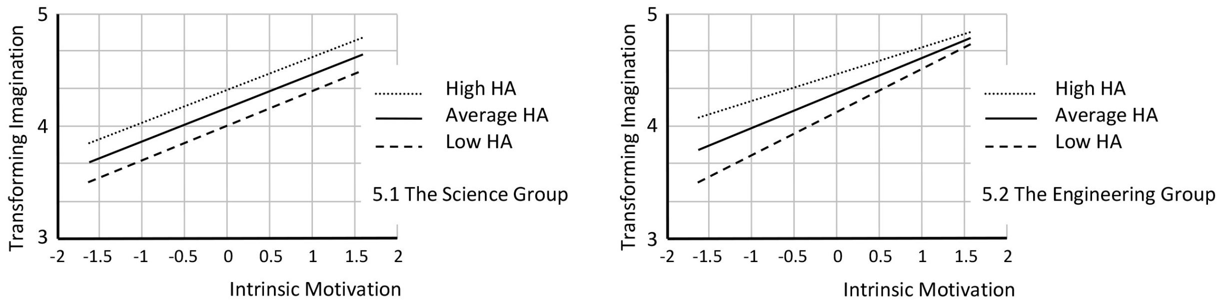

Fig. 5. Plot of intrinsic motivation and human aggregate on transforming imagination.

Table 3. Hypothesis testing summary

Hypothesis	Results	
	Science	**Engineering**
H1: Learning resources predict the three types of imaginative capability.	partially supported	partially supported
H2: Human aggregates predict the three types of imaginative capability.	partially supported	partially supported
H3: Intrinsic motivation predicts the three types of imaginative capability.	partially supported	partially supported
H4: Learning resources moderate the effect of intrinsic motivation on the three types of imaginative capability.	rejected	partially supported
H5: Human aggregates moderate the effect of intrinsic motivation on the three types of imaginative capability.	partially supported	partially supported

motivation and human aggregates on *transforming imagination* in the science group, implying that human aggregates did not affect the influence of intrinsic motivation on transforming imagination in this group. In contrast, the effect of intrinsic motivation on transforming imagination was significantly larger in high human aggregates as opposed to average and low human aggregates (see Fig. 5.2). When intrinsic motivation was low, the conceptual imagination of high human aggregates was greater than that of low human aggregates. However, when intrinsic motivation was high, the conceptual imagination of low human aggregates drew closer to high human aggregates. Table 3 summarizes the results of hypothesis testing.

5. Discussion

Numerous studies have been conducted on the direct influence of learning resources, human aggregates, and intrinsic motivation on the imagination of engineering and science majors. However, few studies have been performed to determine whether learning resources and human aggregates act as moderators between intrinsic motivation and student imagination. Given this notable gap in the literature, we examined the moderating effects of learning resources and human aggregates in the relationship between intrinsic motivation and student imagination, and compared the differences of moderation models between engineering and science majors.

5.1 Moderating effects in the engineering group

In the engineering group, both intrinsic motivation and learning resources had direct effects on initiating imagination, and both intrinsic motivation and human aggregates had direct effects on conceptual imagination. This implies that learning materials and activities could help engineering students generate new and realistic approaches. It also implies that organizational culture could help engineering students focus on learning activities and constantly revise ideas. These findings did not indicate how learning resources and human aggregates can help engineering majors stimulate their transforming imagination to transcend their discipline-based perspectives and actualize their concepts [21]. More research into the relationship between learning context (such as learning resources and human aggregates) and transforming imagination is required.

The results showed that the moderating effects on three types of imaginative capability were significant and similar to each other. Students' imaginative capability was highest when they exhibited high intrinsic motivation, learning resources, and human aggregates. Students whose imaginative capability is highly affected by learning resources demonstrated higher levels of initiating imagination than low learning resources. Students whose imaginative capability was highly influenced by human aggregates had higher levels of conceptual and transforming imagination than those minimally influenced by human aggregates. These results extend previous research, and are a unique contribution to the understanding that learning-resource-related effects are particularly significant in the ideation stage of engineering design, whereas the human-aggregate-related effects are particularly significant in the elaboration and implementation stages of engineering design.

The slopes of low learning resources and human aggregates were steeper than those of high learning resources and human aggregates. Our results contribute to the understanding that the moderating effect of *intrinsic motivation by learning resources* is particularly helpful in stimulating the *initiating imagination* of those students minimally influenced by learning resources, and that the moderating effect of *intrinsic motivation by human aggregates* is particularly helpful for stimulating the conceptual and transforming imagination of those lowly affected by human aggregates. The results advance previous studies such as Kember et al. [44] and Walczyk et al. [47] regarding the impact of learning resources and human aggregates on student motivation, imagination, and learning. We believe that a more thorough understanding by instructors regarding student differences and school culture increases the likelihood that they meet their students' diverse learning needs.

The results indicate that the question of how to develop the imaginative capability of engineering students, particularly for those minimally influenced by learning resources and human aggregates is a critical issue for future exploration. Our test of the moderating effects of *motivation by learning resources* and *intrinsic motivation by human aggregates* constitutes a probe of this issue. Although most engineering design projects are team-based tasks, we suggest that instructors focus on individual needs. Adaptive learning resources, good peer relationships, and an encouraging educational culture can assist engineering students who are unaware of the general educational practices. These findings warrant further inquiry and provide insights for fields such as engineering and science, in which imaginative talent and creative performance are essential.

5.2 Moderating effects in the science group

Our results indicated that student imagination was highest when students exhibited high intrinsic motivation, learning resources, and human aggregates. Although moderating effects were insignificant in initiating and transforming imagination, students whose imagination is highly influenced by human aggregates demonstrate higher levels of conceptual imagination than those minimally influenced by human aggregates. The slope of low human aggregates is steeper than that of high human aggregates (Fig. 4.1), implying that when intrinsic motivation is low, the conceptual imagination of high human aggregates is substantially higher than that of low human aggregates. When intrinsic motivation is high, conceptual imagination is also high. However, almost no differences exist between high and low human aggregates, implying that the moderating effect of *intrinsic motivation by human aggregates* is particularly helpful in stimulating the conceptual imagination of those students minimally influenced by human aggregates.

Our data demonstrated that human aggregates have a direct effect on conceptual imagination. This implies that organizational culture defines what ideas are effective and influence student intuition, logic, and sensibility. This is in line with the suggestions of Gislason [27] and Roehrig et al. [39]. The results also indicated the necessity of focusing on students' intrinsic motivation to stimulate conceptual imagination, particularly for those minimally influenced by human aggregates. Certain individualistic students on campus are minimally affected by educational culture and teacher characteristics. How to stimulate conceptual imagination in these students is a crucial issue to explore in the future. We have contributed to the first step by elucidating the interactive effect of intrinsic motivation and human aggregates.

Our results showed that initiating imagination is directly influenced by intrinsic motivation and learning resources, and conceptual imagination is directly affected by intrinsic motivation and human aggregates. This implies that intrinsic motivation and learning resources could assist science students to develop novel ideas, and intrinsic motivation and educational culture could help them to crystallize abstract concepts. These findings agree with those of several earlier studies [15, 36, 39]. In addition, we found that the joint effect of intrinsic motivation and learning resources on student imagination is insignificant, likely because students focused primarily on the forms of instructional activities and materials rather than on the content topic and learning goal. Our results contribute to the elucidation of the linkages between learning resources, intrinsic motivation, and scientific imagination, and to thereby achieving learning goals.

5.3 Differences between the engineering and science groups

The major differences between engineering and science groups were the moderating effects of *intrinsic motivation by learning resources* on initiating imagination and *intrinsic motivation by human aggregates* on transforming imagination. For both engineering and science groups, intrinsic motivation had a greater effect on *initiating imagination* when learning resources were high. This means that learning resources are a critical source for stimulating the effect of intrinsic motivation on the initiating imagination of engineering and science majors. The slope of low learning resources was steeper than that of high learning resources in the engineering group. This indicates that the initiating imagination for those who do not respond to learning resources is strongly stimulated when their intrinsic motivation remains high. Because most engineering projects are team-based, we suggest that instructors emphasize focusing on each team member and offer adaptive learning materials to optimize students' initiating imagination.

For both engineering and science groups, intrinsic motivation had a greater effect on *transforming imagination* when human aggregates were high. This indicates that human aggregates are a crucial factor for stimulating the effect of intrinsic motivation on the transforming imagination of engineering and science majors. The slope of low human aggregates was steeper than that of high human aggregates in the engineering group. This means that transforming imagination in those who do not respond to human aggregates is strongly stimulated when their intrinsic motivation remains high. We also suggest that instructors focus more on each team member and offer adaptive learning advice to optimize students' transforming imagination.

Although differences exist between the engineering and science groups, Petroski noted that most scientists and engineers move back and forth along the continuum of discovering truth in nature and developing beauty in innovations [10]. Both engineering and science students must learn how to confront arguments and controversies, and must proceed through a laborious and painful conception process before experiencing breakthroughs. They must frequently reason through uncertainty and be flexible in interpreting ambiguous data. All the predictors in this study, such as intrinsic motivation, learning resources and human aggregates, had direct effects on *conceptual imagination* in both engineering and science groups. However, understanding why the moderating effect of learning resources was not displayed in the conceptual imagination of engineering and science majors, in addition to other potential effects resulting from individual differences [54], could be the focus of future research, further establishing methods for arranging learning resources in engineering and science classes.

5.4 Research limitations

This study has several limitations. First, in this study, imagination consisted of self-perceived capabilities. The choice of research tools was based on the preliminary nature of imagination research. Our study samples were sufficiently large and were made across several universities, enabling our findings to be generalized to a larger population. Second, we did not attempt to examine the differences in instructor opinions. For cultural reasons concerning the respect in which teachers are held in Confucianism, we did not explore the potential influences of instructors. Third, we did not analyze institutional difference because it was not the focus of this study. However, the question arose of whether a research intensive university exhibits the same SEM between the cause and effect variables as a teaching intensive university.

6. Closing remarks

Despite the aforementioned limitations, our results provide intriguing insights into the complexities of the interplay between intrinsic motivation, human aggregates, and learning resources. The results reveal that imaginative capabilities became highest when students had high intrinsic motivation, learning resources and human aggregates. In addition, we provided empirical evidence and made unique contributions to the structural view regarding how learning resources and human aggregates moderate the effect of intrinsic motivation on student imagination.

We also contributed to an understanding of the differences between engineering and science majors regarding these moderating effects. According to our data, the major difference between engineering and science groups was the moderating effects of intrinsic motivation and learning resources on initiating imagination. In other words, the initiating imagination for those engineering students who are insensible to learning resources is strongly stimulated when their intrinsic motivation remains high. The other critical difference was the moderating effects of intrinsic motivation and human aggregates on transforming imagination. That is, transforming imagination for those engineering students who do not respond to human aggregates is strongly stimulated when their intrinsic motivation remains high. Practical implications were discussed and research limitations were explained.

We hope that engineering and science educators will use our study as a foundation for developing meaningful research projects and designing appropriate instructional strategies to nurture student curiosity, develop their imagination, and empower them for their careers.

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