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Measurements Of Adaptive Expertise Among Low-Income STEM Students

Dr. Alexander John De Rosa,

Alexander De Rosa is an Associate Professor in Mechanical Engineering at The University of Delaware. He gained his Ph.D. in Mechanical Engineering from The Pennsylvania State University in 2015 and his M.Eng. in Mechanical Engineering from Imperial College London in 2010. Dr. De Rosa is currently working in the areas of deeper learning and knowledge transfer, and has published various articles in the field of spatial skills training and assessment.

Dr. Maxine Fontaine, Stevens Institute of Technology (School of Engineering and Science)

Maxine Fontaine is a Teaching Associate Professor in Mechanical Engineering at Stevens Institute of Technology. She received her Ph.D. in 2010 from Aalborg University in Aalborg, Denmark. Maxine has a background in the biomechanics of human movement, and she currently teaches several undergraduate courses in engineering mechanics. Her research interests are focused on improving engineering pedagogy and increasing diversity in engineering.

Dr. Frank T Fisher, Stevens Institute of Technology (School of Engineering and Science)

Frank T. Fisher is a Professor of Mechanical Engineering at Stevens Institute of Technology, where he served as the Interim Department Director / Department Chair from April 2013 to August 2018. He earned BS degrees in Mechanical Engineering and Applied Mathematics from the University of Pittsburgh, and Masters degrees in Mechanical Engineering and Learning Sciences (School of Education and Social Policy) and a Ph.D. in Mechanical Engineering from Northwestern. His research interests include characterization of multifunctional nano-reinforced polymer systems, multiscale modeling of nanocomposites and materials, vibration energy harvesting/scavenging, and engineering pedagogy and instructional technologies. Awards that he has received include the NSF CAREER award, the 2016 Alexander Crombie Humphreys Distinguished Teaching Associate Professor award (Stevens), the 2014 Distinguished Faculty Mentor Award from the Stevens Student Government Association, the 2009 ASEE Mechanics Division Outstanding New Educator Award, and the 2009 Outstanding Teacher Award from the Stevens Alumni Association.

Dr. Ashley Lytle

Ashley Lytle is an Assistant Professor of Psychology at Stevens Institute of Technology in Hoboken, New Jersey, USA. Lytle earned her PhD at Stony Brook University, New York, USA. Her research explores how prejudice, discrimination, and stereotyping impact academic, social, and health outcomes among marginalized groups. Much of her research has focused on better understanding prejudice toward older adults, sexual minorities, and women, with the goal of creating simple, yet effective, interventions to reduce prejudice.

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Abstract

One of the goals of undergraduate education is to prepare students to adapt to a challenging career that requires continual learning and application of knowledge. Working professionals should have deep conceptual knowledge that they can apply in a range of contexts and possess the attitudes and skills of lifelong learners. The literature suggests the concept of Adaptive Expertise (AE), which can be defined as the ability to apply and extend knowledge and skills to new situations, describes some of these characteristics. Survey data concerning the level of AE displayed by various populations is extremely limited in most contexts, be it education or working professionals. As such, data concerning the level of adaptiveness displayed among various groups needs to be measured if activities designed to promote the development of AE are to be created and then tested in terms of their efficacy. This investigation provides this critical baseline data for future studies as we track the AE development of individual, first-year college students through their undergraduate program of study, with a focus on low-income students as a means to support retention.

In this work, we assessed adaptive expertise among low-income STEM students using surveys and interviews. Low-income STEM students from various stages of their four year undergraduate program (n=208) completed an adaptive expertise survey in spring 2022. Following the survey, 24 of the low-income students (6 per year, 3 male, 3 female) were selected for targeted qualitative interviews to better understand the differences displayed by low and high AE students. Survey results from prior studies were used to draw comparisons between adaptiveness of low-income and non-low-income students.

Results of the AE survey indicated no statistically-significant differences between low-income and non-low-income first-year students in terms of their level of adaptiveness. In addition, the level of AE displayed by low-income students increased through the program in a manner similar to that of non-low-income STEM students. Themes that emerged from the interviews included a general understanding of the importance and likelihood of learning new concepts continually while working in a professional role, and that students expressed growth in understanding the acceptance of reaching out for assistance from other students and faculty after exploring information on their own as they work through challenges in their academic assignments. Two dominant and divergent metacognitive processes were also observed: teaching/explaining concepts to others (highly adaptive) or primarily relying on exam/course grades for feedback on learning (low adaptiveness). Data gathered from interviews demonstrate the need for a greater emphasis on metacognitive practice to promote various aspects of AE.

Introduction

Modern developments in professional practice require that graduating engineers be “T-shaped” individuals with a depth of technical expertise that they can apply across a range of contexts in their careers [1,2]. As such, the goals of undergraduate education need to shift to not only teach students the knowledge and skills they will need for their careers but also how to apply them more broadly [3]. The concept of adaptive expertise as defined here addresses many of these professional characteristics that are required of the current generation of graduating engineers.

Adaptive expertise (AE) refers to the ability to apply or expand knowledge and skills into new contexts [4,5]. This differs from routine expertise which describes someone with a deep and accessible subject knowledge of their field [6] but who may struggle to apply their expertise more broadly and in different contexts. A seminal work describing these differences between AE and routine expertise was provided by [5] in which two expert historians were studied and the characteristics of adaptive expertise identified.

Based on a contemporary literature review, four characteristics of an adaptive expert were identified by Fisher and Peterson in 2001 [7]. These four identified constructs of adaptiveness were used to develop a framework for the assessment of AE: (1) multiple perspectives, (2) metacognition, (3) goals and beliefs, and (4) epistemology. An important distinction here is that the authors of this framework were careful to describe AE in a manner that excluded other dispositions such as innovativeness or self-confidence that are also desirable attributes of engineering graduates. This distinction was based on the fact that AE was considered to be a cognitive approach and a “way of thinking” that was distinct from these other individual characteristics. While someone who is adaptive might display more creative or innovative tendencies, one does not necessarily need to be particularly creative or innovative to be adaptive in a manner consistent with this original AE framework. Using their defined framework for AE, Fisher and Peterson then developed and tested a 42-item survey tool that has been used to measure AE in various student and other groups [7]. A recent review of the literature surrounding adaptive expertise further describes this construct, as well as implementations of this survey and other exercises designed to improve student adaptiveness [8].

As motivation, low-income students at Stevens Institute of Technology, a private, STEM-focused school, are being recruited into a new scholars program aimed at providing targeted support to improve the retention and success of this population. Interventions based around the concept of adaptive expertise (AE) are being developed to support these scholars and as such, baseline data concerning the levels of AE displayed by various student populations are required for comparisons to be made and the effectiveness of this program evaluated.

Methods

At Stevens, as a part of a required sequential first-year writing course, all first-year students are required to participate in human subjects research. Alternative assignments are available to those who wish to opt out of participating in research studies, although only a small percentage (~2%) of students select this option. In Spring 2022, an adaptive expertise survey developed by Fisher & Peterson [7] (see Appendix 1 for survey items) was listed as one of the research studies in the subject pool. A total of n=208 low-income first, second, third, and fourth-year STEM students completed the AE survey, where low-income is defined by the Stevens Office of Financial Aid. Participant demographics for the low-income student survey population (such as gender, age, and race/ethnicity) are provided in Tables 1 and 2. For racial and ethnic identity, students were able to select more than one identity, thus the numbers do not add up to 100%.

Table 1: Low-Income Student AE Survey Demographics

Category	Completed AE Survey	Total Number in class
First-year low-income students	49	201
Second-year low-income students	58	122
Third-year low-income students	61	133
4+ years low-income students	40	340
Total number of low-income UG students	**208**	**796**

Table 2: Demographic breakdown of survey participants

Men	Women	Non-binary	White	Asian	Black / African American	American Indian or Alaska Native	Native Hawaiian or Pacific Islander	Spanish, Hispanic, or Latino
118	88	2	120	72	11	1	2	49

The adaptive expertise survey delivered to these students (see Appendix 1) includes both positively and negatively worded items and participants respond using a 6-point Likert scale ranging from 1 (*strongly disagree*) to 6 (*strongly agree*). Negatively worded items are reverse coded, thus a lower score on the AE measure reflects an individual with higher levels of adaptiveness. There are four subscales on the AE survey:

1. Multiple Perspectives (MP) - approaching problems flexibly, using multiple representations, staying open to alternative solutions
2. Metacognition (META) - monitoring and evaluating progress in learning and understanding
3. Goals and Beliefs (GB) - comfort in facing difficult and challenging tasks, persistence
4. Epistemology (EPIST) - the nature, origin, and scope of knowledge

Sample items for MP include: “When I consider a problem, I like to see how many different ways I can look at it” and “For a new situation, I consider a variety of approaches until one emerges superior.” Sample items for META include: “I often try to monitor my understanding of the problem” and “As I work, I ask myself how I am doing and seek out appropriate feedback.” Sample items for GB include: “Challenge stimulates me” and “Expertise can be developed through hard work.” Sample items for EPIST include: “Scientists are always revising their view of the world around them” and “Scientific theory slowly develops as ideas are analyzed and debated.” The survey was delivered using Qualtrics and incentivized using a gift card raffle to increase participation rates.

Based on the results of the survey, an interview protocol was developed to be used to complement the AE survey and to follow-up on specific areas of AE. Twenty-four low-income STEM students who had completed the AE survey and indicated potential interest in follow-up activities were chosen for a one hour scripted interview. Of these 24 students, 3 men and 3 women were chosen from each year of study (first-year, sophomore, junior, and senior class, as of Spring 2022) and compensated $50 for their time. The interviews were conducted via Zoom and transcribed via the software’s transcription feature with the resulting transcripts then being reviewed and edited for accuracy. Each session started with an introduction to the interview, as well as its purpose and IRB requirements. Students were then asked to provide some background information, as well as to talk about their professional aspirations and the context of knowledge in their field of study. Several questions concerning student perspectives of the different aspects of AE in the context of their academic work and future goals along the four constructs of AE were then covered. Time permitting, additional, optional scripted questions were used to fill out the 1 hour session and to examine other potential areas of interest. Examples of these question topics included: STEM role models, advice for other students, area of largest personal academic growth, recommended changes to the UG program, etc.

The student responses to the following three interview questions which assessed as described below: 1) epistemology; 2) metacognitive self-assessment, and 3) goals and beliefs are still being analyzed for this study:

1. Epistemology - How often do you think professionals in your field need to learn something new as part of their job? How do they do this?
2. Metacognitive self-assessment - How do you determine if you understand a particularly difficult concept covered in class?
3. Goals & Beliefs - When you struggle with a challenging problem in your class, what process do you use to get through those challenges? How do you feel when doing this?

Results & Discussion

Surveys

Table 3 breaks down the results of the AE survey by gender and details overall AE scores as well as scores in each of the four dimensions of AE for low income STEM students. These results indicate that women scored significantly higher than men on metacognition (META) with significant differences by gender not being observed in any other category. These findings are also illustrated graphically in Figure 1.

Table 3: AE data Comparing low-income men (n=118) to women (n=88) students

	Men (n=118)		**Women (n=88)**		**T-test**	
	Mean	**SD**	**Mean**	**SD**	**T-test**	**p-value**
MP	3.9562	0.59144	4.0238	0.55794	-0.830	0.407
META	4.3051	0.61534	4.4848	0.61948	-2.068	0.040
GB	4.0717	0.9718	3.9668	0.51698	1.320	0.188
EPIST	4.5277	0.59056	4.6187	0.55767	-1.121	0.264
AE (Overall)	4.1991	0.46117	4.2424	0.39915	-0.707	0.481

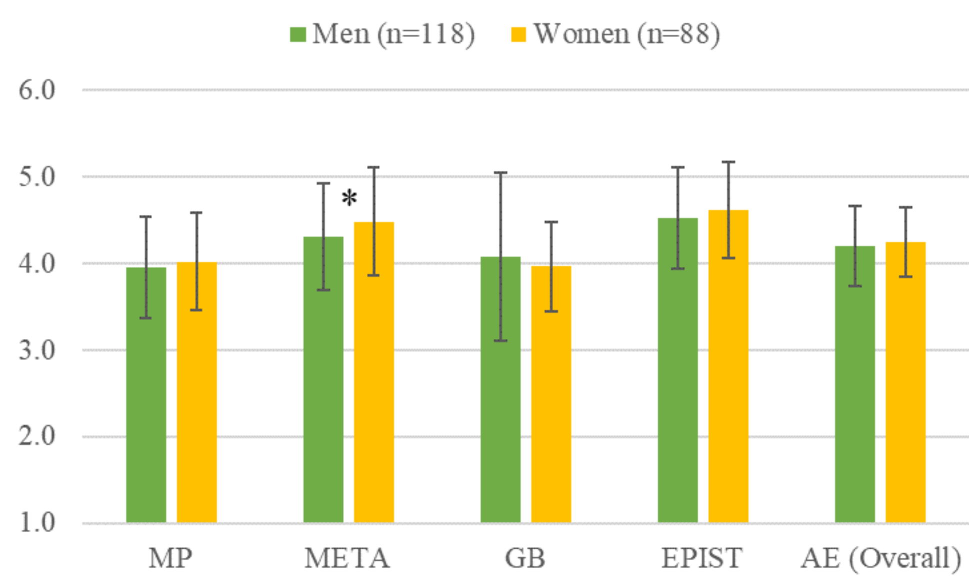

Figure 2: Graphical comparison of AE scores of low-income men and women

The fact that women only outscored men in the category of metacognition differs from the results found in past work [9], where women scored higher in both metacognition (META) and epistemology (EPIST), while men outscored women in goals and beliefs (GB). The differences in this case can potentially be attributed to the various factors such as smaller sample size here, and the fact that the original data included non-low income and low income, STEM and non-STEM students, but only first-year students in the survey population.

Table 4 examines the differences in AE scores between the first-year low-income student population in this study and the general first-year student population examined in the larger, prior study in 2021 [9]. No significant differences were observed in any of the AE subscales or the AE overall score when these groups of students were compared, suggesting that low-income students at Stevens enter their program of study with the same levels of adaptiveness as their peers. In the prior study [9] however, low-income students were found to have statistically lower scores for the EPIST subscale than their non-low-income counterparts. This discrepancy may be attributed to the smaller sample size of this study and will be monitored further in future work.

Table 5 compares data for low-income students by college year. As these low-income students progress through their academic studies, significant differences (p-value ≤ 0.05, colored cells in Table 5) are observed in three AE subscales (MP, META, GB) and overall AE. No significant differences were observed in the EPIST subscale. The data presented in Table 5 is also shown graphically in Figure 2. An emerging research question based on these results relates to the retention of low-income students in their program and whether the data collected here is skewed by survivor bias, where students scoring lower in adaptiveness are not being retained through graduation. This question will be studied as we further track individual students through their undergraduate studies.

Table 4: AE data comparing first-year low-income vs. first-year non low-income students

	First Year Non-Low-Income (n=571)		**First-Year Low Income (n=49)**		**T-test**	
	Mean	**SD**	**Mean**	**SD**	**t-value**	**p-value**
MP	3.9102	0.55851	3.8367	0.52519	0.888	0.375
META	4.2497	0.60702	4.2698	0.58090	-0.224	0.823
GB	3.9443	0.55912	3.9576	0.52338	-0.161	0.872
EPIST	4.415	0.59344	4.4490	0.59618	-0.384	0.701
AE (overall)	4.1079	0.44545	4.1074	0.35817	0.009	0.993

Table 5: AE data for low-income STEM students by college year (n=208)

	First Year (n=49)	Second Year (n=58)	Third Year (n=61)	Fourth and Fifth Year (n=40)	Oneway ANOVA	
	Mean	**Mean**	**Mean**	**Mean**	**F-value**	**p-value**
MP	3.8367	3.8875	4.0641	4.2094	4.445	0.005
META	4.2698	4.2893	4.3934	4.6027	3.754	0.012
GB	3.9576	3.8820	4.0744	4.2984	3.876	0.010
EPIST	4.4490	4.5429	4.6685	4.6027	1.421	0.238
AE (overall)	4.1074	4.1254	4.2763	4.4113	5.282	0.002

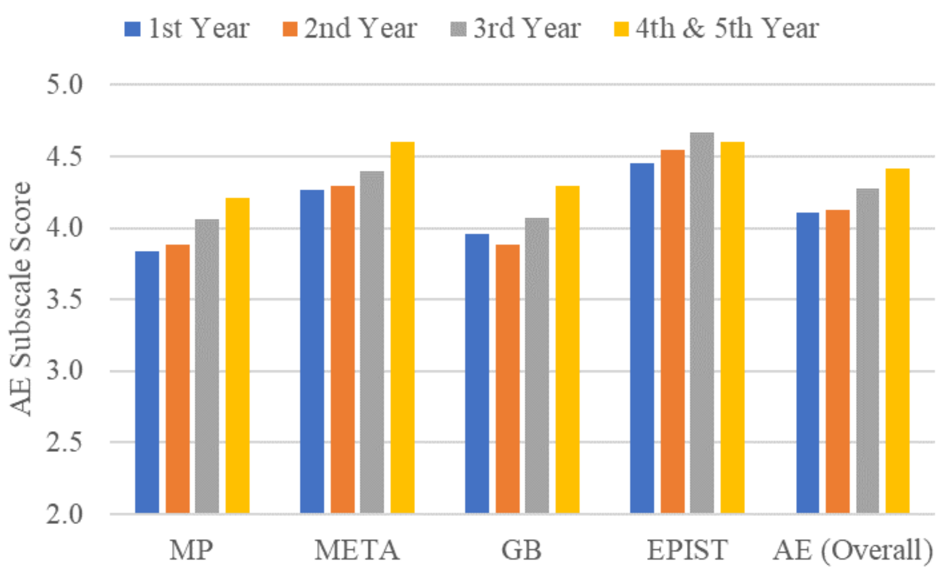

Figure 2: Graphical representation of low-income student AE scores by year of study

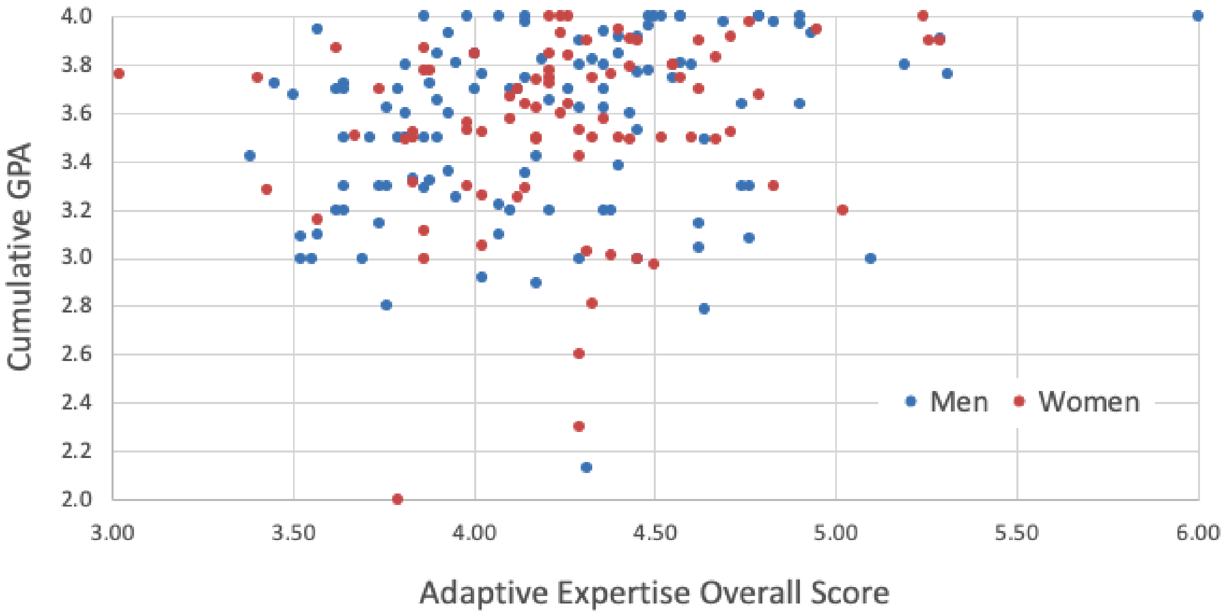

Figure 3: Cumulative GPA versus Overall Adaptive Expertise Survey Score

As can be seen in Figure 3, no correlations were observed between a student's overall AE score and their cumulative GPA. Trends for men and women did not vary in this regard. While further work is needed to examine this result, it is entirely possible, and logical, that GPA is not a predictor of adaptiveness. In the majority of college programs, the traits of AE are neither explicitly taught or assessed and as such, we might not expect GPA and AE to be correlated. Work in the field of psychology has also found little to link GPA to innovative ability [10] - a potential proxy for AE [11]. More recent work in this field has also suggested a negative correlation i.e. lower GPA is tied to greater use of innovative thinking [10]. It is also possible that the students examined in this study are biased towards higher achieving students who are not as innovative given the selectiveness of the institution at which this study was implemented.

Figure 4 details the results in terms of the development of AE throughout a student's course of study and compares this data to results from the original AE survey work of Fisher and Peterson [7] and prior AE survey work at Stevens [9]. In the majority of subscales, an overall increase in the levels of AE is seen as students progress through the program. The highest recorded AE levels in Figure 4 are those among biomedical engineering (BME) faculty in the Fisher & Petersons 2001 study [7].

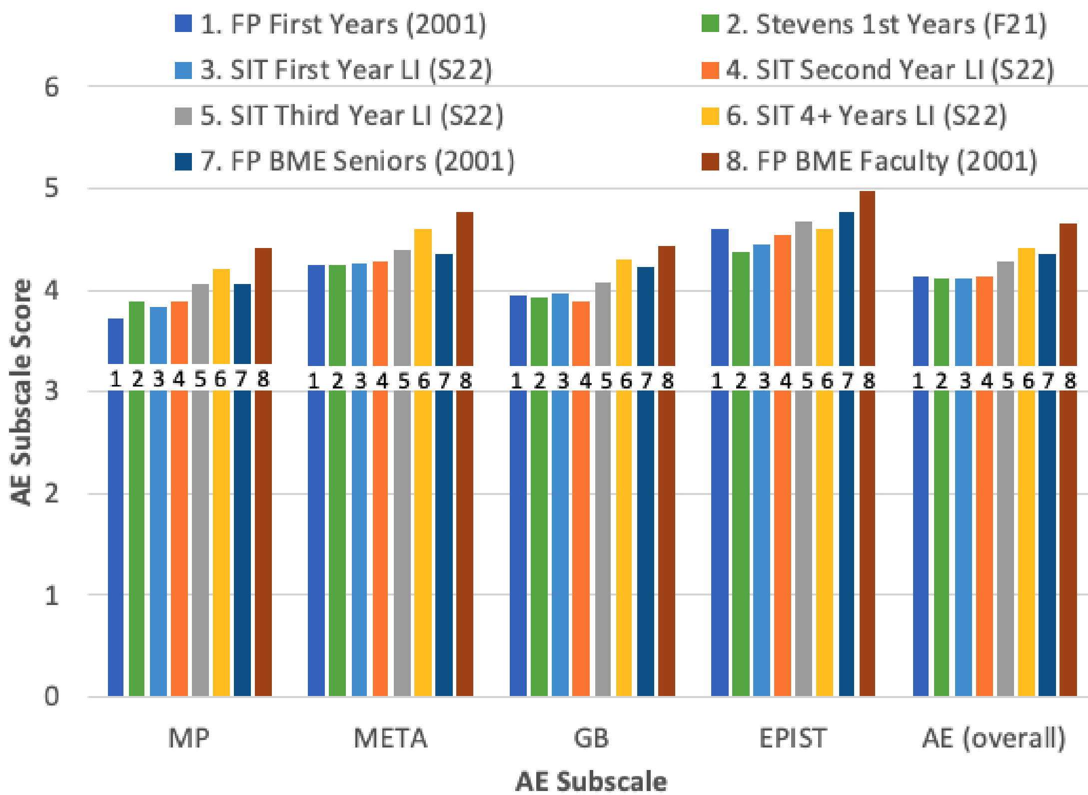

Figure 4: Comparison of AE scores from multiple studies [7, 9]

Interviews

Initially, a selection of interview questions from the larger protocol in the AE constructs of Epistemology, Metacognitive Self-Assessment and Goals and Beliefs were identified for initial analysis:

1. Epistemology - How often do you think professionals in your field need to learn something new as part of their job? How do they do this?
2. Metacognitive Self-assessment - How do you determine if you understand a particularly difficult concept covered in class?
3. Goals and Beliefs - When you are struggling with a challenging problem/project in your class, what is the process you use to get through those challenges? How do you feel when doing this?

Early emerging themes related to the interview question analysis include a general understanding of the importance and likelihood of learning new concepts continually while working in a professional role. Students expressed growth in understanding the acceptance of reaching out for assistance from other students and faculty after exploring information on their own as they work through challenges in their academic assignments. In addition, there were several unexpected observations during the analysis of the survey data and interview responses.

Responses to questions based on the concept of metacognitive self-assessment were particularly interesting. First, several students described homework as a critical aspect of their metacognitive evaluation of learning in a course, which raises questions about how courses with minimal, ungraded, or optional homework may impact student performance. Second, and unprompted by the question, a significant number of students (10/24) described "successfully being able to teach their peers" as a metacognitive strategy to gauge their own understanding of the material. These were two dominant and divergent metacognitive processes observed during the interviews: a) teaching/explaining concepts to others, which is highly adaptive, or b) relying on exam/course grades for feedback, which aligns with low adaptiveness. Interestingly, there was no overlap between students who described using one of these two approaches. Finally, a few students from programming-heavy programs (i.e. computer science or software engineering) mentioned the ease with which they can optimize code to gauge their understanding. Other students from engineering-related programs discussed their ability to practice concepts learned and use them to measure their understanding. These alternative approaches suggest that some metacognitive practices may be more accessible or relevant based on a student's major/field of study. These observations demonstrate the value of the interview protocol, which provides a richer picture of how adaptive expertise may impact undergraduate STEM education.

Future Work

The current study and past study at Stevens [9] have provided critical baseline information concerning the levels of AE displayed by various student populations throughout their course of study. Future work will continue to expand this data collection particularly as we follow several low-income scholars through their undergraduate education. The question of survivor bias raised in this work (AE levels increasing as students move through their program of study) will also be examined further, as well as complete analysis of the interview data collected using the protocol described in this work. The impact of professional experiences (internships, co-ops) on adaptiveness also remains to be analyzed. Several other, overarching questions to be examined in future work include the following: Does adaptive expertise help students in the classroom? Does it promote retention? How do students naturally develop AE? Can this process be taught or nurtured?

Conclusions

Baseline data detailing the levels of adaptive expertise (AE) displayed by various student populations was collected at Stevens Institute of Technology. Particular attention was paid to comparisons between the general STEM student population and a subset of this group:

low-income students. In fall 2021, an adaptive expertise survey was delivered to a large group of first-year STEM students [9]. In spring 2022, the survey was delivered to low-income STEM students in particular, but not limited to first-year students. Low income STEM students in their first through fourth year of study were included. A subset of the low-income students who responded to the survey were then selected to take part in an adaptive expertise interview designed to further examine student perceptions of AE and its relevance to their program of study.

Results of the AE survey indicated no statistically significant differences between low-income and non-low-income first-year students. Additionally, the levels of AE displayed by low-income students developed across all four years of the undergraduate program in a manner similar to all STEM students. Importantly, the results of our current and past work [9] provide critical baseline data for future research as we track the AE development of individual students throughout their undergraduate studies in STEM fields.

A key finding as discovered in the qualitative data from the student interviews, though perhaps unsurprising, is that it appears different majors may provide different metacognitive opportunities for students in that course of study. In particular students made references to differences in the context of programming and design and the opportunities for self-reflection grounded in these activities. The rich qualitative data derived from the interview protocol developed and tested in this study will allow us to better understand adaptiveness and the perceived importance of adaptiveness among students. In addition, the creation of an interview protocol will help foster conversations about educational behaviors and career expectations with a diverse array of undergraduate students.

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Appendix 1

Survey administered using a six-point Likert scale with the order of items scrambled. Note that items marked (*) and in italics denote “negative” items where “strongly disagree” would correspond to the characteristics of an adaptive learner.

Table A1. Fisher-Peterson (2001) Adaptive Expertise (AE) Survey items grouped by construct.

Item	Survey Item
	Multiple Perspectives
1	I create several models of an engineering problem to see which one I like best.
2	When I consider a problem, I like to see how many different ways I can look at it.
3*	*Usually there is one correct method in which to represent a problem.*
4*	*I tend to focus on a particular model in which to solve a problem.*
5	I am open to changing my mind when confronted with an alternative viewpoint.
6*	*I rarely consider other ideas after I have found the best answer.*
7*	*I find additional ideas burdensome after I have found a way to solve the problem.*
8	For a new situation, I consider a variety of approaches until one emerges superior.
9*	*I solve all related problems in the same manner.*
10*	*When I solve a new problem, I always try to use the same approach.*
11*	*There is one best way to approach a problem.*
	Metacognitive Self-Assessment
12	As I learn, I question my understanding of the new information.
13	I often try to monitor my understanding of the problem.
14*	*As a student, I cannot evaluate my own understanding of new material.*
15*	*I rarely monitor my own understanding while learning something new.*
16	When I know the material, I recognize areas where my understanding is incomplete.
17*	*I have difficulty in determining how well I understand a topic.*
18	I monitor my performance on a task.
19	As I work, I ask myself how I am doing and seek out appropriate feedback.
20*	*I seldom evaluate my performance on a task.*
	Goals & Beliefs
21	Challenge stimulates me.
22*	*I feel uncomfortable when I cannot solve difficult problems.*
23*	*I am afraid to try tasks that I do not think I will do well.*
24*	*Although I hate to admit it, I would rather do well in a class than learn a lot.*
25	One can increase their level of expertise in any area if they are willing to try.
26	Expertise can be developed through hard work.
27*	*To become an expert in engineering, you must have an innate talent for engineering.*
28*	*Experts in engineering are born with a natural talent for their field.*
29*	*Experts are born, not made.*
30	Even if frustrated when working on a difficult problem, I can push on.
31*	*I feel uncomfortable when unsure if I am doing a problem the right way.*
32	Poorly completing a project is not a sign of a lack of intelligence.
33*	*When I struggle, I wonder if I have the intelligence to succeed in engineering.*
	Epistemology
34	Knowledge that exists today may be replaced with a new understanding tomorrow.
35	Scientists are always revising their view of the world around them.
36*	*Most knowledge that exists in the world today will not change.*
37*	*Facts that are taught to me in class must be true.*
38*	*Existing knowledge in the world seldom changes.*
39	Scientific theory slowly develops as ideas are analyzed and debated.
40	Scientific knowledge is developed by a community of researchers.
41*	*Scientific knowledge is discovered by individuals.*
42*	*Progress in science is due mainly to the work of sole individuals.*