Attributes of Research Mindset for Early Career Engineering Researchers

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Abstract
Mindset refers to a set of beliefs, attitudes, and assumptions that individuals hold about themselves and the world around them. The literature exploring mindsets suggests the existence of many mindsets relating to the performance of different tasks. Research is one such task or set of tasks undertaken by scholars that requires a mindset to perform research activities. Understanding research mindset is important because researchers are at the center of the research process. The term research mindset is used in the extant literature, but no theoretical base for the usage of this term has been established. The following work-in-progress study is a first attempt to understand the attributes of the research mindset among engineering doctoral researchers. Interviews were conducted with seven early career engineering researchers. Initial findings suggest that research mindset is comprised of six attributes: (1) open-mindedness, (2) believing in oneself and the research, (3) persistence, (4) honesty, (5) being critical, and (6) a writing mindset. The findings from this study provide a foundation for further explorations of research mindset.

Introduction

A mindset is a psychological framework that shapes an individual's perception, interpretation, and response to the world. Mindsets are composed of a complex set of beliefs, values, attitudes, and assumptions that are influenced by a person's experiences, upbringing, culture, and environment. They can have a profound impact on a person's behavior, emotions, and overall well-being. Recognizing and understanding our own mindsets can lead to insights into how they influence our thoughts and actions, which allows us to develop the ability to consciously shift or adapt our mindsets to better serve our goals and aspirations.

Mindsets can influence how individuals perceive and approach various situations and challenges in their lives. Variations in the conceptualization and characterization of mindsets has resulted in some ‘fuzziness’ around this construct [1]. This has led to many definitions of mindset including a sum total of the activated cognitive procedures that consist of the cognitive orientation most conducive to successful task performance [2], a set of beliefs that shapes how one perceives this world and themselves [3], [4], and a cognitive filter or a frame of reference [5]. Each definition suggest mindsets are crucial for the performance of any task. The literature also suggests the existence of many mindsets. Studies related to growth and fixed mindset [6] have inspired many to look into new mindset spaces. Many generic mindsets have been studied since, including global mindset [5] and developmental mindset [7]. This has recently expanded into studies on mindsets that are discipline-specific, including maker mindset [8] and the entrepreneurial mindset [9]. The extant literature on mindsets is abundant and highlights the need for relevant mindsets toward specific task performance [9] – [11].

The term ‘research mindset’ has been used by some researchers [10]–[12], but has yet to be explicitly defined. A few studies call out the presence of research mindset and the related construct of researcher identity [13], [14]. Efforts in this space aim to better understand how mindset plays a role as researchers engage in various research tasks like defining research problems, conducting literature reviews, designing and conducting experiments, writing up results, and working on a research team. Research is a task, or a set of tasks, undertaken by researchers that needs specific constructs or attributes of mindset to perform research activities.

Research and development (R&D) play a crucial role in promoting economic development by fostering innovation and technological progress. According to the World Intellectual Property Organization (WIPO), "Innovation, fueled by investment in R&D, is a key driver of economic growth and job creation in advanced economies"[15]. In fact, numerous studies have shown a positive correlation between R&D spending and economic growth [16], [17]. At the epicenter of R&D are researchers. Researchers play a critical role in advancing knowledge and finding solutions to complex problems. They are responsible for generating new ideas, developing theories, and conducting experiments and analyses to test hypotheses and produce new knowledge. Without researchers, the progress of scientific discovery and innovation would be greatly hindered [18], [19].

Similar to studies proving the need for mindsets towards specific task performance [9]–[11], understanding the research mindset held by researchers would be useful to the community. The following study sought to explore the research mindsets of engineering researchers. Specifically, this study aims to explore the different attributes of research mindset held by early career engineering researchers, i.e., Ph.D. students, within a United States (U.S.)-based R1 university. The following research question guided this study: *What are the different beliefs, attitudes and mental filters held by early career engineering researchers that contribute to a research mindset?*

Conceptual Framework

Mindsets are characterized from the perspectives of: (1) cognitive psychology, (2) social psychology and organizational leadership, and (3) positive psychology [1]. Cognitive psychology suggests mindset characterizations or conceptualization are about the cognitive procedures that are activated in response to a given task [20]–[22]. Social psychology and organizational leadership add that mindset characterizations or conceptualizations are generalized as cognitive filters that attend to and influence the totality of cognitive processes with or without an identifiable task [5], [9], [23]. Finally, positive psychology suggests mindset characterization or conceptualization emphasizes and assumes that mindsets include cognition, cognitive processes, and responses to tasks, but also inherent beliefs or views of reality [5]. Research as a process involves multiple cognitive and social tasks. It is not easy to conceptualize or characterize research mindset based only on the perspectives of cognitive psychology, social psychology, and organizational leadership, or positive psychology. All three perspectives should be considered to understand the attributes of research mindset. This study uses this conceptual framework as a lens, particularly during data collection and analysis procedures.

Methods

This research project is a qualitative study following a case study design [24] with inductive thematic analysis [25], [26]. This section subsequently describes the authors' positionality, research participants and their recruitment process, data collection, and data analysis procedures associated with this study.

Positionality

The authors of this paper have both earned degrees in engineering and have experience as engineering educators and engineering education researchers. The first author identifies as an

international student and early career scholar pursuing his Ph.D. at a R1 institution, while the second author is a domestic engineering faculty member at a R1 institution. Both authors have benefited from research experiences in academic settings at different stages in their careers, including advising students on research projects. These experiences and identities create potential implicit biases toward the benefits of research experiences for students.

Recruitment Process

A screening survey was initially disseminated to Ph.D. students at a single R1 institution in the southwestern U.S. The participants were selected based on the following inclusion criteria: (1) earning a formal degree in an engineering discipline, (2) experiencing the tasks of engineering research at the time of the study, (3) having published at least one conference paper or journal article as first author, and (4) experiencing work within a research team. The selected participants were briefed over email and again at the start of the interview regarding the purpose of this research. Each participant received a $30 Amazon e-gift card as compensation for their participation in the research. The study was approved by the IRB at the authors' institution.

Participants

Seven participants were interviewed. Table 1 describes in detail the demographic information of the participants. All participants identified as graduate students or early career researchers enrolled in Ph.D. programs. Many participants identified as male with two participants identifying as female. The number of publications ranged from one to thirteen. It is worth noting that all participants were international students, primarily from India. The names of the participants are replaced with pseudonyms according to the requirements of the IRB.

Table 1. Demographic information about participants.

Participant Identifier	**Ph.D. major**	**Year in program**	**# of pubs**	**Bachelor's major**	**Gender**	**Country of Origin**
Krishna	Artificial Intelligence	2	4	Robotics	Male	India
Ganesha	Electrical Engineering	1	5	Electronics and Communication Engineering	Male	India
Lakshmi	Mechatronics	4	13	Mechatronics	Female	Nepal
Vishnu	Civil Engineering	2	1	Civil Engineering	Male	India
Shiva	Computer Science and Engineering	3	3	Computer Science and Engineering	Male	India
Ramachandra	Computer Science	1	3	Electronics and Telecommunications Engineering	Male	India
Parvati	Artificial Intelligence	3	2	Computer Science and Engineering	Female	India

Data Collection

Data for this study were collected through semi-structured interviews. Interviews were scheduled based on convenient times for the participants. All interviews were conducted online using the

Zoom videoconferencing platform. The interview duration ranged from 30 to 60 minutes. The average length of an interview was 52 minutes.

The protocol began by asking participants about a research project they were currently working on. They were then asked about research experiences that brought them joy and ones that they found challenging. These opening questions were asked to set the tone and structure for the remaining interview questions. The interview protocol was divided into sections based on the main phases of research: problem definition, literature review, design and experiments, and scholarly writing and publication. Several probes to go deeper into the discussion were included. The interview protocol is as follows.

- *Context Setting:* For the record, in which discipline of engineering did you earn your bachelors degree? Have there been any research activities you've engaged in at any level that have brought you personal joy? If yes, please tell me more. What has been the toughest or most challenging research experience you had to date? Please tell me more.
- *Problem Definition Phase:* How would you describe setting your mind to identify a worthwhile problem for research? How do you gauge whether or not the problem is worthwhile? What set of beliefs or attitudes would you say play a role in how you identify a research problem?
- *Literature review phase:* How would you describe setting your mind while conducting a literature review? What steps do you see as critical when conducting a literature review? What set of beliefs or attitudes would you say play a role when undertaking a literature review?
- *Experimentation phase:* How would you describe setting your mind before or during an experiment? What steps do you see as critical when conducting experiments? What set of beliefs or attitudes would you say play a role when undertaking experiments?
- *Scholarly writing and publication phase:* How would you describe setting your mind before or during the process of writing up your findings as a publishable document? What steps do you see as critical when writing a draft manuscript? What set of beliefs or attitudes would you say play a role in writing a draft manuscript?
- *General Questions:* What do you believe are the sources of your current beliefs or attitudes regarding research? Do you have any other inputs or thoughts you would like to share?

Data Analysis

Interview data were transcribed and analysed using Dedoose software. Thematic analysis [26] using inductive coding was used because very little information about research mindset exists in the literature. The data was looked at from the lens of the conceptual framework. Initial codes were discussed with two participants to ensure that the meaning of the codes matched what they said during their interviews.

A total of 26 codes emerged from the analysis. Some codes were later merged to form themes. A total of six themes emerged from the codes. Table shows the codes and emergent themes. The process of coding was done individually by the first author and later reviewed by the second author.

Table 2. Emergent themes and sub-themes from the codes

Theme	Sub Theme (if applicable)	Code
Be Open Minded		Open minded
		Ready to learn
		Ready to learn from others
Believe	Believe in Yourself	Be positive
		Be motivated
		Be kind to yourself
	Believe in Your Work	Conviction in the work
		Bond with the topic
		Novelty
		Innovativeness
Persist		Persevere
		Have patience
		Things are gradual
		Things are iterative
Be Honest		Be honest
Be Critical		Validate
		Question everything
		Be observant
		Be focussed
		Solidify foundation
		Clarify everything
Have a Writing Mindset	Structuredness	Divide and conquer
		Draft it
		Have a bigger picture
	Tell a story	Storytelling
		Reader's perspective
		Make it easy to understand

Limitations

There exist limitations to this study from the perspective of transferability. The first limitation is the lack of a diverse sample. All participants are international students, with most coming from India. The conceptualization of the research mindset could be influenced by country of origin or perhaps other demographic characteristics (e.g., gender or race/ethnicity). The second limitation is the lack of generalizability of these findings with other domains like basic science research, mathematics research, and social science research. Finally, the sample includes students that represent only a few disciplines of engineering and may not transfer to students across all engineering disciplines.

Results

The six emergent themes were: (1) Be Open-Minded, (2) Believe, (3) Persist, (4) Be Honest, (5) Be Critical, and (6) Have a Writing Mindset. The Believe and Have a Writing Mindset were both broken down into two sub-themes. The subsequent sections explain the emergent themes and sub-themes with key takeaways and example excerpts.

Be Open-Minded

The theme Be Open-Minded was created using the codes open mind, ready to learn, and ready to learn from others. One needs to be open-minded to modify oneself according to a better research direction. This was demonstrated by a comment made by Lakshmi:

> *"Open to ideas. Extremely open to ideas. You have to do that. You cannot say that this is the way to do it. There are different ways to do research. Now we are living in such a global world where you'll find researchers just based on country, they might have a completely different way of doing... And the thing that they bring to table is when they be completely different from what you grew up with or what you think that they can bring over here. So be open to ideas."*

Being open to changes during the due course of research is a mindset one should have while performing research activities. Being receptive to suggestions from others can play a crucial role in research. This is evident in the following statement by Krishna in the context of conducting experiments:

> *"We need to be open to ideas from everyone because everyone has a different background, and we don't know when one thing is going to strike or something others say would really make sense in your mindset, your technical expertise. For example, in the research I was working with in a team and there they were expressing geospatial analysis and they had a term called Moran's I, and it is related to assume that there is any term like Moran's I, and you could come up with that using a predictive model. Then it would make sense. For me, it was just a predictive term, but for them, once the term is predicted, it has value. And that's how we integrated the two ideas."*

One needs to be open to others' comments, feedback, and criticisms when conducting research. A feedback system is inherently infused within all research activities. That is how academic research experiences prepare students to become researchers with a mindset of being open to others' feedback, criticisms, and comments. The feedback or criticisms can come from peers, supervisors, or reviewers. These are in line with the following statement made by Parvati,

> *"But in research team, I found that there were other team members who are also experts in the field, and it's very important to understand what they have to say about the problem being solved. What is their opinion? Once you propose an approach or once you give your review of the research topic, what is their feedback. I think it's very important to really be open to feedback and constructive criticism both when you're working in research team."*

Believe

The theme Believe consists of two sub-themes: Believe in Yourself and Believe in Your Work. The codes used to create the sub-theme 'Believe in yourself' are be positive, be motivated and be kind to yourself.

Early career researchers are in the phase of acquiring the skills and knowledge needed to perform research-related tasks. Having confidence in what has been learned is an important aspect. One must believe in the capabilities and skillsets they have obtained over their career. This drives persistence within a career without losing hope. Also, this is a critical mindset one should have while approaching any research task. This is evident in the following statement made by Ramachandra:

> *"I think having a positive mindset is very important. For example, I can look at a problem and I can see that, "Oh, this is too hard, I won't be able to solve it." That mindset will lead me to either rejecting the problem or selecting the problem reluctantly and most likely will lead to being a failure. On the other hand, if I strongly believe that this is something that I can solve, then that will help that negative attitude, mindset, or belief."*

Believing in ourselves is essential, while at the same time, believing that our research work is worthy is equally essential. A firm conviction that the work being done is worthy and valuable will enable the researcher to motivate oneself, build passion, and make progress in the research activities. Often this mindset can be possessed by perceiving the research has novelty and innovativeness. These are well reflected in the following statement by Shiva in the context of problem definition:

> *"Therefore, I think that one of the first beliefs is that your research does matter. Maybe you might not have immediate success or immediate number of citations from that research or immediate results from that paper itself, but if you have a strong conviction that there is a research contribution here, that there is science in what you have done rather than just engineering, at that point, that kind of belief and attitude will definitely help in this pursuit of Ph.D. or research."*

Persist

Persist is created from the codes persevere, have patience, things are gradual, and iterative. One needs to understand that research tasks take time; it happens gradually and often requires patience. One also needs to put in consistent continued effort to see results. Having this mindset will help one to perform better in research tasks. These are well explained in the following statement made by Shiva:

> *"One of the most important things is that I see in people who are involved in research is that immediate result attitude, where they would like to see immediate results for any effort that you put in. But it does not happen that way in research. That kind of belief and that ability to say that, "Even if there are no immediate results, it's okay. I trust in the efforts that I put in or in this project or in this research. I'm willing to persevere with it until I see good results." So yeah, that was probably the most important part."*

Another key takeaway of this theme is understanding that research tasks are iterative as opposed to linear or sequential. One may be needed to go back and forth many times to arrive at the best

outcome. Having this mindset would help researchers perform better in their tasks. This is clearly visible in Vishnu's statement in the context of experimentations:

> *"And then I kept that mindset that "Okay, might not get the results first time because I think if we are getting the results first time, then either we are way too genius, which is that's absolutely not true, or we are doing something wrong." So I think I kept that belief that "Okay, I will have to repeat some experiments, but I will still plan it and I'll try to finish my work well within time."*

Be Honest

Be Honest refers to having a mindset of being honest while performing any research tasks. Honesty is a crucial aspect of research activities. One needs to continuously have a mental filter of being honest while doing any research task. This is clearly visible in the following statements by Ramachandra in the context of experimentation:

> *"...plus, I think integrity is very important, because whenever you talk about proper... From a moral perspective, integrity is important that you maintain throughout. It's very easy to be tempted to take a shortcut. "No, it's taking too long. I know it should work, so I might as well take one." Those are two very different things, so to do it properly, integrity. Second is doing our due diligence. Diligent find, I would say, doing something 90% of the way and doing it 100% are two very different things. If you expect two plus two to be four, or eight, or something simple like that, even then, as a researcher, you have a duty to make sure that it's always that way. Just because your first 90% of your experiments agree with you doesn't mean that there won't be any cases that it doesn't work."*

Be Critical

The theme Be Critical is created out of the codes question everything, validate, be observant, be focused, clarity, and solidify foundation. One needs to be critical during a research study. Research starts with questions. Questioning everything is the nature of scientific research. A researcher should have this mindset of being critical with every research task being performed. One needs to be critical to become focused while doing research tasks, especially since it is easy to become distracted with other things happening around the research. This is very clearly highlighted by the following statement made by Vishnu in the context of the literature review phase:

> *"So, I would be trying to learn the things from very basic point of view. I do not want to see only the results that. So, for example, in our concrete, if someone is reporting strength, I do not want to see, "Okay, they are getting 100 MPA or 80 MPA." I want to see why they're getting. So, for me, my mindset is always, "Okay if this paper cannot give me the reason of the results... The significance of the research, why are they actually doing this problem statement, I'm not sure if that is a good paper to review for a literature review for me." So, for my general approach is always to first look at the abstract and get an idea, "Okay, is there something concrete in it that they're trying to solve?" Then go to the conclusions and then go to their problem statement. I will read their problem statement to see why did they*

pick up this research and what are they trying to achieve? And then I will go in depth of that paper."

Validation is an essential aspect of research, including the validation of our ideas, experimental design, and results. All of these phases become complete with validation. Having a mindset to validate everything becomes essential in research. Ganesha clearly explained this in the context of experimentation:

> *"It depends. For me, conducting experiment, it is like check it, whether that is working or not, whether the idea that you have, validate yourself, validate your idea. And from that you can gain knowledge. Sometimes, while validating, you'll get, "Okay, this is how we should think." Instead of conducting the experiment, you can come to the conclusion."*

Have a Writing Mindset

The theme of Have a Writing Mindset has two sub-themes: Structuredness and Tell a Story. The codes used to create the sub-theme Structuredness are divide and conquer, draft it, and have a bigger picture. The codes used to create the sub-theme Tell a Story are storytelling, make it easy to understand, and readers' perspective.

This overarching theme relates to the scholarly writing phase of the research. The codes of this theme are not visible in any other phases of the research warranting the use of the term writing mindset. The two sub-themes refer to the mindsets one should have to develop a better research article. Structuredness refers to the mindset one should have when first beginning to write up results. It could be either in the form of a rough draft, an outline, or even a mental image of the entirety of the work. This mindset will ensure that the researcher will not miss out on any details and develop a good research manuscript. The following statement made by Lakshmi explain this essence:

> *"So before writing any article, I would have the outline of things that I wanted to do and one of the things that I'm going to put in over there. For example, the introduction, you were just going to say the problem statement, very standard. So you're shifting from what might be a presentation to an Overleaf document, just copying the ideas and then trying to form sentences from it. Okay. So once you already have the skeletal, it's much easier to shift to the other place."*

The second sub-theme is Tell a Story. Having a mental image of what one wishes to write is useful, but it is also important to focus on the end users of the article. There is no point in writing an article that cannot be easily understood. This aspect helps in attracting the most readers and citations. This is highly evident in the statement made by Ramachandra:

> *"This is when you have to think like someone who's trying to write a story, that's one mindset… You need to be thinking creatively. You need to think, eloquently, what you're writing, whether that makes sense and whether your writing flows. You have to be creative to write the story, and then, at the same time, you have to*

constantly be looking at it and asking yourself. Does that make sense? Does that make sense? Does that make sense?"

Discussion

The emergent findings of this study suggest the presence of six research mindset themes: Be Open-Minded, Believe, Persist, Be Honest, Be Critical, and Have a Writing Mindset. It is interesting to observe that a few emergent themes for research mindset have also been seen for other mindsets but with different contexts attached to them. Being open-minded is a construct observed in many other mindsets (e.g., entrepreneurial mindset [27] and design thinking mindset [28]). The context within which open-mindedness is considered is different in these mindsets. The conceptualization of open-mindedness is relatively similar for all considered mindsets.

The theme Believe had two sub themes, including Believe in Yourself and Believe in Your Work. The sub theme Believe in Yourself combines self-efficacy [29] with a growth mindset [6]. One needs to be confident in the skills and knowledge acquired while being positive and motivated when applying such skills in research-related tasks. An interesting note about this sub-theme is that it could apply only to early career researchers or Ph.D. students. The participants included in this study are in the process of acquiring skills and knowledge. They currently participate in research activities as a part of their dissertation or research assistantships. This sub-theme may not be observed if the same study is conducted with expert researchers.

The other Believe sub-theme, Believe in Your Work, indirectly indicates the passion one needs to build within oneself toward the research they are doing. Numerous studies indicate how passion at work helps improve performance [30]–[32]. Passion for the research work one is doing comes from bonding with the topic and getting convinced that the research work is worthy and helpful, from both the societal and research community perspectives. This can be enhanced by perceiving the novelty and innovativeness within the research problem one is pursuing.

There is literature suggesting honesty and critical thinking by themselves are mindsets. Aesthetic judgement, truth telling, individual responsibility, and professionalism are part of an ethical mindset, along with many other factors [33] that are very closely related to the theme Be Honest about the current research. Numerous articles also indicate the need for a critical thinking mindset [34], [35]. Factors such as truth seeking, analyticity, systematicity, and inquisitiveness [35] are particularly relevant from the perspective of the research mindset.

All themes were observed across phases of research except having a writing mindset, which was only captured during the scholarly writing phase of research. This could be because the participants are early career researchers in their Ph.D. program and have little experience writing scientific articles. These participants invest significant time in writing as part of their dissertation studies. Some studies show how students face challenges in writing because of a lack of a proper writing mindset [36]. This theme may be specific to early career researchers and may not be noticed if the same study is conducted with expert researchers as participants.

Future Work & Implications

This study explored the attributes of research mindset according to early career researchers i.e., Ph.D. students. Results establish a baseline for further exploration of research mindset held by

others who engage in research. Exploring the attributes of research mindset according to expert researchers will be helpful in expanding our understanding of such mindsets. Additionally, exploring the research mindsets of undergraduate students would also provide additional insights into even earlier career researchers. Looking at research mindset across the continuum of academic and professional research experience would provide a natural ramp to observe the development of research mindset. This approach would also provide an opportunity to observe change in research mindset over time.

The emergent constructs or attributes of the research mindset can become a foundation for future work exploring this space. More research is needed with a diverse population to make the attributes of the research mindset more transferable. Also, there is a need to understand the attributes of the research mindset for domains other than engineering (e.g., mathematics, science, and the social sciences). The conceptualization of research mindset in these domains can make such explorations more impactful to the community.

Doctoral education is responsible for cultivating a proper research mindset among early career researchers. STEM Doctoral education in the U.S. is not only designed to enhance critical thinking, and persistence over the Ph.D. journey of a student [37], [38] but also to develop the ability to work in collaborative and team settings and acquire the capacity to communicate, both orally and in written form [38], [39]. Honesty and ethical conduct are an integral part of any doctoral education [40], [41]. There are numerous studies indicating that open mindedness improves doctoral education [42]–[44]. Similar is the case with growth mindset which is related to the study's emergent theme Believe [45]. No literature was found on how doctoral education incorporates open mindedness and growth mindset within its design. Further in depth studies on understanding the attributes of research mindset may help design better doctoral education experiences for students.

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