2018 ASEE Annual Conference & Exposition
June 24-27, 2018
Salt Palace Convention Center
Salt Lake City, UT

Paper ID #23334

Adaptive Expertise: The Development of a Measurement Instrument

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Adaptive Expertise: The Development of a Measurement Instrument

Introduction:

In this research paper, we discuss the development of an adaptive expertise survey instrument. The recent development of the National Academy of Engineering's Global Grand Challenges for Engineering and the United Nations' Sustainable Development Goals highlight the need to revolutionize engineering education to prepare next generation workforce capable of addressing increasingly complex and "wicked" problems facing humanity today [1]-[3]. Rittel and Webber originally defined "wicked problems" as complex, open-ended, and ill-structured challenges with societal, economic, cultural, and political implications [4]. These are problems that cannot be solved using a habitual in engineering technical-rational approach [5] that is based on theory and best empirical evidence, or through the use of routine expertise that relies on extensive domain-specific knowledge and experience. Rather, these are problems that must be addressed through adaptive expertise, defined as the ability to apply prior knowledge to new ill-defined situations with flexibility and imagination [3], [6]-[10].

As well, the increasing complexity of work environments – due both to higher task variety and volatility, and to higher levels of required knowledge [11] – makes the development of adaptive expertise an urgent priority for today's post-secondary students, particularly engineering students (e.g., [9]-[10]). Static subject expertise is no longer sufficient for a successful career, if it ever was. Current students will need to be employees who can take their subject expertise and apply it in novel ways: invent new procedures, solve novel problems, and/or combine their insights with those of other fields [11] - [14]. Moreover, rapid technological change and economic shifts have made the ability to respond quickly to new work requirements and environments vital: workers who perform as novices when faced with change are not as competitive as those who are able to quickly transfer existing expertise [15].

Developing adaptive expertise in engineering students, therefore, is of increasing importance as we strive to educate lifelong learners who can address increasingly complex problems and respond to changes in their disciplinary field by flexibly applying their theoretical knowledge and prior experience to new situations [16] - [18]. Beyond engineering education, scholars and practitioners in medical education, teacher training and human resources development have been proposing and evaluating interventions designed to foster adaptive expertise as a part of efforts to revise curricula and training programs for learners who are increasingly viewed as "autonomous, reflective, active agents in their education, developing competencies that will lead them to lifelong learning" [19].

To understand the extent to which different curricular and educational practices meet this aim, a means of measuring the performance of this complex cognitive skill is necessary. In this paper, we introduce a revised Adaptive Expertise survey, building on Fisher and Peterson's 42-item scale [20]. Our 13-item instrument reflects advances in adaptive expertise research from both the learning sciences and human resources literatures and has been developed through cognitive interviews, pilot testing, and exploratory factor analysis. We propose three sub-scales for capturing adaptive expertise: Domain Agility, Self-Assessed Innovative Practice, and Orientation to Innovation. It is our hope that this instrument will further the conversation about methodological approaches to measuring adaptive expertise and offer scholars a core set of questions useful for adaptation to their specific contexts and research questions.

Current Understandings of Adaptive Expertise & Existing Measures

Hatano and Inagaki's ground-breaking work to distinguish adaptive and routine expertise presented a typology of the environments in which each is most advantageous: in stable, predictable environments, routine expertise is efficient; in complex, changing environments, however, effective workers must be able to move beyond the application of standard operating procedures to solve problems by applying conceptual knowledge and skills to novel situations [7]. Hatano and colleagues theorized that adaptive expertise could be distinguished through both the capacity to modify approaches to a task (in response to shifting requirements, goals, and circumstances) and through the ability to explain the underlying principles guiding an approach to a task [7], [8]. As Anthony *et al*., explain, the pursuit of adaptive expertise is the pursuit of knowledge of "why and under which conditions certain approaches have to be used or new approaches have to be devised" [21].

Given the increasing focus on preparing students to thrive in complex environments, learning scientists, educators and human resources scholars have been focusing on interventions which would enable learners to acquire adaptive expertise. In engineering education most of these interventions stem from bioengineering and related fields (e.g., [20], [23]-[24]) and have been focused on design-based educational environments (e.g., [25], [26]), challenge-based instruction (e.g., [23], [27]), and How People Learn (HPL) Star Legacy pedagogy [29]. Associated with these efforts are attempts to develop different approaches to measuring adaptive expertise at different scales and across different contexts [30]. These processes of theoretical development and measurement design have progressed together as scholars debate both theories of adaptive expertise, and how they can clearly and rigorously identify adaptive expertise in practice.

Evaluations of adaptive expertise have taken several approaches: the direct observation of the performance of adaptive expertise, either in authentic or laboratory conditions; interview and reflection protocols designed to elicit self-reports about responses to complex environments; and survey instruments, in which respondents rate their agreement with statements pertaining to either attributes related to adaptive expertise or the prevalence of actions characteristic of the performance of adaptive expertise [9].

Across all of these studies, different sub-components of adaptive expertise have emerged. While there is broad consensus that adaptive expertise is built on top of subject expertise (e.g., [11], [20]-[22]), there is significant variety amongst descriptions of the additional attributes. Bohle Carbonell *et al*. suggest that these attributes can be divided into metacognitive skills and other cognitive skills and abilities, including "flexibility, ability to innovate, continuous learning, seeking out challenges, and creativity" [11] (see also [22] and [23]). Some authors additionally include psycho-social constructs and environmental factors incorporating concern, control, curiosity and confidence [31], competency of commitment [32], social recognition [13], [33], and degree of task volatility and environmental change [33].

The most commonly used framework to assess adaptive expertise (according to a meta-analysis by Bohle Carbonell *et al*., [11]) is Pulakos *et al*.'s taxonomy, which includes: solving problems creatively; dealing with uncertain or unpredictable work situations; learning new work tasks/technology/procedures; interpersonal adaptability; cultural adaptability; physically-oriented adaptability; handling workplace stress; and handling emergencies/crisis situations [34]. There is no published instrument associated with this taxonomy; those authors taking it up have created procedures and instruments based on their own operationalization of the dimensions. Notably, this taxonomy focuses explicitly on observed behaviors, rather than on the metacognitive or cognitive skills and abilities identified in the rest of the literature, as being central to adaptive expertise, making it particularly difficult to design an instrument using this taxonomy, which might speak to the variety of workplace contexts encountered by students on Co-operative education placements.

These divergent approaches to the measurement of adaptive expertise speak to the challenge of devising an instrument that could measure such a complex and overlapping set of behaviors, skills, and dispositions – many of which would display themselves in highly context-specific ways. These approaches have also led to the proliferation of contextually-grounded measurement tools for the assessment of adaptive expertise.

In designing our revised Adaptive Expertise instrument, we theorized four sub-scales addressing innovative skills, domain skills, metacognition [35], as well as self-efficacy and resilience. The revised scale included modified items from Fisher and Peterson's 2001 survey [20], additional items of our own construction, and several items based on work by van der Heijden [33], Charbonnier-Voiirin *et al.,* [36], Bohle Carbonell *et al.,* [35], and the General Self-Efficacy Scale (GSES-12) [37], [38].

We were guided to include domain skills by the near-consensus in the adaptive expertise literature that adaptive expertise is built on top of subject-specific routine expertise. Our proposed domain skill items address student perception of growth in their field, as well as their ability to pursue expertise and integrate new developments in the field [33], [35]. Innovative skills by contrast focus on student reports of pursuing new skills, applying knowledge from one context to another, and exercising flexibility as they pursue tasks [20], [35]. Our metacognitive sub-scale items attempt to examine learners' skill in self-assessment of knowledge and performance and their facility in seeking out feedback [33], [39].

Our instrument also includes a theorized novel sub-scale, based in emerging literature, that focuses on self-efficacy and resilience and that incorporates elements of the 'goals and beliefs' sub-scale found in Fisher & Peterson [20], as well as items adapted from the GSES-12 [37], [38]. Notably, the Fisher & Peterson Adaptive Expertise instrument, developed for bio-medical engineering students, is one of the only Adaptive Expertise instruments designed specifically for use with post-secondary students. This instrument includes: (1) questions targeting both behaviors and beliefs in one of its sub-scales: 'Multiple Perspectives,' which addresses flexibility in problem solving approaches; (2) one behavior-only sub-scale: 'Metacognitive Self-Assessment,' addressing the acquisition of new knowledge and feedback; and (3) two attitudinally-focused sub-scales: 'Epistemology,' focused on beliefs about how knowledge changes over time, and 'Goals and Beliefs' sub-scale, which addresses attitudes towards challenges, the acquisition of expertise, and comfort with ambiguity/failure [20].

Bohle Carbonell *et al*. reject the inclusion of 'goals and beliefs' in the development of their scale (which they, in turn, base on Pulakos *et al*., [34], Charbonnier-Voirin and Roussel [36], Fisher and Peterson [20], and van der Heijden [33]), their reason for doing so is that Fisher and Peterson's focus on the conceptual framework necessary for adaptive expertise comes at the expense of domain-specific skills that are necessary to understanding expertise. However, as Bohle Carbonell *et al*., require that the domain skill-related questions address an epistemological perspective, which embraces change in disciplinary knowledge, they do acknowledge the importance of attitude as foundational to adaptive expertise. Moreover, learning scientists are increasingly identifying attitude and disposition as a key variable in understanding student success in mastering both knowledge and skills. This emphasis on teaching beyond knowledge calls back to Polanyi's emphasis on providing students with ways-of-being: as Kek and Huijser state, "overall, it is the attitude in particular (as part of a way-of-being) that provides students as lifelong learners with ongoing choices in terms of where they would prefer to live and work in the world" [40] (see also [41] - [45]).

Our work to create a revised Adaptive Expertise instrument shares Fisher & Peterson's (2001) inclusion of both attitudinal and behavioral items in our instrument. Given our mission as an educational institution to inculcate in our students the attitudes and dispositions which will serve them well, we have made the decision to include questions addressing both beliefs and behaviors in our survey instrument; at least for understanding of students' adaptive expertise, both types of questions are vital to recognizing how we can support their development of both the skills/habits and the attitudes/dispositions, which will enable them to demonstrate (and to continue acquiring) adaptive expertise throughout their careers, both in the workforce and as lifelong learners.

Following a process of iteratively developing the survey, including developing questions, piloting the survey through cognitive interviews with students and surveying a subset of students, and finally from the evaluation of our first full use of the survey in Fall 2017, we identified three component factors of adaptive expertise contained in this tool: Domain Agility, Self-Assessed Innovative Practice, and Orientation towards Innovation. These factors, a result of both reflection on the literature of adaptive expertise and a factor analysis of our instrument, capture both student practice of the foundational skill of domain expertise (including the key component of acquiring an epistemological outlook that embraces change to the domain), and student practices of and attitudes towards innovative skills.

Evolving an Adaptive Expertise Measurement Tool: Context and Procedures

As part of our ongoing effort to implement curricular changes that will support our students in becoming self-directed and adaptive learners, Northeastern University implemented a requirement that students undertaking their first co-operative education experience write a series of four short guided inquiries in response to prompts designed to elicit reflection. To understand the potential impact of this new curricular requirement on the students, we designed and implemented a multiyear, longitudinal study which includes the administration of pre- and post-test instruments that measure students' adaptive expertise and self-directed learning. Students were invited to participate during each co-operative education placement; students on their first Co-op placement were also invited to take the pre- and post-test instrument before and after they completed the guided reflections required as a part of their Co-op experience (comprising of three reflections during their Co-op and one reflection two months after their Co-op experience when they were back at the University taking courses). While students on subsequent Co-op placements were not required to complete guided reflections as part of their Co-op curriculum, they were invited to do so through our study; they also completed the pre- and post-test instruments.

To reduce survey fatigue, subjects were randomly assigned to complete either an Adaptive Expertise survey or a Self-Directed Learning survey. To measure student adaptive expertise, we made use of Fisher & Peterson's 2001 tool [20], modified slightly to address discipline-neutral co-operative education experiences, rather than the originally-specified Biomedical Engineering content (See table 1).

This project has been ongoing since 2014 and has resulted in a large data set of student reflections, as well as pre- and post-test scores. As approximately half of respondents were asked to complete the Adaptive Expertise instrument prior to our Fall 2017 implementation of the revised scale, we have collected 2,024 pre-test and 1,215 post-test responses for our discipline-neutral version of Fisher and Peterson's Adaptive Expertise scale [20].

Table 1: Adaptations of Fisher & Peterson (only adapted items listed; for all items, see Fisher & Peterson [20])

Original Item from Fisher & Peterson [20]	Revised Item for use with discipline-neutral Co-op experience
"Please indicate how much you disagree or agree with each of the following statements when thinking about your current Co-op placement"	
I create several models of an engineering problem to see which one I like best.	I develop several approaches to a problem to see which one I like best.
When I consider a problem, I like to see how many different ways I can look at it.	When I consider an assignment, I like to see how many different ways I can look at it.
Usually there is one correct method in which to represent a problem.	Usually there is one correct approach to solving a problem.
I tend to focus on a particular model in which to solve a problem.	I tend to focus on a particular approach to solving a problem.
Experts in engineering are born with a natural talent for their field.	Experts in the field that my Co-op is in are born with a natural talent for it.
I feel uncomfortable when unsure if I am doing a problem the right way.	I feel uncomfortable when I am unsure if I am completing a task the right way.
Poorly completing a project is not a sign of a lack of intelligence.	Poorly completing a task is not a sign of a lack of intelligence
When I struggle, I wonder if I have the intelligence to succeed in engineering.	When I struggle, I wonder if I have the intelligence to succeed in the field that my Co-op is in.
Scientists are always revising their view of the world around them.	Experts are always revising their view of the world around them.
Scientific theory slowly develops as ideas are analyzed and debated.	Theories slowly develop as ideas are analyzed and debated.
Scientific knowledge is developed by a community of researchers.	Knowledge is developed by a community of experts.
Scientific knowledge is discovered by individuals.	Knowledge is discovered by individuals on their own.

In spring 2017, we conducted an interim evaluation of the scales used in the research project, including Fisher and Peterson's Adaptive Expertise instrument. A Cronbach's alpha of the scale produced reliability scores for the test's sub-scales in the poor-acceptable range: multiple perspectives, 0.68; meta-cognition, 0.68; goals and beliefs, 0.73; epistemology, 0.5 [46], [47]. This is particularly significant, given the large number of items in each scale, which can inflate Cronbach's alpha scores [46]. A factor analysis failed to replicate the factor structure outlined by Fisher and Peterson, and we were unable to uncover any clear 2, 3, 4, or 5 factor structures using our data.

As a result, we embarked on a process of designing a revised scale, which, we hoped, would provide more sensitive and coherent results on undergraduate students from all of Northeastern University's programs and disciplines on co-operative education placements. Following a literature review, we drew on instruments produced by scholars in the fields of higher education, psychology, and human resources (e.g., [20], [33], [35], [36], [37]). We assembled a new list of questions, including some of our own invention, which were designed to assess the underlying concepts of the domain skills, innovative skills, metacognitive skills, as well as self-efficacy and resilience, as outlined above. Each sub-scale contained between 7 and 13 items, including both positively- and negatively-phrased items. In order to evaluate mistaken readings of the questions as a source of error with this population, we included some negative items, which were phrased as simple grammatical negatives (e.g., "I did not find other people's suggestions or ideas helpful to my work"), and some, which were positively phrased but conceptually negative (e.g., "I found unfamiliar tasks to be frustrating") [48].

Piloting the Survey: Cognitive Interviews

The first step in the process of refining the scale was to conduct cognitive interviews with undergraduate students to ensure that the questions were clear to this audience, and to minimize potential sources of confusion or error in our data. In preparation for student feedback, we entered each new survey item into Qualtrics, an online survey creation and distribution tool. Items were arranged to maximize the distance between positively-phrased and negated items, which spoke to the same underlying concept [48] and to ensure that each block of questions contained an even distribution of items from each posited sub-scale. Each block was set to randomize the order of questions within it, though the order of blocks was non-random to preserve maximum distance between closely-related questions. The rating scale was a 6-point Likert-style agreement arranged as follows: Strongly Disagree; Disagree; Somewhat Disagree; Somewhat Agree; Agree; Strongly Agree. We did not include a neutral middle-category to encourage students to choose between agreement and disagreement, especially at the interview stage, and because we implemented Fisher and Peterson's instrument using that same 6-point scale.

Interview subjects were drawn from the regular respondent population used in the larger research project. For this project, 150 students were randomly selected from the 2,770 students, who did not respond to our earlier invitation that term to participate in the Spring 2017 round of surveys and guided reflections. Students were subjected to the same screening questions as participants in the larger study (to confirm that they were undergraduates, currently on Co-op[1], and will be completing a Co-op placement of at least 6 months at a single employer). Students were offered a $15 Amazon gift card to compensate for 30 minutes of their time. We offered students the option of completing the interview either in person or remotely. To accommodate the schedules

[1] Co-operative education in the Northeastern University context consists of six-month student placements in full-time positions, often paid, in either the for-profit or non-profit sectors, which complement classroom study.

of students who were on Co-op placements, a mix of appointments during the work day, in the evening, and on Saturday were offered.

Of the 12 students who responded and indicated that they would like to participate, we were able to schedule and conduct interviews with 9. Interview subjects came from health, business, science, engineering, and social science/humanities fields, and included both men and women; both international and domestic students were represented in this pool. Students interviewed in person were presented with the Qualtrics survey pre-loaded on a computer; the students participating remotely completed the survey while sharing their screen and video-chatting with the interviewer. All subjects were instructed to 'think out loud' while answering each question. The interviewer provided minimal guidance beyond prompting the students to verbalize the reasons for any hesitations and reminding them to continue thinking out loud if they fell silent. Following the completion of the survey, students were asked to share their thoughts on the instrument as whole, as well as to contextualize information about their Co-op experiences, background and goals. Participants were engaged, enthusiastic, and thoughtful in their feedback.

These interviews were then used to clarify the wording of scale items and refine items that received mistaken answers (i.e., answers which were at odds with interviewee's stated intentions). We specifically rephrased grammatically negatively-worded questions (i.e., those questions with a 'not' or a 'no,' instead of positively phrased questions with a negative relationship to our underlying concept), as these produced higher cognitive load and were a source of mistaken answers for our respondents, especially when they wished to provide a negative response to a negatively-worded question.

Following these revisions, we invited 2,610 students to respond to a new version of this survey. The targeted students were drawn from the same population as our interviewees – students on a Spring 2017 Co-op experience who had been invited to participate in the reflection research project, but who had not responded to that invitation. As such, they shared major characteristics with our core study population. We excluded from this invitation students who had been asked to participate in our cognitive interviews. Students who participated were offered the chance to enter a raffle for one of two $50 Amazon gift cards or one of five $15 gift cards. We received 311 complete responses to the survey.

An exploratory factor analysis on these responses was then performed, both to understand whether the actual factor structure of the data matched our expectations and intentions and to reduce the number of survey items. Since our data is ordinal, we chose weighted least squares as our factor extraction method. We also chose to use oblique rotation, as there are strong theoretical reasons to expect there to be correlation between the factors [49] - [52].

An examination of the scree plot suggested a four-factor model [49], and goodness-of-fit tests were significant for models including 16 and 14 items. We made the decision to include additional 4 questions, which came close to meeting the factor loading threshold, as we wanted to determine if the larger sample size or deployment of the test on our larger population (as opposed to students who had already opted out of participation in the main research project) might produce different results.

Insights gained in our cognitive interviews guided our efforts to shape the scale in light of the factor analysis. For instance, we were unsurprised that the item ‘I focused on developing existing skills’ did not load, when reversed, into our ‘innovative skills’ factor. While we had initially theorized that agreement with this statement might indicate a lack of attention to developing ‘innovative skills,’ student descriptions of their reasons for agreeing indicated that approximately half of them viewed this question as inquiring as to how they added new skills onto the foundations provided by prior knowledge, making it an unreliable component of the ‘innovative skills’ sub-scale.

The resultant 20-item survey was used in our Fall 2017 round of data collection with students who were participating in the study for the first time (returning students were asked to complete our previously-used adapted version of Fisher and Peterson’s scale to maintain the longitudinal nature of the project with those students). For this iteration, we also used to a 7-point scale, in response to suggestions during the student interviews that they would enjoy having a neutral option, and in the hope of introducing greater variance into our responses. The included items were as follows:

Table 2: Included survey items, source, and theorized sub-scale

Survey Item	**Theorized Sub-Scale**	**Adapted From**
I gained a better understanding of concepts in the field of my Co-op	Domain Skills	Bohle Carbonell *et al.* [35]
When I was provided with suggestions, I was able to incorporate other people’s ideas into my work	Domain Skills	Van der Heijden [33]
My understanding of concepts in my field did not change	Domain Skills (Reversed)	Bohle Carbonell *et al.* [35]
I realized that once you become an expert in my field, you do not need to continue learning in order to stay an expert	Domain Skills (Reversed)	Bohle Carbonell *et al.* [35]
I realized that knowledge in my field is set and does not change	Domain Skills (Reversed)	Bohle Carbonell *et al.* [35]
I focused on new challenges	Innovative Skills	Bohle Carbonell *et al.* [35]
I focused on developing new approaches to solving problems	Innovative Skills	Fisher and Peterson [20]
I looked for unfamiliar tasks	Innovative Skills	New
I was able to draw on prior knowledge to perform tasks at my Co-op	Innovative Skills	New
During my Co-op, I applied knowledge I learned in my courses	Innovative Skills	New
I showed that I am willing to keep learning new information and skills related to my field	Innovative Skills	Bohle Carbonell *et al.* [35]

Survey Item	Theorized Sub-Scale	Adapted From
I was able to see how knowledge I learned on my Co-op related to what I had learned in the past	Innovative Skills	New
I took expertise from one context and applied it to another	Innovative Skills	New
My prior knowledge was not helpful when performing unfamiliar tasks	Innovative Skills (Reversed)	New
I was able to recognize who can help me add to my knowledge of the field of my Co-op	Metacognition	Van der Heijden [33]
When I received feedback, I did not find other people's suggestions or ideas to be helpful to my work	Metacognition (Reversed)	Van der Heijden [33]
I did not often monitor my own performance on tasks	Metacognition (Reversed)	Fisher & Peterson [20]
I kept trying to learn new things, even if I didn't succeed right away	Self-Efficacy & Resilience	GSES-12 [38]
I enjoyed the challenge of learning difficult new things	Self-Efficacy & Resilience	GSES-12 [38]
When trying to learn something new, I gave up if I was not initially successful	Self-Efficacy & Resilience (Reversed)	GSES-12 [38]

Preliminary Results from Survey Deployment

Of the 1,342 students who participated in our Fall 2017 round of data collection, 901 students were exposed to this survey instrument and of those 881 rated all of the items associated with our new Adaptive Expertise scale. After re-coding the negative items, the results were as follows:

Table 3: Descriptive Statistics for Adaptive Expertise Survey

Survey Item	N	Mean	Median	Std. Dev.
During my Co-op, I applied knowledge I learned in my courses	894	4.99	5.00	1.56
I did not often monitor my own performance on tasks	882	5.54	6.00	1.31
I enjoyed the challenge of learning difficult new things	901	6.12	6.00	0.95
I focused on developing new approaches to solving problems	894	5.59	6.00	1.06
I focused on new challenges	901	5.91	6.00	0.95
I gained a better understanding of concepts in the field of my Co-op	901	6.07	6.00	1.07
I kept trying to learn new things, even if I didn't succeed right away	900	6.18	6.00	0.87

Survey Item	N	Mean	Median	Std. Dev.
I looked for unfamiliar tasks	894	5.30	5.00	1.23
I realized that knowledge in my field is set and does not change	901	5.70	6.00	1.46
I realized that once you become an expert in my field, you do not need to continue learning in order to stay an expert	883	6.10	7.00	1.41
I showed that I am willing to keep learning new information and skills related to my field	882	6.12	6.00	0.89
I took expertise from one context and applied it to another	882	5.53	6.00	1.04
I was able to draw on prior knowledge to perform tasks at my Co-op	894	5.62	6.00	1.22
I was able to recognize who can help me add to my knowledge of the field of my Co-op	894	5.92	6.00	1.02
I was able to see how knowledge I learned on my Co-op related to what I had learned in the past	882	5.44	6.00	1.25
My prior knowledge was not helpful when performing unfamiliar tasks	901	5.02	6.00	1.64
My understanding of concepts in my field did not change	882	5.57	6.00	1.34
When I received feedback, I did not find other people's suggestions or ideas to be helpful to my work	894	5.85	6.00	1.29
When I was provided with suggestions, I was able to incorporate other people's ideas into my work	901	5.98	6.00	0.94
When trying to learn something new, I gave up if I was not initially successful	894	5.97	6.00	1.18

Analysis of Cronbach's alpha for the scale shows that the instrument is not unidimensional, and it also suggests that our predicted sub-scales are not strongly manifesting in our results.

Sub-Scale	Valid N	N of Items	Cronbach's Alpha
Domain Skills	882	5	.615
Innovative Skills	882	9	.782
Metacognitive Skills	893	3	.590
Self-Efficacy & Resilience	882	3	.538

To determine the underlying structure of the data, we performed an exploratory factor analysis, again using oblique rotation (direct oblimin) and generalized least squares for factor extraction and using scree plot examination to determine the number of extracted factors. Our initial factor analysis of all 20 survey items produced a factor structure, in which all negatively-worded questions were grouping together into a single factor, regardless of their theorized sub-scale and despite the values having been re-coded to match the positively-phrased items. This suggests that more work remains to be done to reduce the cognitive load involved in answering negatively-worded questions and to reduce the prevalence of mistaken answers to these questions.

Once these items and items with strong cross-loadings were removed, we were left with a three-factor model consisting of 13 items:

Item	Theorized Sub-Scale	Factor Loadings		
		1	2	3
I kept trying to learn new things, even if I didn't succeed right away	Self-efficacy & resilience	.722		
I enjoyed the challenge of learning difficult new things	Self-efficacy & resilience	.682		
I focused on new challenges	Innovative skills	.653		
When I was provided with suggestions, I was able to incorporate other people's ideas into my work	Domain skills	.596		
I gained a better understanding of concepts in the field of my Co-op	Domain skills	.583		
I showed that I am willing to keep learning new information and skills related to my field	Innovative skills	.436		
I was able to recognize who can help me add to my knowledge of the field of my Co-op	Metacognitive skills	.370		
During my Co-op, I applied knowledge I learned in my courses	Innovative skills		.821	
I was able to see how knowledge I learned in my Co-op related to what I had learned in the past	Innovative skills		.708	
I was able to draw on prior knowledge to perform tasks at my Co-op	Innovative skills		.667	
I focused on developing new approaches to solving problems	Innovative skills			.623
I looked for unfamiliar tasks	Innovative skills			.557
I took expertise from one context and applied it to another	Innovative skills			.397

The model's K-M-O test of sampling adequacy statistic was .891, and Bartlett's Test of Sphericity had a significance of .000, indicating that factor analysis was appropriate for this data.

The first factor contains a mixture of items we had theorized as being a part of self-efficacy and resilience, innovative skills and domain skills. What unites these items is that they all speak to the students' self-assessments as being open to change. The two 'innovative skill' items included in this scale are both more generally phrased than the others, in that they speak to 'challenges' and a general desire to keep learning (and that latter, as it is phrased to state that the students 'showed' that they are willing to keep learning, could be interpreted in terms of exhibiting the domain skill of epistemological commitment to coping with a changing work environment). Conceptually this meshes well with the underlying construct of domain skills, as does the included metacognitive skill (which could be understood as the performance of epistemological commitment to change in the domain), as well as the self-efficacy & resilience skills, both of which evoke the persistence required to master those domain skills in the Co-op environment. This sub-scale, which we are calling 'Domain Agility,' has a Cronbach's Alpha of .816.

The second factor is distinct from the first in that the 'innovative skill' items included here speak specifically to acts of transfer between prior learning and the context of Co-op, while the third factor, also made up of items we had theorized as being 'innovative skills,' focuses on more general attitudes towards novelty and transfer. We have termed this second factor 'Self-Assessed Innovative Practice' (Cronbach's alpha of .790). Factor three was named 'Orientation to Innovation' (Cronbach's Alpha of .635). As the Cronbach's alpha of 'Orientation to Innovation' warrants caution, we tested the combination of the latter two factors into a single 'Innovation' sub-scale; it received a more robust Cronbach's alpha of .760. This suggests that these sub-scales warrant further development and testing to more robustly capture and differentiate the underlying concepts from each other as we continue to tease out the roles which goals, beliefs, and practice play in the development of adaptive expertise.

Conclusions and Next Steps

It has been our hope with this paper to advance the conversation about the theoretical and empirical challenges of measuring adaptive expertise in post-secondary students in general and engineering students specifically. As the need to provide our students with opportunities to understand and develop these key habits, skills, and abilities becomes ever more pressing, it is critically important that we engage in an ongoing process of evaluating not only our curriculum and student outcomes, but also our measurement instruments and research approaches. The difficulty of constructing a scale that can measure a construct as theoretically complex, inherently dynamic, and contextually grounded as adaptive expertise, points us to three directions for future work.

The first is continued reflection, conversation, and engagement about the meaning of adaptive expertise for our students: what are the skills, dispositions, and attitudes which can be coherently captured in this concept, and how do they connect to student success? The increased attention to the concept of adaptive expertise in the fields of engineering education (see [9] and [10]), learning science, psychology, human resources and teacher training is encouraging both because of the promise of this research, but also for the rich possibilities of emerging inter-disciplinary conversations. It is this interdisciplinarity around the definition of adaptive expertise which may hold the most promise for learning scientists in general and engineering education scholars and practitioners specifically: since we hope to create educational curricula, environments, and interventions that will serve our students over the course of their lives, engaging with scholars who study related phenomena in different contexts can only enrich our understandings.

Secondly, consistent with the calls of other engineering education scholars (e.g., [9]), we invite engineering education community to join us in the ongoing continued work to develop robust survey instruments for the efficient and rigorous collection of information about adaptive expertise. In the future, we will continue to iterate our Adaptive Expertise survey; our immediate intention is to rephrase the problematic negative items and to develop additional items speaking to potential emergent sub-scales. (i.e., domain agility; self-assessed innovative practice; and orientation to innovation). This instrument suggests that future adaptive expertise research might consider sub-scales for (1) unpacking the transfer of learning across contexts (self-assessed innovative practice); and for (2) measuring general attitude towards new tasks (orientation to innovation). We will also continue to research the ways in which students interpret our survey items, and how student context and experiences shape their reactions to the survey items. Specifically, our work may be extended to understand the ways in which engineering students interpret and respond to the survey instrument differently than non-engineering students. It is our hope that education scholars in other contexts will find the core of our revised survey a useful starting point for their own iterations and context-specific refinements. Importantly, such subscales (about beliefs/attitudes and transferring learning from one context to another) have methodological implications because neither can be identified through direct observation alone.

Finally, scholarly attention has increasingly been turning towards multi-method approaches to understanding both performance and perception of adaptive expertise in different contexts. We continue to explore the possibilities of different research modalities – including interviews and observation of task performance in addition to self-assessment. While more resource intensive, these approaches provide a promising avenue through which to contextualize and refine our larger-scale analyses, and this less-generalizable data may still aid in theorizing definitions and generating hypotheses for larger-scale testing in engineering education and beyond.

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