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Encouraging a Growth Mindset in Engineering Students

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Dr. Megan Frary is an Associate Professor in the Micron School of Materials Science and Engineering at Boise State University. She is also a Faculty Associate for the Center for Teaching and Learning where she coordinates the Graduate Certificate in College Teaching. In the past four years, Dr. Frary has implemented a fully flipped classroom in two of her undergraduate Materials Science and Engineering courses, allowing students to be more actively engaged with course materials during her class sessions. Her recent research includes investigating the role teaching experience and interactions with pre-service elementary teachers has on how graduate students develop their professional identities. Dr. Frary is very involved in facilitating programs through the Center for Teaching and Learning at Boise State and works closely with graduate student instructors as a teaching mentor. In 2016, Dr. Frary received the ASEE Outstanding Teaching Award from the Pacific Northwest Section. In 2008, she received the Bradley Stoughton Award for Young Teachers from ASM International. Dr. Frary received her B.S. and M.S. in Materials Science and Engineering from Northwestern University and her Ph.D. in Materials Science and Engineering from the Massachusetts Institute of Technology.

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Introduction and background

The idea of "mindset" became widely known due to Dweck's 2008 book [1]. A person's mindset guides a great deal of how they approach life – and especially how one approaches education. Dweck defines two different mindsets: a "fixed mindset" and "growth mindset" [1]. Someone with a fixed mindset believes that their intelligence is fixed and unchangeable. On the other hand, someone with a growth mindset believes that their intelligence is changeable and can grow as they learn more. Most people's mindset lies along a continuum with these two mindsets at either end. In addition to other outcomes, the mindset that a person has determines how they interpret mistakes they make; while someone with a fixed mindset thinks mistakes are failures and result from their innate lack of ability, someone with a growth mindset views mistakes as opportunities to reflect and learn more.

The two different mindsets grew out of the earlier work of Dweck *et al.* who considered how children deal with failure [2, 3]. They found that students who placed more emphasis on the role of effort were more likely to persist during challenging tasks. As a result, Dweck and Legett [4] went on to describe two different forms of self-concept, one following an entity theory and the second following an incremental theory; these would later become the "fixed" and "growth" mindsets. The authors explain the implications for learning based on which self-concept an individual possesses and how that affects that individual's motivation. Understanding a person's psychological concept of self is very important when considering a person's motivation for and success in education. Several studies which use interventions based on students' psychologies, including their mindsets, have proven to be effective in affecting educational outcomes [5-9], especially in at-risk and underrepresented groups.

The literature includes few studies wherein the growth mindset has been applied in engineering settings. However, numerous papers have looked at how engineering students' motivation [10, 11] and self-efficacy [12, 13] are related to their success, retention, and/or persistence in engineering. Although having a growth mindset is different from being motivated to succeed in engineering, these studies have demonstrated that students' attitudes about their own abilities are important in their academic success. In a qualitative study of students who left engineering majors [14], the authors found that students who left shared a common feeling of not being up to the task of studying engineering and not seeing a path to success. While these authors did not explicitly consider students' mindsets, had the students who they interviewed had stronger growth mindsets, they may have persisted in engineering. Finally, Suresh [15] investigated how students' attitudes and preparation affected their persistence in engineering based on their performance in barrier courses. The author found that the "single most important factor that played a role in persistence was student determination to succeed, and to not quit when they

encountered difficulties" [15]. This was true regardless of how students performed. While the result was not attributed to students' mindsets, it clearly points to having a growth mindset as being a very important factor in persistence, more so even than measures such as high school GPA. The importance of a growth mindset in engineering students' success has recently been highlighted in the Washington State STARS program [16]. The rubric designed to assess the STARS program explicitly considers the state of a student's mindset along fixed-growth continuum using Dweck's Implicit Theories of Intelligence Questionnaire [17]. While students' mindsets are assessed, Ref. [16] does not indicate what kind of interventions are used to support students in developing more of a growth mindset.

Project overview

It is not surprising that students think that some classes are easy and that others are hard. MSE 308, Thermodynamics of Materials, falls into the latter category. Students have heard from their peers that the class is difficult and that the time commitment is high; many have also heard that the professor is supportive and is interested in helping students learn. If students have a fixed mindset, they may be at a disadvantage coming into a class that they think is going to be especially difficult because they don't think that their hard work will help them succeed. In contrast, students with a growth mindset might appreciate the learning opportunities that a well-structured but difficult class offers.

The purpose of this project was to first determine the mindset of MSE 308 students and then to determine if their mindsets can be shifted away from a fixed mindset and toward a growth mindset. There were two research questions this project sought to address based on the planned interventions, (1) will those students with a more fixed mindset adopt more of a growth mindset? and (2) will students' attitudes about their own abilities in what are perceived to be difficult classes change?

Method: participants

There were 26 students enrolled in the course in the fall of 2016. For a student following a typical four-year plan, this course is taken in the fall of the third year. The demographic characteristics of the students are summarized in Figure 1. There were 20 males and 6 females. Of the students in the course, 14 graduated from high school in 2013 or later (i.e., were, at most, three years out from high school (HS)), 4 graduated from high school in 2010 to 2012 (i.e., were 4 to 6 years out from HS), 1 graduated from high school in 2007-2009 (i.e., was 7 to 9 years out from HS), and 7 students graduated from high school in 2006 or earlier (i.e., were 10+ years out from HS). As a point of reference, in fall 2016 when the study was conducted, Boise State University had 20,209 undergraduate students enrolled (16,053 were degree-seeking), ~55% of whom were female. Of the degree-seeking undergraduates, the average age was 24.2 years old.

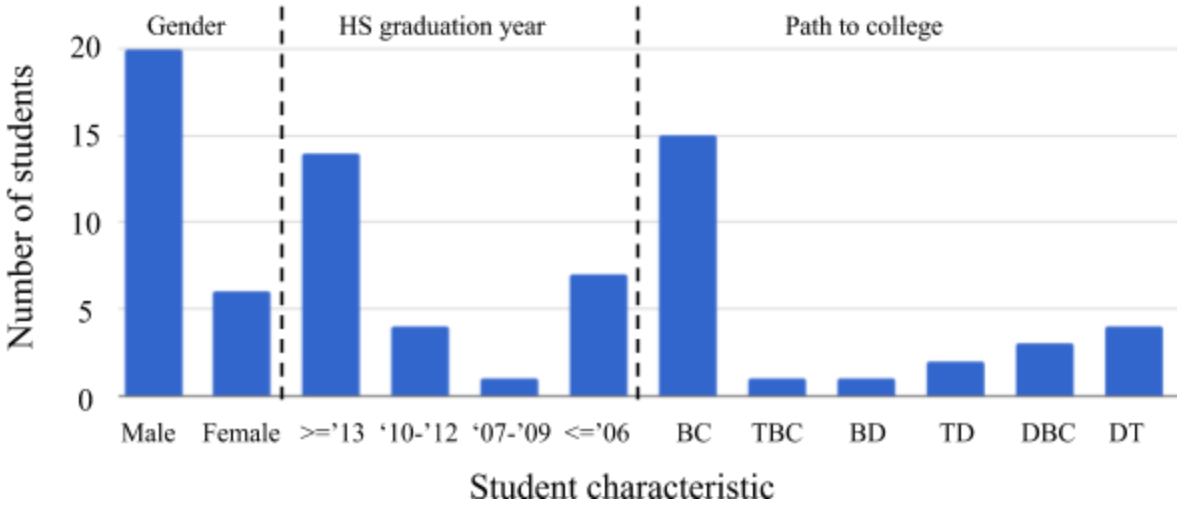

Figure 1: Demographic data for study participants

As the final piece of demographic data, students were asked to describe their path to Boise State University. Six different paths were identified and are coded in Figure 1 as follows:

- BC (Boise State University, continuous): Started college at Boise State University right after HS; have been continuously enrolled) and haven't been unenrolled since starting (N = 15)
- TBC (transferred in, continuous): Started college elsewhere right after HS; transferred to Boise State University with no more than 1 semester away from school (N = 1)
- BD (Boise State University, discontinuous): Started college at Boise State University right after HS; have taken at least one year off (N = 1)
- TD (transferred in, continuous): Started college elsewhere right after HS; enrolled at Boise State University after at least one year off (N = 2)
- DBC (delayed start, Boise State University, continuous): Didn't start college right after HS; have been enrolled at Boise State University (more or less) continuously since starting (N = 3)
- DT (delayed start, transferred in): Didn't start college right after HS; have attended at least one other college (N = 4)

Method: procedure and instruments

Students' mindsets were determined using a survey at the beginning and end of the semester (see Appendix A) which included both Likert scale questions and open-ended questions. The Likert scale questions were based on those in Ref. [18] and expanded upon Dweck's Implicit Theories of Intelligence Questionnaire [17]. The survey also asked about their perception of difficult classes and their beliefs about learning and intelligence. In order to try to affect change in students' attitudes and mindsets, we talked about brain-based learning and adopting a growth

mindset throughout the semester; students also reflected on the learning process to see that they are capable of changing their intelligence.

The following chronological list summarizes the specific activities that were completed as part of the growth mindset intervention in MSE 308:

- In the first week of class, students completed a "before" survey asking about their attitudes and current mindset. This was administered via Google forms. Students were prompted to choose an identifier (i.e., a code number or fake name) so that their "before" survey could be linked to their "after" survey, but so that they retained their anonymity.
- In the first week of class, students watched both the TED talk by Carol Dweck [19] and a Kahn Academy video on growing your mind [20]. Students talked about their main takeaways during class.
- As part of their weekly homework in week 4, students were asked, "Review the article 'Why Understanding These Four Types of Mistakes Can Help Us Learn' [21]. Write a short summary of each of the four kinds of mistakes. Which kind(s) do you make most often? Which kind do you think you are most likely to make it MSE 308?"
- As part of their weekly homework in week 9, students were asked, "Review the article 'Why a Growth Mindset is Essential For Learning' [22]. Which parts of the article resonate with you? Why? Has you approach to learning evolved in MSE 308 toward more of a growth mindset? Do you have ideas for things to try over the rest of the semester (or in future classes)?"
- As part of their weekly homework in week 13, students were asked, "Read the article 'Forget Talent' [23]. Which parts of the article resonate with you? Why? How has your approach to learning evolved in MSE 308 toward more of a growth mindset? How might you approach future classes differently given what you've learned about growth mindset this semester?"
- At the beginning of class each day, the instructor shared a growth mindset quote with the students. A few times throughout the semester, we talked about the quote and how it was related to their learning and experiences in MSE 308.
- In the last week of class, students completed an "after" survey asking about their attitudes and current mindset. This was administered using Google forms. Students were reminded to use the same identifier (i.e., code number or fake name) so that their "after" survey could be linked to their "before" survey.

In order to determine the effect of the interventions, the data analysis included a review of students' reflective writing, an analysis of their responses to open-ended survey questions, and a comparison of the numerical data from the quantitative survey questions at the beginning and end of the semester.

Findings: Changes in students' mindsets

The first research question asked, "Will those students with a more fixed mindset adopt more of a growth mindset?" The numerical data from the mindset survey were used to answer this

question. Among the survey items were a set of questions where students ranked their agreement (or disagreement) with a series of statements. Some statements represented fixed mindsets and other represented growth mindsets. On a scale from 1 (strongly agree) to 7 (strongly disagree), the average responses to each set of questions (fixed mindset and growth mindset) are shown for each individual student at the beginning and end of the semester in Figure 2.

For the data in Figure 2, it was expected that the average scores at the end of the semester for the growth mindset questions would go down (i.e., students would agree more strongly with these statements) and that the average scores for the fixed mindset statements would increase (i.e., students would disagree more strongly with these statements). Of the 26 participants, 14 showed the expected shift for growth mindset statements (i.e., they agreed more with growth mindset statements at the end of the semester) and 12 showed the expected shift for fixed mindset statements (i.e., they disagreed more with fixed mindset statements). There were 11 participants (of 26) who both agreed more with growth mindset statements and disagreed more with fixed mindset statements at the end of the semester; this is the overall shift that was expected.

Instead of looking at each set of statements separately, another way to analyze the data is to generate a composite score where a higher score represents a stronger growth mindset (see, e.g., Ref. [24]. Figure 3 shows the mindset survey data scored in this way where the strongest growth mindset would earn a score of 60. From Ref. [24], a score of >45 represents a strong growth mindset, while a score of 34 or higher represents a growth mindset with some fixed ideas. At the beginning of the semester, 8 students had strong growth mindsets and 14 more had growth

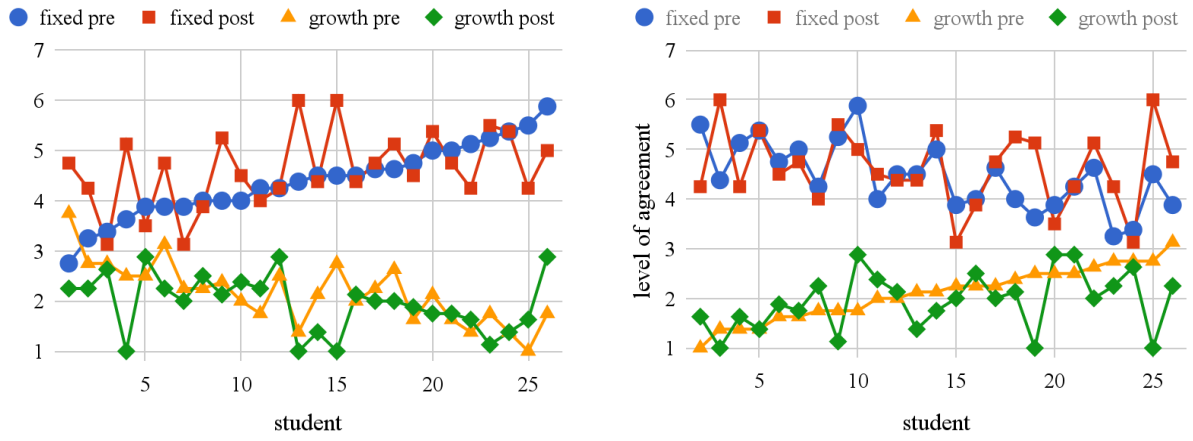

Figure 2: Student agreement with fixed and growth mindset statements at the beginning and end of the semester. The y-axis scale shows level of agreement where 1 = strongly agree, and 7 = strongly disagree. Left: responses are sorted from the most fixed mindset to the least at the beginning of the semester. Right: the same data, but responses are sorted from the most

growth mindset to the least at the beginning of the semester. The two different views make it easier to see changes in individual students' mindsets.

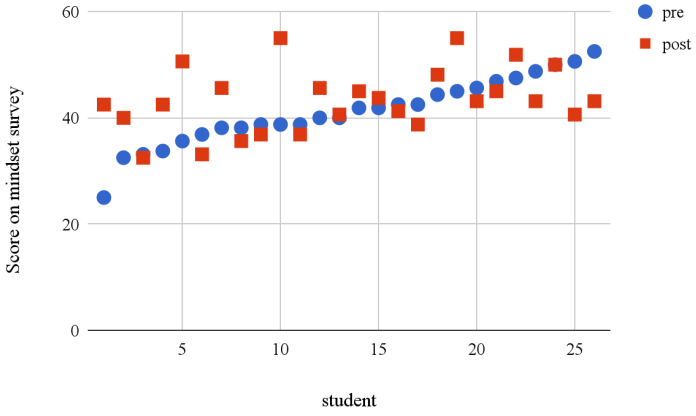

Figure 3: Composite scores from mindset survey; a maximum score of 60 represents the strongest possible growth mindset.

mindsets with some fixed ideas. At the end of the semester, 10 students had strong growth mindsets and 14 more had growth mindsets with some fixed ideas. According to this scoring methodology, one conclusion that can be drawn is that the students already had relatively strong growth mindsets to begin with.

In looking at shifts in student mindset, Table 1 summarizes how the change in a student's mindset over the semester is related to how long the student has been out of high school. While the data set is small, the impact of introducing students to and working to change their mindsets seems to be more profound for students who are have been out of high school longer. It is possible that these non-traditional students may carry with them life experiences which suggest that they don't have what it takes to succeed at an academic pursuit and therefore stand to benefit more from learning about the growth mindset.

Another way to examine changes to the students' mindsets was through their reflections regarding the readings they completed. For example, in week 9, students read the article "Why a

Table 1: Summary of how composite mindset scores changes from the beginning to the end of the semester based on when a student graduated from high school. Increases in composite score represent a shift toward a stronger growth mindset. For those where the composite score decreases, the number in parentheses indicates the number of students whose score decreased by more than 5 points (noting a strong shift as compared to a mild shift).

Graduation year	2006 or earlier	2007-2009	2010-2012	2013 or later
Composite score increased	4	1	3	5

No change in composite score	0	0	0	1
Composite score decreased	3(1)	0	1	8(2)

Growth Mindset is Essential For Learning" [22]. They reflected on which parts of the article resonated with them and how their approach to learning evolved in MSE 308 toward more of a growth mindset. Here are some excerpts from their answers which demonstrate that they are adopting more of a growth mindset and are better able to apply the principles of a growth mindset in their role as a student:

- "The changes I have been successful at making have been extremely helpful; mainly, using my mistakes and misunderstandings as opportunities for learning rather than failures."
- "I do find myself getting extremely frustrated and sometimes angry over my performance, but am getting better at trying to find solutions to fix my lack of knowledge and understanding."
- "Learning about the growth mindset has made me aware of my own fixed mindset. In previous classes when I run into a problem that takes some effort I would give up quickly. After becoming aware of growth mindset, I remember that when I run into difficulty to keep putting in the effort. I find this to be rewarding when I solve the difficult problem."
- "I believe that my approach in MSE 308 this semester has leaned a lot more toward the growth mindset since I have often chosen to take time and think about a specific problem set or activity rather than taking a shortcut and asking for the answer."

In addition, in week 13, students were asked to read 'Forget Talent' [23], then to reflect on how their approach to learning evolved in MSE 308 toward more of a growth mindset and how they might approach future classes differently given what they'd learned about growth mindset. Here are some excerpts from their answers:

- "Learning is more important to me than grades now."
- "Learning about the growth mindset in this class has been very helpful in accepting that 'failures' are just learning opportunities. I've become much more focused on learning than getting a particular grade."
- "Throughout the semester, I started feeling more optimistic about assignments even though I didn't know how to do the problems and thought that they were difficult. This made it easier to start on assignments earlier and be more motivated when working on them."
- "I plan on realizing that… it's the first time I've ever seen most of the topics and coursework, so I shouldn't be ashamed if it doesn't come as easily as other courses have. Also the more time I put into something the greater the reward and my understanding will be."

- "My mindset has evolved to think that intelligence is always changing. I am willing to spend more time working on a problem outside of class than I was when I first started this class… I have realized that I learn more when I try longer."

Again, their responses demonstrate they they are adopting new ways of approaching learning and now view mistakes as opportunities to learn rather than as failures.

Findings: Changes in students' attitudes about their abilities

The second research question asked, "Will students' attitudes about their own abilities in what are perceived to be difficult classes change?" One questions on the mindset survey asked, "In what ways do you approach a class that you think is going to be difficult differently from those you think will be easier?" (pre-semester) and "In what ways will you approach a class that you think is going to be difficult differently from those you think will be easier?" (post-semester). The main themes from the answers are summarized in Table 2. While the answers at the beginning and end of the semester are quite similar (i.e., students' approaches to hard classes weren't much changed by the experience), more students did comment about committing more effort to the course. This suggests that they are adopting more of a growth mindset because they recognize that time and effort are what is needed to learn something new.

Another survey item which was related to the first research question asked students to complete the sentence, "Intelligence is…". Of the 26 students in the course, 7 showed a marked shift toward a growth mindset in completing this statement (as shown in Table 3). Some of their pre-semester answers showed a fixed mindset, while others focused on intelligence as a process

Table 2: Summary of student responses to questions about how they have approached or will approach courses that they think are going to be difficult. The number of similar responses in is given parentheses.

Pre-semester responses	Post-semester responses

● I set aside a greater amount of time to study, complete homework, etc. (10) ● Get outside help from professors, tutoring, and peers (7) ● I organize myself better (3) ● I am more serious about it and put a lot of effort into it at the beginning of the semester. (3) ● Prioritize/start working earlier (2) ● Make a constant effort to learn material (2) ● I mentally prepare myself more. ● I treat every class like it is the most difficult one I have ever had ● The same just more reading	● Dedicate more time and effort (15) ● More preparation, prepare for every class, do every assignment well (3) ● Seek outside resources more (3) ● I assume every class I take will be the most difficult one I have ever taken (2) ● I will just look at it as a challenge that I can overcome if I just dedicate enough time. ● Organize notes better, include more detail in those notes. Maintain a tighter time management schedule. ● Prepare more for it mentally

Table 3: Selected responses to the prompt, "Intelligence is…" which demonstrate shifts toward a growth mindset.

Pre-semester	Post-semester
being able to learn easier than others.	The ability to learn.
Well rounded understanding of anything and everything.	Continuation of learning and retention of said learned stuff.
the ability to collect information, analyze and break it down.	being able to gain knowledge and learn from mistakes.
genetic.	improvable.
understanding what you don't know in order to expand your knowledge base.	can change as a person develops.
to act intelligently.	[could be] gained.
the capacity to learn new information.	flexible and capable of changing.

or as content knowledge. At the end of the semester though, these students clearly demonstrated the belief that their intelligence was changeable and was something over which they had control. Students who moved toward more of a growth mindset on this survey item were more likely to have graduated high school less recently; students who graduated high school more recently tended to either already answer this question in line with a growth mindset at the beginning of the semester or to continue to focus on intelligence as process or content.

Conclusions and Future Directions

The anecdotal evidence suggests that students learned a lot about the growth mindset and were able to apply it in MSE 308; however, the numerical data doesn't necessarily support the conclusion that learning about a growth mindset will enable all students to shift from a fixed mindset to a growth mindset. The numerical data show that 50% of students shifted to a stronger growth mindset. One interesting outcome of the study is that many students' mindsets were already either in the category of "strong growth mindset" or "growth mindset with some fixed ideas" at the beginning of the semester. Despite this, the explicit introduction to the idea of a growth mindset was likely helpful even to students who may have inherently held such a mindset without knowing they did so.

Regarding students' attitudes toward difficult courses, the intervention in the study resulted in students using more growth mindset language when talking about their approaches to difficult courses. Furthermore, at the end of the semester, there was a marked shift with more students describing "intelligence" through a growth mindset lens instead of a fixed mindset one.

The results of this study suggest several different paths forward. To begin, it would be helpful to introduce students explicitly to the growth mindset at an early point in their academic career and to continue to reinforce the principles of this mindset throughout a student's college career. Although this study introduced the mindsets in an academic setting, these mindsets are applicable in all areas of life and learning. Even if interventions such as the one in this study don't affect all students' mindsets, there are still many students for whom learning about growth mindset will make a difference. In order to more robustly investigate the question of shifting mindsets, it would be necessary to carry out the study on a larger sample of students. It would also be helpful to administer the survey to a similar group of students who did not receive the intervention. Based on the lack of literature about the growth mindset in engineering curricula, this area of study has much potential.

Appendix A: MINDSET SURVEY

Attitudes about difficult classes and learning

1. What have you heard about the difficulty of MSE 308?
    a. It's really hard
    b. It's kind of hard
    c. It's not too hard
    d. It's not hard at all

2. What have you heard about the time commitment involved with MSE 308?
    a. It takes a ton of time
    b. It takes a lot of time
    c. It takes a moderate amount of time
    d. It is not too time intensive

3. What else have you heard about MSE 308? (short answer)

4. What are you expectations for your learning in MSE 308? (short answer)

5. How have you done in hard classes before?
    a. Better than I expected to
    b. As I expected to
    c. Worse than I had hoped to

6. In what ways do you approach a class that you think is going to be difficult differently from those you think will be easier? (short answer)

7. Complete this sentence, "Intelligence is…" (short answer)

8. Complete this sentence, "Learning is…" (short answer)

9. What are you most proud of? (short answer)

Mindset questions

The following questions use a Likert scale from 1 (strongly agree) to 7 (strongly disagree).

1. Your intelligence is something very basic about you that you can't change very much.
2. No matter how much intelligence you have, you can always change it quite a bit.
3. You can always substantially change how intelligent you are.
4. Music talent can be learned by anyone.
5. Only a few people will be truly good at sports – you have to be "born with it."
6. Math is much easier to learn if you are male or maybe come from a culture who values math.
7. The harder you work at something, the better you will be at it.
8. Trying new things is stressful for me and I avoid it.
9. I appreciate when parents, coaches, teachers give me feedback about my performance.
10. I often get angry when I get feedback about my performance.
11. All human beings without a brain injury or birth defect are capable of the same amount of learning.
12. You can learn new things, but you can't really change how intelligent you are.
13. An important reason why I do my school work is that I like to learn new things.
14. Truly smart people do not need to try hard.
15. To tell the truth, when I work hard, it makes me feel as though I'm not very smart.
16. I like work that I'll learn from even if I make a lot of mistakes.

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