Assessing Children's Progress in Taking Intellectual Risks in a Mathematical Inquiry Classroom with a Positive Learning Approach

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Intellectual risk is valued among 21st century skills. Three primary teachers who promoted positive learning within mathematical inquiry collaborated with researchers to design and apply a rubric to assess children's progress in taking intellectual risks twice during the year. Results suggest that handling setbacks and giving feedback to peers were the most challenging skills initially, but showed significant gains by the end of the year. Teacher interviews discussed challenges that students faced and how positive classroom culture encouraged intellectual risk.

Emphases on 21st century skills (e.g., www.p21.org)—creativity, critical thinking, collaboration and communication—promote inquiry as a way to develop learning and innovation skills. Mathematical inquiry is used broadly to describe a process of solving complex, open-ended problems. In mathematics, creativity is often neglected, perhaps because there is an assumption that there is no place for creativity in mathematics. One characteristic of creativity is the capacity to take intellectual risks. Intellectual risk involves a willingness to attempt to solve a problem or critique an idea when there is uncertainty about the outcome (Atkins, Leder, O'Halloran, Pollard, & Taylor, 1991). To promote intellectual risk, a classroom culture is vital as "a social atmosphere in which children feel secure enough to play with ideas and to take risks" (Binkley et al., 2012, p. 38). Students' perceptions of support significantly contribute to their willingness to engage in intellectual risk (Beghetto, 2009). Beghetto (2009) defines intellectual risk taking in science as

> engaging in adaptive learning behaviors (sharing tentative ideas, asking questions, attempting to do and learn new things) that place the learner at risk of making mistakes or appearing less competent than others. … [It] highlights the fact that learning (like most any action) involves uncertainty and, therefore, some degree of risk. (p. 210)

An important aspect of learning mathematics through inquiry is the willingness to take intellectual risks. Some forms of mathematical inquiry involve ambiguity in the statement, goals or possible solution pathways of the problem (Makar, 2012). This requires students to negotiate meanings, including navigating differences of ideas to work towards a solution. This process of offering and negotiating ideas can lead to anxiety, however, if students fear criticism (Çetin, Ilhan, & Yilmaz, 2014).

This paper reports on teachers' assessment of their students' willingness to take intellectual risk. The teachers collaborated with researchers to develop criteria for taking intellectual risk within mathematical inquiry, then drafted a rubric to assess students' progress over a year. The rubric also provided them with a framework for developing classroom norms to promoted students to take intellectual risks in mathematical inquiry.

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Methodology

Participants and Study Context

The participants of the study were three teachers and their students (aged 9-12, n = 84) in a suburban primary school in Queensland. The teachers had been teaching mathematics through inquiry for at least six years. Recent efforts to improve scaffolding norms of inquiry-based argumentation and developing positive learning identity had sensitised them to focus on promoting students' intellectual risk in the classroom (see Makar, Bakker, & Ben-Zvi, 2015 and O'Brien, Makar, Fielding-Wells, & Hillman, 2015 for further background on these projects).

Design and Application of Assessment Rubric

To track progress, the teachers worked with the research team to generate five criteria in the areas of innovation, resilience and feedback in which they could assess their students' progress to take intellectual risk:

- Innovation: Generating and developing ideas
- Resilience: Handling setbacks
- Feedback: Giving and responding to feedback

For each of the five criteria, the teachers described students they had taught over the years that struggled with or excelled at each area and through their anecdotal narratives, generated qualities in each area at low, middle and high levels of behaviour. Through discussion of the narratives, a 3-level rubric (Levels 1-3, with 3 the highest level) was created to capture qualities they could observe in students at each level. Level 0 was added to accommodate cases where the "low" level was still developing and not yet met (see Appendix for descriptors of Levels 1 and 3).

Table 1
Inquiry Units Videotaped

Year level	Term 2 Inquiry Unit	Term 4 Inquiry Unit
Mrs Bluett, Year 4	*How big is 10000?*	*How far can a Year 4 jump?*
Ms Thomson, Year 5	*Can you predict the sum of the angles of a polygon?*	*What is the best strategy for the game of Plinko?*
Ms Jones, Year 6	*What is the biggest pyramid you can make from an A3 sheet of paper?*	*Have athletes become faster?*

Aided by videotapes of their classrooms during inquiry lessons, the teachers assessed each student's achievement in each criteria in inquiry units that were videotaped in Terms 2 and 4 of the previous year (Table 1). An intermediate score was applied if students demonstrated standards between levels (e.g., a score of 1.5 if Levels 1 and 2 were given for different aspects of a criterion). Teachers' judgement—in particular cases that either were challenging or stood out—was discussed in a group interview which was audiotaped during a working meeting between the teachers and research team. Each student was assigned a score of 0-3 for each criteria from their inquiry lessons in Terms 2 and 4. The

data were collated from the three classes to capture students' levels of intellectual risk, both for each criteria and averaged over the five criteria. The purpose of the analysis was to assess overall shifts but also to gain insight into elements that appeared easier or harder to shift. An overall average score for *Intellectual Risk* was generated by averaging the scores of the five criteria. Hypothesis tests for comparing means were conducted at critical level α=0.05.

Results and Discussion

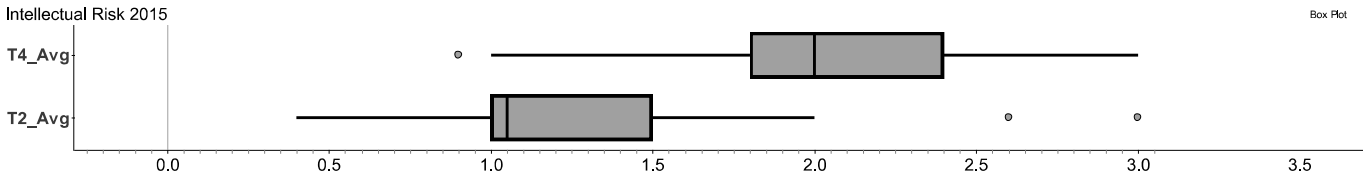


Figure 1. Distributions of average scores on *Intellectual Risk* (scale 0-3) in Term 2 and 4 inquiry lessons

Figure 1 presents the three combined classes (n = 84 students) distributions of average scores for overall levels *Intellectual Risk* in Terms 2 and 4. The data suggest that overall, students showed gains in average levels of *Intellectual Risk* as measured by the rubric. Table 2 shows the results broken down by criteria, with students significantly improving by the end of the year with moderate to strong effect sizes (Ferguson, 2009). Table 3 further summarises the distributions of scores at lower (Level 1 or below) and higher levels (above Level 2). While the improvement of these students is encouraging news, a further analysis was needed to understand how each criteria may have contributed to this. Each criterion with respect to these results are discussed in the subsections below.

Table 2
Average (sd) Scores (Scale 0-3, 3 = High) for Intellectual Risk in Terms 2 and 4

Criteria	Term 2 avg (sd)	Term 4 avg (sd)	Avg difference (sd)	p-value	Effect size
Generating ideas	1.38 (0.47)	2.17 (0.52)	0.79 (0.49)	<0.01	1.6
Developing ideas	1.25 (0.52)	2.10 (0.55)	0.85 (0.55)	<0.01	1.5
Handling setbacks	1.14 (0.55)	2.14 (0.55)	1.00 (0.54)	<0.01	1.8
Responding to feedback	1.24 (0.53)	2.05 (0.69)	0.81 (0.58)	<0.01	1.4
Giving feedback	1.15 (0.68)	1.91 (0.70)	0.76 (0.55)	<0.01	1.4
Overall Intellectual Risk	1.23 (0.45)	2.07 (0.53)	0.84 (0.41)	<0.01	2.0

Table 3
Distribution of Student Performance in Term 2 and Term 4 for each Criterion

Criteria	Term 2	Term 4	Term 2	Term 4
	Level 1 or below		Above Level 2	
Generating ideas	55%	5%	2%	32%
Developing ideas	68%	10%	2%	25%
Handling setbacks	77%	8%	2%	29%
Responding to feedback	76%	21%	2%	31%
Giving feedback	69%	20%	3%	24%

Overall Intellectual Risk	50%	6%	2%	42%

Generating and Developing Ideas

Generating Ideas is about the willingness to offer contributions with the intent to either get the group started or to consider a new direction. At the lowest levels, students did not contribute (see Appendix). The reasons could have been lack of confidence, but it could also be lack of willingness to share. For example, one teacher described a student in her class who was a strong student, but saw his ideas as his own.

> *Ms Thomson*: By the end of the year, … he showed his mathematical thinking a lot and would have the big conversations. … But at the beginning of the year he would just sit there … He wouldn't share anything. He just hid stuff away from everyone. It took me a long time and a lot of discussion to get him to a point where [he realised] 'it's ok to share'. [19:15, 5 March 2016 working session]

Although initial ideas may have lacked depth, typically, students found the criterion Generating Ideas the least difficult (Table 2, mean = 1.38), with this skill significantly higher on average in Term 2 than the combined mean of the other four criteria (1.19, sd 0.48, $p = 0.015$); however, only 45% of the students initially demonstrated the criterion of *Generating Ideas* above Level 1 (Table 3). Again at the end of the year, the students still found the criterion Generating Ideas the least challenging to achieve high levels, with 95% achieving above Level 1 (being willing to contribute ideas) and 32% achieving at or near the highest level (Level 3: offering new and substantive contributions; encouraging contributions from others). By Term 4, the average level of students (2.17, sd 0.52) was not significantly higher than the combined mean of the other four criteria (2.05, sd 0.56). This suggests that perhaps lower levels of generating ideas are quite accessible but as expectations rise, it is no easier to obtain high levels of this criterion than the others.

Initiating an idea takes intellectual risk, but it's also a risk to take an unformed idea and develop it into a useable one. At the lowest level of *Developing Ideas*, students were able to take directions to complete a task given by someone else (see Appendix). This shows that a student is willing to engage with the process of developing an idea. Building on or adapting ideas, even at a mid-level (Level 2), was not typical for students in Term 2 (32% of students). This improved to 90% by Term 4, with 25% of students (all in the older two grades) observed extending ideas substantially (Level 3); only two students (2%) demonstrated Level 3 on this skill in Term 2. Building on others' ideas is a skill that students find challenging initially and likely need other argumentation skills such as being an active listener and learning to justify thinking before they can build on others' ideas (Makar et al., 2015).

Handling Setbacks

Learning always involves setbacks. Students with low tolerance for setbacks are often unable to persist in the face of difficulties. In the Term 2 inquiries, students had the most difficulty in the criteria *Handling Setbacks* (mean = 1.14) with only 23% able to demonstrate these skills above Level 1 (low, see Appendix).

As the teachers described students in their class who were challenged by setbacks initially, two categories of behaviour stood out for them: (1) students who were fearful of mathematics generally (and setbacks reminded them of their struggle to achieve), or (2) children who focused on levels of performance and got frustrated by mistakes. Ms

Thomson spoke of a student fearful of mathematics who used to tear up if she was asked any questions in class about mathematics. But by the middle of the year, things changed.

> *Ms Thomson*: She said, "This is the new me. I can't believe what I was like at the beginning of the year". … She really embraced the "I am allowed to make a mistake, and I'm allowed to, but I have to do something about it". And, um, I think she realised that making a mistake or getting something wrong, there is just no issue with it. As long as you move on from it and find a better way of doing things – and there are heaps of ways of doing things. … And so, that sort of language and being able to accept that changed her—in everything. [0:24]

This excerpt was followed by others in which teachers described students who had sulked, threw tantrums, cried or withdrew in the first half of the year in the face of setbacks. The skill of responding to setbacks showed the greatest improvement over the year, with average level of 2.14 (sd 0.55) by the end of the year. By then only 8% of students remained at Level 1 or below (Table 3).

Responding to and Giving Feedback

Feedback is another aspect of intellectual risk that is influential as feedback is a key vehicle for making improvement. *Responding to Feedback* at Level 1 was recorded as being willing to listen to feedback, a skill in which not all students showed evidence. 76% of students were at Level 1 (and 2% at Level 0) at the beginning of the year (mean 1.24, sd 0.53). The teachers worked with students during the year to help them to understand that feedback is not just being critical, but aims to provide them with ways to improve. The teachers discussed students who struggled to receive feedback from their peers initially.

> *Ms Thomson*: He was always offering, he would offer suggestions and things, but no one was allowed to challenge him. You know, no resilience whatsoever. … When someone else was speaking he would just sit there. And didn't listen to others.
>
> *Mrs Bluett*: That's what I've found. I've had two kids, Liam and Harry, and they were so, in that first inquiry they were going their own way and there was no moving them even when people gave them feedback, it was still there. Yet their feedback was really good to others. They actually really thought through and listened to what other people were saying and gave good feedback to others. … At the end of the year, their work was a lot better than it had been at the first of the year. [10:13]

These descriptions were common of students who performed well in more conventional mathematics lessons. They were accustomed to being right and didn't believe that other students (who didn't perform as well as they did) could tell them anything useful.

Giving feedback was also very difficult at the start of the year for most students. It required students to both be willing to explain and justify their ideas and be active listeners (i.e., listening and making sense of their peers' reasoning), then make connections to their own reasoning and offer suggestions. At the beginning of the year, *Giving Feedback* had one of the lowest means (1.15, sd = 0.68), with only 31% of students above Level 1. By the end of the year, students still had the lowest levels in both criteria of *Responding to Feedback* (mean 2.05, sd = 0.69) and *Giving Feedback* (mean 1.91, sd 0.70), with 79% and 80% of students, respectively, able to demonstrate these skills above Level 1. Students' skills in giving feedback in Term 4 were assessed as significantly lower than the combined mean of the other four criteria. This suggests either that this is an area of particular challenge for students or that the teachers' expectation of achievement was set higher than the other skills. That is, it is possible that the standards written in the rubric for achieving a

middle (Level 2) or high (Level 3) level of skill in responding to or giving feedback were more ambitious than in the other areas of intellectual risk.

Inquiry Experience in Prior Year

Seven students in the cohort were in an inquiry class the previous year. Although this is a small number for a confident and detailed analysis, there are some potential patterns that would be worth following up with a larger cohort.

At the start of the year, the overall average mean level of *Intellectual Risk* for students who were in an inquiry class the previous year (1.75, sd = 0.65) was not significantly higher than those without inquiry (1.18, sd = 0.41). This suggests—indeed highlights—that children do not necessarily act on these criteria in isolation from the context of the class. That is, a student could be more likely to demonstrate taking intellectual risks in a class where their peers also do so than in a class where their peers do not.

Three criteria in Term 2 did stand out for these children, however. (1) First was their handling of setbacks. On average, they achieved a significantly higher level (mean 1.79, sd 0.70) on *Handling Setbacks* than their peers who were not in an inquiry class the previous year (mean 1.08, sd 0.50, p = 0.04). (2) The second was their response to feedback with the students who had been in an inquiry class the previous year having a significantly higher mean (1.86, sd 0.69) on *Response to Feedback* than their peers who had not (1.18, sd 0.48, p = 0.04). Finally, the students from an inquiry class the previous year had a significantly higher level of *Giving Feedback* (mean 1.86, sd 0.69) than their non-inquiry peers (mean 1.08, sd 0.65, p = 0.03). What is interesting about these results is that the three areas where the students with inquiry the prior year outperformed their peers were in the three skills which were typically most difficult to achieve early in the year. Again, the small cohort prevents confidence in these outcomes, but further research on this with a larger cohort would be beneficial.

At the end of the year, none of the five criteria showed significant differences between students who had been in an inquiry class the prior year and their peers who had not been in an inquiry class. This suggests that these skills can perhaps be developed within a single school year.

Intellectual Risk and Classroom Culture

In Term 2, only two of the 84 students had achieved a rating at Level 3 in any criteria for Intellectual Risk as measured by the rubric (see Appendix). These results suggest firstly that all five criteria for intellectual risk were difficult for students to demonstrate early in the year. There was significant improvement by students in all criteria by Term 4. However, the shifts across these criteria were not uniform, nor did they happen without significant effort from the teacher.

In the meeting at the beginning of this year when we compiled these data, the teachers were setting up their new classrooms and reflected on the process of now developing a classroom culture which would develop students' capacity for taking intellectual risks.

> *Ms Jones*: It comes back to your classroom culture, doesn't it? … Setting that classroom culture has built up a rapport in our classroom that … it's ok to have a go. [If] it's not quite right, [we] do all that "roadblocks" [discussion] straightaway now … And I think having that culture has just alleviated a lot of things. … [25:51]
>
> *Mrs Bluett*: My problem is that … you just do too much talk.

Ms Thomson: We've all said that, though. But you know what? I've, I've been thinking about that, too. That's why you've got that classroom culture. Because [in the beginning] we say it over and over and over and over and over and over and over again. I just kept thinking, why am I saying this, trying to get these kids to tell me what active listening is—*again*? Like I've already, I did it two days ago, why am I going through that *again*! [32:46]

Mrs Bluett: … You have to model the talk. You have to teach and you have to model. Because you can't expect kids to do it like that (snap)! [33:45]

What their discussion emphasises is that intellectual risk is developed through a classroom culture which promotes it. And that culture both takes time to develop and requires significant scaffolding by the teacher (see Makar et al., 2015 for Mrs Bluett's scaffolding to develop her classroom culture over a year).

Limitations of Results

There are many limitations to this study. First, the scores are based on our retrospective self-reports of students' level skills at two points in the year. Second, the data are from students at one school, our own students. The convenience sample used is therefore not able to be generalised to all students or classrooms. Third, the sample size is quite small. The intent of the analysis is to seek possible patterns rather than to be confirmatory in nature. Fourth, the skills described in the five criteria were part of our larger effort to develop both norms of inquiry in our classrooms and also students' positive learning identities. The intent is not to suggest that mathematical inquiry develops these skills.

Conclusion

If schools are serious about developing 21st century skills then they must find ways to promote students' capacity to take intellectual risks. This study assessed students' progress in developing intellectual risk from two points in the year. Three key ideas can be learned from analysing the change in levels for the criteria associated with intellectual risk. First, the consistent shift with moderate to strong effect sizes (Ferguson, 2009) in all criteria (Table 2) suggest that development of these five skills over the year are achievable. The sample size is not high enough to explore whether and how these five criteria are related, but the aim is not to examine the psychometric properties of the rubric. The criteria and standards in the rubric were created as a pedagogical resource for teachers to support (and record) students' progress and development. Second, the elements of managing setbacks and providing feedback to peers appear to be the most challenging for students initially. Third, a classroom culture which creates an environment to develop these skills appears to be critical. More work in this area is needed.

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Appendix: Criteria for Intellectual Risk and Descriptors at Two Levels

Criteria	High level (Level 3)	Low level (Level 1)
Generating ideas	Offers new or incomplete ideas that lead to or integrate major (productive) ideas	Waits for others to contribute or contributes ideas that may not be relevant or practical
	Supports and encourages contributions from others	Acknowledges the ideas of others
Developing ideas	Substantively builds on, extends or adapts others' ideas	Contributes to working on tasks that develop ideas
	Keeps group on track towards a solution	
Setbacks	Embraces setbacks as challenges that can be overcome	Is aware of setbacks
	Uses setbacks to extend, improve or alter thinking	
	Promotes a culture within the group of positive responses to setbacks	
Responding to feedback	Seeks feedback or critique	Listens to feedback but may not respond to or act on it
	Evaluates, responds to and/or uses feedback to integrate or improve (deepen/expand) ideas	
Giving feedback	Provides substantive feedback that engages with the issue and has the potential to improve the thinking, process, evidence or solution	Gives surface feedback that may not progress the idea, process or solution
	Seeks clarification to promote understanding	