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An Analysis of Engaged Thought through the Lens of Undergraduate Research

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Abstract
The engineering community values the development of critical thinking, but the techniques for most efficiently achieving this outcome are still up for debate. The literature suggests that research experiences provide a strong opportunity for students to develop cognitive abilities, but much of the research is based on the self-reported perceptions of the student participants and often lacks evidence of validity. This paper examines the perceptions and use of engaged thinking, a term that encompasses critical and reflective thinking, by six students throughout a 10-week Research Experience for Undergraduates summer program. An analysis of a series of interviews conducted with each student throughout their research experience presented themes related to prerequisites for engaged thinking (background knowledge, disposition, and transitional circumstances) which could address some of the shortcomings that have previously prevented undergraduate research from reaching its full potential.

Introduction

The development of critical thinking skills represents one of the primary goals of undergraduate engineering education.[1-3] In our previous work, we connected critical thinking with reflective thinking, suggesting that the two types of thought overlap and might be more appropriately presented together in what will henceforth be referred to as "engaged thinking."[4] We further suggested that the overarching goal of engineering education should be to develop adaptive experts and showed that the skills of adaptive expertise relate closely to those of an engaged thinker. The optimal techniques used to develop these skills have been widely researched,[5-42] but a definitive solution remains elusive.[14,20,23,28-30,34,43-52] While utilization of a variety of approaches will likely produce optimal development of these skills, active, student-centered, and inquiry-based learning appear to be common themes amongst the critical thinking literature.[4]

One such activity that promotes active, student-centered, and inquiry-based learning for undergraduate students is the undergraduate research experience.[53-57] The Boyer Commission contributed a significant push in recent years towards increasing the availability and participation in undergraduate research at research universities, suggesting that research and creative endeavors provide superior mechanisms for learning over simple transmission of knowledge.[53] Undergraduate research presents students with open-ended tasks set in real-world contexts, which are often considered important factors in promoting critical thinking.[58]

While accounts are often vague, typically lack discussion regarding processes, mechanisms, and degrees of effect, and rarely provide evidence of validity of findings, there exists a multitude of sources associating participation in research with growth in critical thinking and cognitive skills.[59,60] The list of skills and traits allegedly developed through the research experience is extensive and includes originality, creativity, curiosity, the ability to think independently, the general understanding of the nature of science, the ability to cope with ambiguity, the ability to apply skepticism to information, and many other general research skills.[59,61-65] These claims generally derive from participant, alumni, and faculty surveys and were occasionally compared to students who did not participate in undergraduate research. Results also suggested that these improvements tended to be less significant when students' interest in research or their project

was lower and when faculty mentors did not modify projects to accommodate the skill level of an undergraduate researcher.[63,65]

To temper these claims, however, though undergraduate research appears to provide excellent growth in many cognitive abilities, it does not necessarily correspond directly with development of higher-order thinking skills.[62] The adequate to significant gains in specific content knowledge reported do not always appear to accompany comparable gains in conceptual understanding.[59] Such gains require sufficient time to achieve familiarity with background content and comfort in using specific equipment associated with a given project. Additionally, opportunities to engage in higher-order thinking is dependent upon whether or not the student is involved in designing research questions and strategies. Further, despite improvements in many cognitive abilities, one study suggested that none of those improvements matched students' expected levels of growth.[62]

The research question guiding this study is: How is engaged thinking developed and used while students are performing undergraduate research? We present data from six students who participated in a 10-week summer Research Experience for Undergraduates (REU) to identify some of the factors associated with the use of engaged thinking in undergraduate research. We will discuss the prevalent themes that will be henceforth referred to as prerequisites to engaged thinking.

Methodology

This study seeks an understanding of the use of engaged thinking in undergraduate research through a descriptive collective case study analysis. Case studies are used to explore complex phenomena in the context in which they occur by using a variety of lenses.[66] The different lenses considered included a set of four interviews with each REU participant, surveys of the faculty and graduate student mentors for each student, and reports produced by the students during their projects, though only the interviews will contribute to the discussion here. As the context of each individual student's experience varied significantly based on their background, the project for which they were selected, the mentors with whom they worked, and the strategies employed by those mentors, each student represents an individual case, and the students together form a collective case study, providing for a cross-case analysis. To reduce the length of this paper, the cross-case analysis will be the primary focus.

The data was collected in the summer of 2013 at a southeastern research university with very high research activity. This institution is a large four-year, primarily residential university with a majority undergraduate population. The College of Engineering hosted a 10-week REU pertaining to infrastructural materials. Students lived on campus in apartment-style dorms with one another. Information regarding the students presented in this paper and their corresponding home universities is presented in Table 1. Pseudonyms are used in the table and the home institution profile codes are based on the Carnegie Classification of Institutions of Higher Education: RU/VH designates research university, very high research activity; Master's L designates institutions that award at least 200 masters-level degrees; DRU designates Doctoral/Research Universities; VHU designates very high undergraduate enrollment; HU designates high undergraduate enrollment; MU designates majority undergraduate enrollment; FT4 designates Full-time, four-year institutions; MS designates more selective; S designates selective; HTI designates Higher transfer-in; LTI designates lower transfer-in; L4 designates

large four-year; M4 designates medium four-year; S4 designates small four-year; NR designates primarily nonresidential; R designates primarily residential; and HR designates highly residential.

Name	Gender	Race	Major	Year in school	Home institution profile
Anusha	Female	Not given	Mechanical Engineering	Sophomore	RU/VH, MU, FT4/MS/LTI, L4/R
Eric	Male	Asian	Materials Science and Engineering	Senior	RU/VH, HU, FT4/MS/HTI, L4/HR
Graham	Male	White	Mechanical Engineering	Junior	Master's L, MU, FT4/MS/LTI, S4/HR
Kimberly	Female	White	Mechanical Engineering	Junior	DRU, HU, FT4/S/HTI, L4/NR
Mya	Female	White	Physics	Senior	Master's L, VHU, FT4/S/HTI, M4/R
Walter	Male	White	Chemical Engineering	Junior	RU/VH, HU, FT4/MS/HTI, L4/R

Table 1. Demographic information of participants using pseudonyms.

Each student participated in a series of four semi-structured interviews at weeks 1, 3, 7, and 10. The initial interview was designed to provide baseline information regarding the students' perceptions of research and engaged thinking (referred to in the interviews as critical and reflective thinking) while the subsequent interviews were scheduled and designed to correspond with the points in the research where the students were expected to be conducting literature review, experimentation, and data analysis and presentation, respectively. The questions in the second, third, and fourth interviews were intended to determine the students' perceived use of critical thinking while performing the respective phases of research in their projects and to provide a final reflective perspective. The study was approved by the REU institution's Institutional Review Board. The students did not receive any compensation for participating in the study.

After the conclusion of the program, the interviews were transcribed. Each interview was analyzed using a set of *a priori* codes as determined through literature reviews on critical and reflective thinking.[4,58] Additional codes and sub-codes were added in order to capture recurring themes and to improve resolution of the data. The primary codes were as follows:

1. Background knowledge
2. Dispositional traits
3. Transitional (engagement inducing) circumstance
4. Developing or modifying background knowledge through engaged thinking
5. Analyzing (processing, examining, or interpreting)
6. Synthesizing, reflecting, or using metacognition
7. Problem-solving, designing, or creating
8. Generalizing, transferring, or adapting
9. Communicating or explaining

These codes fall into three basic groups: prerequisites of engaged thinking (codes 1-3); development of knowledge (code 4); and tasks associated with development or application of knowledge (codes 5-9). Sub-codes were used to resolve various specific distinctions within larger codes and codes were further differentiated based on whether the participant identified the item in the context of their use or perception of engaged thinking or if the analyst identified the participant's reference to the item as being associated with engaged thinking. This distinction was included to capture instances where the participant may have used engaged thinking but was discussing their experience outside of the context of engaged thinking. Additionally, that distinction provides information that can carefully analyzed to indicate the student's awareness of their use of engaged thinking.

Each student was analyzed individually to determine a holistic view of that student's particular experience. Each of those cases was then compared to one another to identify common trends amongst the participants. As this paper means to identify potential solutions to the inadequacies of research as a tool for developing engaged thinking rather than the ways in which it is used, we focus our examination on codes 1-3, corresponding to prerequisites of engaged thinking.

Results

The dataset is extensive enough to provide copious analysis that can lead to several conclusions. However, as mentioned previously, the results presented here will focus on the data pertaining to the prerequisites of engaged thinking. While analysis of the interviews for each individual case revealed differences amongst participants in terms of perceived ability to think critically, interpretations of the meaning of critical thinking or engaged thinking, confidence, and awareness of (or at least willingness to discuss) use of engaged thinking, general trends did emerge.

The three codes corresponding to prerequisites for engaged thinking were heavily present in the dataset, though dispositional traits were the least identified of the three. They were often used to qualify, permit, or facilitate the use of engaged thinking. Each of the three areas will be presented more thoroughly below.

Background knowledge

The concept of background knowledge, particularly domain-specific knowledge, was identified by at least the analyst in every single interview with every single participant. Comments often related to the participant's need to have knowledge about a topic before being able to promote their thinking to engaged thinking and how the knowledge they have might affect the product of that thinking.

> Anusha, interview 3, discussing if she could work independently in the lab:
> "I probably wouldn't be comfortable with that because I really don't know anything about it. Like we're etching our sample with Nitol and stuff and there is just like, I guess things like this happen every once in a while where I kind of like definitely notice how much I don't know which is like, you know, we're up in the room with the fume hood for the Nitol and we're working with that and when we're done we have to put it in the waste bottle. But I didn't, like, there's a waste bottle for, you know, acetic acid and nitric acid,

water and some other stuff, but I don't actually even know what goes into Nitol. But my post-doc can just look at that bottle and be like, 'yeah, okay, that has three of the same things that are in this Nitol bottle so we might as well go and dump it into that waste container.' But I don't have the knowledge to like realize things like that. So it's just like I'm missing a really big body of information that I would need to work on my own in that lab."

Eric, interview 1, discussing how different people will produce different designs:
"So personally, some people would be, would create one thing, another person creates another thing, that's just because that's the information that they know personally."

Graham, interview 2, discussing the need to know the big picture before being able to understand specifics presented in the literature:
"You touch on each one and then you go back and you get a little more in depth with each one after you get the basic outline."

Kimberly, interview 1, discussing approaching problems:
"…in order to think critically you have to have some sort of background information and relate it to what you're applying to at that moment."

Mya, interview 4, explaining why she had not inquired more deeply about the content of project:
"I feel like I kind of have a pretty good grasp on the project like as far as what's going on, but like it's not that I don't really care about where it's going or why it's useful, it's that like my mind – like two months ago I didn't even know any of the words existed that I'm like, that I wrote my poster with so it's just like I suppose if I was working on it longer then I would be able to like start to care about that, but it's like my brain won't hold any more information right now."

Walter, interview 3, explaining how critical thinking is involved in planning an experiment:
"You've got to think about how exactly you're going to test, test like each individual variable. And that's kind of where the critical thinking comes in. You kind of, you've got to have a knowledge of, you know, background knowledge of, I guess, I mean, just whatever field you're working in, just that knowledge to find out how to test a specific variable."

Each of these quotes represents an instance where the participant suggests the necessity of some degree of initial domain-specific knowledge in order to conduct more engaged thinking. However, participants also emphasized a need to have personal, hands-on experiences.

Eric, interview 3, explaining ways in which engaged thinking can build knowledge:
"If you don't have the background knowledge you can just have an experience and then also learn it that way. Like I said, it's dual channel, both ways. It can go any direction."

It also appears as though the practice of applying background knowledge to solve unfamiliar

problems is strengthened by the experience of doing so during research.

> Anusha, interview 4, discussing growth in engaged thinking due to research:
> "But if you're just, you know, you're in like a lab setting and the problem comes up to you then you're like hmm, you know, you don't have any clues as to how to solve it, but you kind of have to use your own knowledge to figure that out. And so I guess the process of figuring out how to do something is something that I've developed more here than I ever would in a class."

However, the concept of needing background knowledge to perform engaged thinking posed a few challenges to the participants. In some situations, it was suggested that having background knowledge prevents engaged thinking, while at other times, participants suggested that engaged thinking may be deeper without having background knowledge.

> Kimberly, interview 1, presenting an alternate view about having background knowledge discouraging critical thought:
> "Because if you, if you already know something you're not going to want to really think critically about it"

> Eric, interview 3, discussing trying to understand an experience with an absence of background knowledge:
> "As opposed to if you just took a lab course without anything you just feel like this, you have to be like Einstein, you've got to figure out this equation on your own without knowing previous knowledge."

Of course, the potentially contradictory point exhibited by Eric could be explained by acknowledging that no situation occurs in a vacuum, and that we always will have some degree of at least general background knowledge to employ when analyzing a situation.

Dispositional traits

Dispositional traits were by far the least identified of the three prerequisites for engaged thinking. As the data presents itself, it might be more appropriate to consider dispositional traits as being factors that lower the requirements necessary to produce engaged thinking, rather than being absolute necessities. The traits that appeared most frequently pertained to persistence, curiosity, and inquisitiveness.

> Mya, interview 3, discussing the experimentation process:
> "It's a very good test on my patience sometimes… you like wait three hours to see if something worked or not and then like if it didn't work you like do this thing to it and then let it sit overnight and then see if it worked then. And then if it didn't work then you start over."

> Eric, interview 1, discussing learning in class:
> "I want to learn more so I go online and look up more information, read my own papers on my own time, um, yeah, it's not like a teacher's telling me this information, I'm using

my own time to understand more or more of the topic than I learned in class so once you do that you can formulate a better idea of it."

Other traits were mentioned throughout the interviews that suggest that having certain traits, such as being open-minded or flexible or having a strong work ethic or desire to succeed, make promotion to engaged thinking much easier. Further, while the trait of confidence was rarely explicitly discussed, the way in which each student talked about his or her project throughout the summer exhibited a perceivable growth in confidence that cannot be easily captured with a few short quotes, but nonetheless contributed to a likely increased tendency to utilize engaged thinking.

Transitional (engagement inducing) circumstance

This concept appears to be the most important factor for promotion of engaged thinking. Almost every instance in which a participant discussed the use of engaged thinking, there was a surrounding mention of something that would be considered a transitional circumstance. These circumstances include meeting constraints, wanting to achieve goals, recognition of danger, ambiguous situations, the prospect of being evaluated, the desire to improve accuracy or efficiency, and, most frequently, unexpected/unfamiliar/unique situations, being forced to do something independently or individually, difficulty or struggle, and personal importance, relevance, or interest.

Anusha, interview 4, discussing having to learn without her mentor:
"I guess that was probably one of the better learning experiences of just being left in the lab alone, you know, didn't have anyone to tell me anything for a week but I figured it out, it wasn't the biggest deal in the world, it wasn't like I needed somebody there to tell me that."

Eric, interview 2, responding to struggle while reading literature:
"I guess critically thinking we hit those points in the literature where we kind of forget or don't understand and you look it up, um, you find key words and you think back to your old coursework and you remember more detail of it or how you can relate it to, um, an unknown fact that you're trying to figure out right now."

Graham, interview 3, wanting to improve the accuracy and efficiency of his experimental design:
"I think the best way and most accurate way to test it is again just to set the model up and put the uplift float where it will be and then use these linear motion transducers to see the change, um, basically the height change in each component."

Kimberly, interview 1, explaining what inspires her to think critically:
"I think interest is very important but also wanting to, um, maybe learn something new just to, um, to broaden your education and just to learn something new so I think that's important. Because if you, if you already know something you're not going to want to really think critically about it unless you are super interested and want to improve it."

Mya, interview 3, discussing how having her goal in mind helps with assessing the appropriateness of an experimental result:
"Well, when you have like your end result in mind that you want to get eventually."

Walter, interview 1, explaining what might compel him to pursue a research topic:
"Maybe if there's, not necessarily a problem but a better way to do something, um, if it's more cost effective, easier to do, um, that could be motivation to try to, you know, find something to ah, innovate, is that right word, I guess innovate something that's already in place."

Discussion

As the results indicate, significant overlap among the prerequisites for engaged thinking exists. In several of the quotes related to background knowledge, the idea of interest, personal relevance, or ambiguity (or several others) appear to be present. The dispositional trait of curiosity or inquisitiveness tends to reduce the threshold necessary for someone to be interested in a topic. Further, the dispositional traits of persistence and work ethic are likely important due to the fact that difficult or unexpected situations produce engaged thinking. And, of course, the number of situations that would be unfamiliar or unexpected would be inversely proportional to the amount of background knowledge someone has in a given domain. This intricate web of relationships makes it somewhat difficult to truly isolate any one prerequisite for engagement, but seems to support the claim that background knowledge is a necessary, but individually insufficient condition for critical thinking.[58]

With all this in mind, there should be some clear directions that can be taken with undergraduate research programs in order to produce a greater likelihood of improving engaged thinking. The following is a set of recommendations derived from this research that could lead to stronger growth.

Increase preparation for project and communication with research student prior to arrival

The claim from the introduction that sufficient time is necessary for a research experience to significantly improve cognitive abilities[59] meshes well with the concept that some degree of background knowledge is necessary before engaged thinking can truly take place. In many cases, REU participants arrive without any previous experience and have to spend a large portion of the beginning stages of the project gaining comfort with the topic. Taking proper steps before a research participant begins a project to familiarize that participant with the vernacular of the domain area and some of the key concepts can vastly improve the amount of time the participant will be able to conduct higher level thinking on the project. This could be as simple as contacting the student a month before the program begins to provide the student with literature related to the project. Additional contact with the student to discuss the literature, provide clearer scope of research interests, and address any questions would produce greater even greater benefits.

Increase the length of the REU program or have multiple summer projects

While the previous recommendation is still strongly encouraged, lengthening the overall REU program, or extending the program to span an additional summer, would provide the participants with a more adequate amount of time to establish sufficient background knowledge to use engaged thinking in research. In nearly all of the cases studied, the first four to six weeks were

often necessary for the student to gain enough understanding to develop the confidence necessary to work independently. When asked in the final interviews what past experiences best prepared them for their research experience, multiple students specifically cited the first several weeks of their projects as providing them with the tools they needed to finish the final few weeks. This means the beginning of an REU essentially trained the student how to conduct research and provided familiarity with their research topic. When this is compounded with inevitable complications like scheduling issues or broken equipment, a 10-week program barely offers any time for the student to actually utilize their newly acquired skills and knowledge.

Reinforce research-benefitting dispositional traits and habits

While it may be difficult to alter some of the dispositional traits a research participant brings to the table, it may be possible to reinforce the more desirable traits or habits. As undergraduate students who are novice to research, the uncertainty and openness of a research project presents students with a greater degree of ambiguity and more frequent instances of potential failure than most students have experienced in the more familiar classroom setting. Helping students navigate the ambiguous terrain and explaining that pursuit of wrong paths is an expected part of the research process may reinforce an appropriate mindset of persistence. Further, being mindful of desirable qualities such as curiosity, reflectiveness, self-regulation, and confidence and explicitly encouraging and praising these qualities when noticed could significantly strengthen those tendencies.[67] Additionally, requiring purposeful reflection in reflective journals may also reinforce desirable habits.[17]

Match participants with projects based on interests

It may also be possible to cater projects more specifically to the interests of each student. As every student mentioned needing to be interested in a subject in order to use engaged thinking, finding an applicant who will be interested in a specific topic seems extremely important if we want the student to be engaged with the project.[68] Obviously there are always complications with research, but more thoughtful and careful matching of participants with a given set of interests to a particular project related to those interests may be a significant improvement. This may mean not always selecting the absolute best applicant in favor of an applicant who will be highly interested, and therefore more highly motivated to work on a specific topic than a superior candidate with no associated interests.

Involve the REU student in the planning and experimental design

Allowing a student to be involved in the design of the official research question or project design, even if they are mostly just present during this task, will help improve their interest by providing a sense of ownership over the project. This does not mean that the student would need to be involved in designing the entirety of the project or making any major decisions. As noted previously, they don't have enough background information or confidence in the subject to do so, anyway. However, if the projects are planned in advance and the student is given literature and important information before arriving to the program, they might be able to contribute to the setting a specific research question or planning some of the smaller components of their project. Even participating in the setting of small scale goals that don't affect the overall scope of the project, especially when they develop or are presented with alternative choices, can provide the student with a significantly enhanced level of motivation for the project.[69-71]

Provide appropriate levels of autonomy

It is important for a research mentor to assess a student's ability levels and provide the appropriate amount of support to allow that student to succeed. As Anusha, the youngest and least experienced participant, pointed out, there was a significant amount of knowledge and experience that she lacked that made it difficult for her to work independently in the lab. Anusha's mentor did a good job of providing her guidance when she needed it, but also allowed her to work independently on a task as soon as he recognized her ability to do so. The data suggests that when the students had their figurative hands held, they did not utilize engaged thinking, simply allowing their mentors to shoulder that weight. This suggests that with too much autonomy, a student's lack of experience and background knowledge may result in a lack of confidence and an inability to perform, while too little autonomy will dissuade the student from engaging. Thus, the exact right amount of autonomy should be given to the student in order to achieve the greatest degree of motivation toward engaged thinking.[67,71]

Conclusion

The analysis of the participants' thoughts during their summer research experience indicates that there is ample opportunity for undergraduates to develop engaged thinking during research. While previous studies suggest that there may be issues that prevent higher-level thinking in some undergraduate research, the locations of where those holes present themselves is apparent in our data. This provides us with a number of considerations when designing future undergraduate research programs.

Undergraduate research possesses significant potential for developing engaged thinking, as it exposes students to challenging, open-ended problems that often require independent thought. However, as the study suggests, students need sufficient background knowledge before beginning a project. The students then need an adequate amount of time performing the research to gain enough comfort to actually apply their new knowledge and understanding. Finally, they have to experience a circumstance that will transition their thought to engaged thinking. This can be achieved by presenting challenging tasks and through independence, and could perhaps be fabricated for the student to an extent, but may be best established through an authentic experience that meets the student's natural passions and interests.

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